UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Arquitectura



Bioclimatic Design and Indoor Human Comfort in Commercial Sector:

A Case Study of Traditional Bazaar of Iran (Arak)

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Ali Heidari

Master of Science Degree of Construction Management

Madrid, 2023

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***To my love**,*

Dr. Somayeh Pour Mohammadi,

Whose presence illuminates every chapter of my life.

Acknowledgement

First and foremost, my deepest gratitude goes to my indefatigable pillar of strength, my wife Somayeh. From the conception of this research to its culmination, she has been my constant beacon of support, both intellectually and emotionally. Her unwavering belief in my capabilities and her boundless patience have been my guiding lights through the most trying times. To say that this journey would have been insurmountably challenging without her would be an understatement. To her, I owe more than just words can convey.

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In this journey of knowledge and discovery, while these pages bear my name, they are imbued with the collective efforts and love of those who've walked beside me. To all of you, thank you from the deepest recesses of my heart.

Ali Heidari

Madrid, 2023

Abstract

The present study comprises two essential components, each focusing on a separate aspect of sustainable design practices and their impact on energy efficiency.

In Part I, an in-depth scientometric analysis through the utilization of a bibliometric search, scientometric methodology, and a rigorous qualitative analysis is conducted on the practice of bioclimatic retrofitting in commercial buildings. This method is considered crucial in reducing energy consumption and addressing the challenges posed by climate change. By leveraging the extensive literature search capabilities of Scopus, we collected bibliographic data from about 400 papers. And finally, 81 articles were meticulously examined in accordance with the research objectives. The scientometric approach incorporates a range of quantitative criteria, such as intermediate citations, occurrences, average publication year, and overall connection strength. An analysis of historical data spanning from 2008 to May 2022 indicates a noticeable increase in scholarly investigations pertaining to commercial structures during this 15-year period. Nevertheless, there has been a notable increase in research pertaining to bioclimatic design, retrofitting techniques, and green building practices within the context of commercial buildings, particularly during the period from 2016 to 2020. This section also provides qualitative perspectives, emphasizing research topics such as thermal comfort, energy management, ventilation systems, sustainable architectural designs, retrofitting strategies for enhancing energy efficiency, the relationship between CO2 levels and energy resources, solar energy utilization, and techniques for simulating building energy consumption.

Part II of this study presents an in-depth study of the traditional bazaar of Arak city, focusing on its bioclimatic design and thermal performance. Situated at latitude 34.07°N and longitude 49.78°E in Iran, Arak experiences distinct hot summers and cold winters, demanding efficient architectural solutions for thermal comfort.The research utilizes the Design Builder software to simulate the thermal behavior of the Nowzari Caravanserai within the bazaar, particularly examining the influence of different roofing types—dome, flat, and sloped. The study's findings indicate that dome-shaped structures, characteristic of traditional Iranian architecture, provide superior insulation and thermal efficiency. This is evidenced by the significant indoor temperature variations compared to outdoor temperatures, in the hottest month of the year, with a mean absolute temperature differential of -6.44°C during the day and -1.54°C at night. The average daytime temperature difference in the coldest month is 19.32 °C. On average, nighttime temperatures vary by 21.94 °C.

Additionally, buildings with dome roofs featuring ventilation apertures exhibit reduced energy consumption, highlighting the importance of passive ventilation strategies.The study reveals that the variation in energy efficiency and thermal

regulation among different architectural designs is significant, particularly underlining the effectiveness of dome-shaped edifices in Arak Bazaar. A notable finding is that the indoor air temperature in the caravanserai remains within the comfort range for the majority of the year, deviating only 18.75% in July and 12.5% in December from the ideal thermal comfort levels.

The research also acknowledges the limitations posed by the software used, suggesting that future investigations might explore additional factors and employ experimental methodologies to validate the simulation results further. This study contributes significantly to the field of sustainable architectural design, particularly in the context of traditional marketplaces, offering insights that can inform decision-making in sustainable building design and urban planning.

Resumen

El presente estudio comprende dos componentes esenciales, cada uno centrado en un aspecto separado de las prácticas de diseño sostenible y su impacto en la eficiencia energética.

En la Parte I, se realiza un análisis cientométrico en profundidad a través de la utilización de una búsqueda bibliométrica, metodología cientométrica y un riguroso análisis cualitativo sobre la práctica del retrofit bioclimático en edificios comerciales. Este método se considera crucial para reducir el consumo de energía y abordar los desafíos planteados por el cambio climático. Al aprovechar las amplias capacidades de búsqueda de literatura de Scopus, recopilamos datos bibliográficos de unos 400 artículos. Y finalmente, 81 artículos fueron meticulosamente examinados de acuerdo con los objetivos de la investigación. El enfoque cientométrico incorpora una gama de criterios cuantitativos, como citas intermedias, ocurrencias, año promedio de publicación y fuerza de conexión general. Un análisis de datos históricos que abarca desde 2008 hasta mayo de 2022 indica un notable aumento en las investigaciones académicas relacionadas con estructuras comerciales durante este período de 15 años. Sin embargo, ha habido un notable aumento en la investigación relacionada con el diseño bioclimático, técnicas de retrofit y prácticas de construcción verde en el contexto de edificios comerciales, particularmente durante el período de 2016 a 2020. Esta sección también proporciona perspectivas cualitativas, enfatizando temas de investigación como el confort térmico, la gestión de la energía, sistemas de ventilación, diseños arquitectónicos sostenibles, estrategias de retrofit para mejorar la eficiencia energética, la relación entre los niveles de CO2 y los recursos energéticos, la utilización de energía solar y técnicas para simular el consumo de energía en edificios.

La Parte II de este estudio presenta un estudio en profundidad del bazar tradicional de la ciudad de Arak, centrándose en su diseño bioclimático y rendimiento térmico. Situada en la latitud 34.07°N y longitud 49.78°E en Irán, Arak experimenta veranos calurosos y fríos inviernos, lo que exige soluciones arquitectónicas eficientes para el confort térmico. La investigación utiliza el software Design Builder para simular el comportamiento térmico del Caravasar de Nowzari dentro del bazar, examinando particularmente la influencia de diferentes tipos de techos: cúpula, plano e inclinado. Los hallazgos del estudio indican que las estructuras en forma de cúpula, características de la arquitectura tradicional iraní, proporcionan una mejor aislación y eficiencia térmica. Esto se evidencia por las significativas variaciones de temperatura interior en comparación con las temperaturas exteriores, en el mes más caluroso del año, con una diferencia de temperatura media absoluta de -6.44°C durante el día y -

1.54°C por la noche. La diferencia promedio de temperatura diurna en el mes más frío es de 19.32 °C. En promedio, las temperaturas nocturnas varían en 21.94 °C.

Además, los edificios con techos en forma de cúpula que cuentan con aperturas de ventilación muestran un consumo de energía reducido, destacando la importancia de las estrategias de ventilación pasiva. El estudio revela que la variación en la eficiencia energética y la regulación térmica entre diferentes diseños arquitectónicos es significativa, subrayando en particular la efectividad de las edificaciones en forma de cúpula en el Bazar de Arak. Un hallazgo notable es que la temperatura del aire interior en el caravasar permanece dentro del rango de confort durante la mayor parte del año, desviándose solo un 18.75% en julio y un 12.5% en diciembre de los niveles ideales de confort térmico.

La investigación también reconoce las limitaciones impuestas por el software utilizado, sugiriendo que futuras investigaciones podrían explorar factores adicionales y emplear metodologías experimentales para validar aún más los resultados de la simulación. Este estudio contribuye significativamente al campo del diseño arquitectónico sostenible, particularmente en el contexto de mercados tradicionales, ofreciendo perspectivas que pueden informar la toma de decisiones en el diseño de edificios sostenibles y la planificación urbana.

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Abbreviations and acronyms

HVAC	Heating, Ventilation, and Air Conditioning
MET	Mean Effective Temperature
V	Velocity
Tr	Temperature
Ta	Air temperature
Rh	Relative humidity
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfaction
WMO	World Meteorological Organization
LEED	Leadership in Energy and Environmental Design
GB	Green Building
ND	New Design
RD	Reinforcement Design
PSA	Passive Solar Architecture
OAPEC	Organization of Arab Petroleum Exporting Countries
VOSviewer	Visualization of Similarities Viewer
BIM	Building Information Modelling
CBES	Commercial Building Energy Saver
DRs	Domed Roofs
VRs	Vaulted Roofs

1. Chapter 1

Introduction

In an era that is characterized by the depletion of fossil fuel reserves and a growing global population, it is of the utmost importance to take into consideration a variety of factors. These factors include the enhancement of the quality of life, the occurrence of global warming, and the environmental consequences that result from the utilization of limited energy resources and methods that are not sustainable. These characteristics are of the utmost importance in determining the wellbeing of future generations and shaping the course of destiny that our planet will take in the future.

When it comes to the many stages of the manufacturing process for building materials, the construction of buildings, and the maintenance of appropriate thermal conditions for occupants, the incorporation of energy is an essential component. In addition to this, the availability of energy is necessary for the operation of a wide variety of appliances and systems that are housed within buildings (Navarro et al. 2016). Transportation is another important application of energy.

Therefore, the incorporation of sustainable building design has become an essential component of architectural practice as a result of rising levels of energy use and concerns regarding the environment (Asman et al. 2019). The optimization of energy performance in buildings is an essential component in mitigating the impact of the built environment. This is due to the fact that buildings are responsible for a significant amount of the world's energy consumption and emissions of greenhouse gases (Liu et al. 2022). According to the data of the International Energy Agency (2021), it is possible to draw the conclusion that buildings are responsible for roughly thirty percent of the total energy consumption across the globe and twenty-seven percent of the carbon dioxide emissions that are associated with energy consumption (Gielen et al. 2019).

In spite of the fact that investments and financing for clean energy have increased by a factor of two over the course of the last decade, the rate of growth has not been adequate to overcome the resistance of mechanisms that consume energy. According to Gielen et al. 2019, it is of the utmost importance to improve the energy efficiency of buildings in order to reduce the emission of greenhouse gases and diminish the negative impact that buildings have on the environment.

At the present time, there have been considerable advancements made in the field of building air conditioning systems. These advancements have made it possible to construct buildings in a wide variety of geographical regions all over the world, regardless of the weather conditions that are now in effect. The aforementioned advancements have resulted in a considerable improvement in the thermal comfort that those who reside or work in buildings enjoy. This has made it possible for these folks to endure extreme climatic conditions without experiencing any pain. Nevertheless, it is of the utmost importance to acknowledge that despite these advancements, the prioritization of sustainable practices and the utilization of renewable energy sources ought to be emphasized in order to mitigate the environmental consequences that are associated with the consumption of energy in buildings (Parkinson, 2020).

The ability to produce the essential outcomes was absent a century ago; but, with the exploitation of water and energy resources, we have now attained a high level of achievement in this regard. Despite the fact that, over the course of the last few decades, construction operations, together with industrial, service, and agricultural activities, have collectively contributed to significant environmental pollution, this is despite the fact that these activities have had a favorable impact on human welfare and comfort. According to Khalili and Amindeldar (2014), the application of natural cooling methods in the construction of buildings has been prevalent in the desert parts of Iran for a considerable amount of time.

According to Altomonte (2014), it is thought important to reexamine the fundamental design concepts and climatic rules that underpin traditional architecture. This is because the modern era places a strong emphasis on the preservation of energy and the deployment of passive systems to promote environmental purity.

An excellent example of climatic architecture is the Iranian architecture that is designed in accordance with the principles of traditional architecture. According to Sahebzadeh et al. (2017), it demonstrates the most effective solutions with regard to the preservation of the environment, the comfort of humans, and the effective usage of natural energy sources. Hence, through the identification of the underlying principles and regulations that govern this particular architectural style, coupled with the presentation of a model that takes into account the scientific comprehension of novel materials as well as the climatic and functional implications arising from technological advancements, it is indeed

possible to apply the traditional architectural knowledge and process in novel constructions while still maintaining a contemporary outlook. According to Varzaneh et al. (2014), Iran's indigenous architecture has, for ages, provided its inhabitants with good living conditions while simultaneously consuming less energy. This is comparable to the architecture of a number of historical civilizations.

According to Dehghani-Sanij (2022), architects and engineers who originated in Iran demonstrated their unique abilities during earlier historical times by making use of natural variables, such as wind patterns and swings in air temperature, in order to achieve the optimal thermal conditions within constructions. By taking this method, the goal was to ensure that comfort could be maintained despite the dry and highly hot temperature of the desert. This technology was able to successfully circumvent the requirement for energy consumption, which is a significant accomplishment. According to Awada et al. 2021, Iran has established itself as an important entity in the field of historical architecture. This is because Iran is widely recognized as a notable exemplar of architectural systems that efficiently handle its diverse environment and ethnic makeup. According to Manzano-Agugliaro (2015), the extensive understanding that Iranian communities have regarding the natural dynamics of energy, both in the atmosphere and beneath the surface of the Earth, has led to the formulation of architectural principles that are considered to be indispensable for architects all over the world, particularly those who have Iranian heritage. It is required to combine a large number of architectural components in regions that have a climate that is hot and dry, where the weather conditions are generally unfavorable and the living situations that are influenced by these conditions are fairly challenging (Oktay, 2002).

These contain a wide range of architectural elements, including the construction of underground structures, water storage facilities, excavated pits for gardening purposes, dwelling units that are connected to one another, and homes that are equipped with wind deflectors and dome-shaped roofs. As stated by Singh et al. (2011), the architectural characteristics that were noticed, such as the presence of small windows, mat houses, and structures with thick walls, can be evaluated in terms of the impact that they have on the climate. The utilization of natural resources by builders in order to enhance living conditions and increase comfort is demonstrated by these features, which provide strong evidence of the builders' efforts. The construction methods that were utilized were

specifically designed to create a livable environment that promotes comfortable habitation without relying on external equipment (Day et al. 2020). This was accomplished in spite of the adverse environmental conditions that were prevalent in the open space during the summer, such as high temperatures, severe storms, and strong winds.

It is vital to participate in study that is both broad and extensive if one want to have a complete grasp and appreciation of the historical significance of living and residing in Iran. A number of regions in Iran are able to provide clear evidence of the widespread prevalence of this phenomena as well as the observable characteristics that it possesses. It is of the utmost importance to investigate and investigate the extent to which these structures have improved the well-being of the people who live in them. Through the utilization of the collected knowledge of long-standing local customs that have been passed down from generation to generation, it is possible to find potential advancements and reductions in pricing. It has been demonstrated that a significant amount of knowledge and expertise has been acquired, which demonstrates the capability to successfully reduce dependency on fossil fuels and improve environmental and resource sustainability.

It is of the utmost importance to recognize that having an awareness of historical events does not represent a return to the conditions that existed in the past situations. The purpose of this research is to describe in a thorough manner the characteristics, methodologies, and core principles of historical climate architecture. The ultimate objective of this study is to preserve it as a valuable resource for future generations. In addition, the process of critical analysis and evaluation will be supported by this record, which is directly related to the continual growth of indigenous knowledge. In order to acquire a better understanding of how to achieve pleasant conditions while simultaneously decreasing energy usage, the purpose of this study is to investigate the use of climate principles and passive approaches. For the purpose of establishing cooling techniques that embrace a naturalistic perspective and try to increase energy efficiency, it is possible to develop a foundation based on an understanding of this matter.

1.1. Research Aim and Objectives

The objective of this thesis is to examine the bioclimatic tactics employed in the traditional bazaar of Arak city, with a specific focus on their impact on thermal comfort. The traditional bazaar of Arak city serves as an illustrative example of major commercial buildings that have been constructed in accordance with bioclimatic principles.

Additionally, the primary goals are:

1. *To Conduct a literature review in order to:*
    a. performs a comprehensive literature analysis on the topic of bioclimatic techniques implemented in contemporary commercial buildings across various countries.
    b. examines the bioclimatic design principles employed in traditional Iranian building.
2. *To Conduct a simulation of the Arak market with the aim of investigating the bioclimatic factors present in the environment.*
3. *To verify the data acquired through simulation by means of experimental data derived from field observations.*

1.2. Research Hypothesis:

The type of roof used in the Arak bazaar significantly influences its bioclimatic behavior, reducing its energy demand and improving indoor comfort conditions.

2. Chapter 2

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State of the Art

2.1. Thermal Comfort

Thermal comfort is a crucial element of indoor environmental quality, with a significant impact on occupant satisfaction and energy consumption within buildings.

The major objective of HVAC design engineers, architects, and building operators is to ensure the preservation of thermal comfort for individuals occupying a structure. There exists potential for enhancement. According to Doulos et al. (2020), thermal comfort ranks as the second most significant cause of discontentment in US office buildings, following sound privacy. The study reveals that over 50% of occupants express displeasure with their thermal environment. Simultaneously, it is noteworthy that the energy consumption attributed to heating, ventilation, and air conditioning (HVAC) systems is substantial, reaching around 71% of the total primary energy use in commercial buildings, which in turn accounts for 18% of the overall society energy consumption (Kamilaris et al., 2014).

There exist numerous factors contributing to this subpar performance, encompassing mechanical aspects such as the building envelope, systems, and controls. However, it seems that designers and operators have a limited or outdated comprehension of how comfort is influenced by the complete spectrum of potential indoor temperature conditions. In the realm of architectural and HVAC system design and operation, possessing knowledge about human thermal comfort can present prospects for energy conservation while concurrently enhancing, or at the very least, not sacrificing the existing levels of occupant contentment (Martínez-Molina et al., 2016).

Illustrative instances could include the expansion of thermostat heating and cooling setpoints. Another example pertains to the utilization of personal comfort systems, as examined by Zhang (2009). Additionally, the prevention of excessive cooling throughout summer and overheating during winter, can serve as another illustration.

The utilization of such methodologies necessitates a comprehensive comprehension of the manner in which individuals react to various environment factors, as well as the intricate interplay between their respective thresholds. Thermal comfort prediction and

visualization technologies have the potential to enhance the capabilities of designers and building operators in the areas of thermal comfort design, operation, and comprehension.

In addition to thermal comfort, the consideration of acoustic environments, including the quietness of service equipment, and visual comfort, including both artificial and natural illumination, are also integral components of the human comfort categories that warrant careful attention during the construction of buildings (Abdullah, 2007; Bansal, Hauser, & Minke, 1994). Nevertheless, the primary focus of this study pertains to the thermal comfort experienced by those using commercial structures. According to Douvlou (2003), the consideration of thermal comfort holds significant importance in the architectural design of buildings. According to Abdullah (2007), the presence of certain factors in a structure has the potential to enhance both the cognitive abilities and overall well-being of its tenants.

According to Heidari (2009), incorporating considerations of thermal comfort into the design process has numerous benefits, including improved indoor air quality, decreased incidence of sick building syndrome, reduced energy usage, and minimized environmental impact. Additionally, it serves as a notable benefit in professional and commercial environments by fostering increased human productivity. This study investigates commercial blocks and emphasizes the need of addressing thermal comfort. It is argued that individuals working in extreme cold or hot surroundings are more likely to experience a decline in performance compared to those working in optimal thermal conditions (Health and Safety Executive, n.d.-a). The following are examples of performance implications.

- Employing expedient measures to exit an unfavorable setting
- Within high-temperature settings, workers may exhibit inadequate adherence to protective gear protocols, so amplifying their health and safety jeopardy.
- The capacity of employees to maintain focus on a given activity may significantly diminish, thereby increasing the likelihood of errors.

According to the Health and Safety Executive (n.d.-a), it is important to comprehend and effectively address the underlying causes of these behaviors in order to enhance productivity and promote the well-being and safety of employees. This is because individuals have a threshold beyond which they are unable to adapt to their surroundings,

such as the act of removing or donning clothing, without experiencing a subsequent impact on their comfort. (The thermal comfort model utilized in this investigation is described in greater depth in the appendix on page 35 - 38.)

2.1.1. Factors Affecting Thermal Comfort

The maintenance of thermal equilibrium within the human body is a critical factor in achieving optimal thermal comfort, and this equilibrium is subject to the influence of various parameters.

These criteria are divided into two groups; personal and environmental determinants (ASHRAE, 2013; Health and Safety Executive, n.d.-a).

Personal factors

Activity level or metabolic rate (M): The degree of activity or metabolic rate (M) is directly proportional to the necessity for dissipating internal metabolic heat production from the body.

Thermal insulation: Thermal insulation is a characteristic of clothing that is quantified using the unit of measurement known as "clo." The various types of insulation present in clothing have an impact on the heat transfer process involving convection between the body surface and the surrounding environment.

Environmental factors

The design team has the ability to regulate environmental conditions, as stated by Douvlou (2003) These factors are also mentioned by Douvlou (2003), and Design Builder (2015).

Relative air velocity (V): The thermal comfort is influenced by the convection process through the relative air velocity (V).

Mean radiant temperature (Tr): Mean radiant temperature (Tr) is a metric expressed in MET (Mean Effective Temperature) units. It plays a significant role in influencing the radiative heat exchange between the human body and its surrounding environment.

Air temperature (Ta): The air temperature (Ta) is the primary factor that directly impacts the heat exchange between the environment and the individuals in most scenarios.

According to Hensen (1990), air temperature is considered the primary environmental characteristic in relation to thermal comfort among all other thermal comfort factors. In addition, Douvlou (2003) exclusively focused on the impact of temperature variations on thermal comfort, deeming it a significant determinant.

Relative humidity (Rh): According to Douvlou (2003), when the relative humidity (Rh) falls within the range of 20% to 70% and the operative temperature, which considers factors such as air temperature, radiant temperature, and air speed, is within the comfort range or thermal comfort zone, the impact of RH on thermal comfort is negligible. In this scenario, the primary factor influencing the thermal comfort of occupants is the air temperature.

According to Douvlou (2003, p. 72), Macfarlane (1978) asserts that the utilization of dry bulb temperature serves as a sufficient indicator, with humidity only exerting a substantial impact on the comfort rating of air temperature in the humid tropics.

All of these aspects contribute to the establishment of a comfortable environment for individuals. According to Olgyay (1992, p. 18), a comfort zone can be defined as the specific range or area within which individuals experience a lack of discomfort or unease. According to Douvlou (2003), it is widely acknowledged that a zone is considered thermally comfortable when a minimum of 80% of the population falls inside the acceptable zone.

The concept of the comfort zone lacks a precise delineation due to its dependence on factors such as individual activities and wardrobe choices. However, it is imperative to establish and employ rules, guidelines, and limitations for pragmatic objectives.

According to Abdullah (2007), there exists a disparity in the comfort levels experienced by individuals residing in cold or moderate climates compared to those residing in hot climates. According to Givoni (1992), it is crucial to recognize temperature as a significant determinant. Givoni suggests that those residing in a temperate environment should consider a suitable temperature range of 20°C to 27°C during the summer months and 18°C to 25°C during the winter months, when there is no air movement. However, this is applicable just under the condition that the humidity levels are not elevated (Douvlou,

2003). According to Givoni (1992), individuals residing in regions characterized by high temperatures may experience an extension of the upper temperature threshold by two degrees Celsius. Consequently, the tolerable temperature range for such individuals would span from 18°C to 29°C. The specific utilization of this spectrum in the Arak Bazaar case study will be further examined in Chapter 4.

2.1.2. Techniques for Characterizing and Depicting Comfort and Comfort Zone

Methods have been devised to assess the thermal comfort levels of occupants with the aim of improving their comprehension of this aspect. The Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD) are widely utilized thermal comfort models, originally formulated by Fanger in 1970 and then incorporated into ISO7730 in 2005.

This standard employs 22 °C as the neutral temperature (Tcomf) in winter and 24°C in summer (Taleghani, Tenpierik, & Dobbelsteen, 2012). The PMV (Predicted Mean Vote) employs a thermal sensation scale consisting of seven points, with a rating of +3 indicating a perception of heat and a rating of -3 indicating a perception of coldness. Hence, when the Predicted Mean Vote (PMV) reaches a value of 0, it indicates a state of thermal neutrality, when the majority of occupants experience optimal thermal comfort (Abdullah, 2007). The Predicted Mean Vote (PMV) is determined by the utilization of six fundamental variables, namely humidity, mean radiant temperature, air velocity, air temperature, clothing, and activity. The findings are consistent with many assessments conducted on a significant sample size, encompassing various environmental conditions.

Furthermore, the term PPD, which stands for Predicted Percentage of Dissatisfied, is frequently employed in the field. It is contingent upon the PMV (Predicted Mean Vote) value and is associated with the six primary criteria. The Predicted Percentage Dissatisfied (PPD) is a metric used to forecast the level of unhappiness among occupants in specific conditions or at each Predicted Mean Vote (PMV). The PPD model is utilized to determine the thermal satisfaction levels of individuals, with 90% and 80% of the population being accounted for in these calculations. The correlation between the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD)

demonstrates that while the PMV is at 0, the PPD does not fall below a minimum value of 5%.

This implies that, despite the classification of the environment as thermally comfortable, complete contentment among all inhabitants is unattainable, as there will always be those who express dissatisfaction with the comfort level that appears acceptable to the majority. The variation in comfort evaluation arises due to individual differences among individuals. According to Kim, Min, and Kim (2013), the PMV graph indicates that a range of -0.5 to +0.5 is commonly associated with 90% thermal satisfaction.

2.2. Climate

Climate is what we expect, weather is what we get.

Mark Twain (1835–1910)

Mark Twain consistently demonstrates his ability to emphasize the fundamental nature of a matter through succinct and clever expressions. The author skillfully articulated the distinction between climate and weather, wherein weather refers to the immediate atmospheric conditions, while climate encompasses weather patterns and various related factors (such as topography, vegetation characteristics, bodies of water, etc.) aggregated over an extended duration (Szokolay 2014; Goosse 2015). Climate is typically represented by average values and typical patterns. The present condition of the weather can significantly diverge from climatic attributes as a result of the deterministic chaotic nature of weather phenomena. Nevertheless, when considering a suitably extended temporal framework, climate effectively characterizes the prevailing meteorological conditions experienced at a specific geographical area over the recorded timeframe.

Based on the findings of the World Meteorological Organization (WMO), it is deemed suitable to utilize a standard timeframe of 30 years to accurately depict the prevailing meteorological conditions within a certain geographical area (Goosse, 2015). The feasibility of this phenomenon arises from the substantial quantity of accessible data obtained through precise and regular observations conducted by weather monitoring stations.

The presentation of climate features is contingent upon the intended application of the data, as argued by Hartmann (2016). Hence, it is imperative to accurately depict climate features in accordance with their intended purpose. This entails determining the desired temporal resolution (e.g. monthly, daily, or hourly values) and spatial granularity (e.g. macro-, mezzo-, or micro-level), as well as selecting the appropriate variables for presentation.

When considering bioclimatic design, as well as any other type of building design, it is essential for the designer to gather and evaluate pertinent climate data. This process is crucial in order to enable the identification and implementation of strategic design measures that are suitable for the specific climatic conditions of the location (Olgyay 1963; Upadhyay 2007; Szokolay 2014). The utilization of climate analysis can be employed to enhance or facilitate the enhancement of a building's performance. The climate parameters and their impact on the design and functionality of bioclimatic buildings constitute one of the three components of the bioclimatic design process. The comprehension and accurate interpretation of climate features at the intended site of construction play a pivotal role in the building design process, particularly when employing the analytical bioclimatic method. Hence, possessing a fundamental understanding of climatology is necessary for building designers, including architects and architectural engineers, in order to effectively implement climate-adapted designs. Bioclimatic design can be considered a manifestation of architectural regionalism, as it involves the development of building forms that are influenced by the specific qualities of the place, particularly its climate (see Figure 1).



Figure 1: Variability of the Earth's climate—from Polar Regions (top left) through temperate midlatitudes (top right) to arid deserts (bottom left) and tropical areas (bottom right)—dictates and determines the design of bioclimatic buildings. (Image source: Košir, 2019)

In the context of bioclimatic architecture design, a comprehensive grasp of annual and daily temperature variations, relative humidity, and the corresponding solar radiation received is of utmost importance for the development of climate-adapted designs. The formation of indoor environments and the thermal response of buildings that are primarily dominated by their envelope and rely on natural ventilation are primarily governed by three climate characteristics. These characteristics, include the temperature of the external air, relative humidity, and solar radiation.

The temperature of the external air impacts the thermal flow through the building's envelope, while relative humidity plays a role in defining the indoor comfort of occupants. Solar radiation directly affects the internal thermal conditions through solar gains and indirectly by heating the external surface of the building. Nevertheless, even in the scenario of buildings where internal loads are the primary factor, and their dependence on climate is relatively low, solar radiation can significantly impact the thermal performance of these structures. This is principally due to its ability to intensify overheating in such buildings. Moreover, the influence of air mass movement, specifically wind, might be a significant climatological consideration in the field of building design.

2.3. Climatic Design

Everything we design is a response to the specific climate and culture of a particular place.

Norman Foster (1935)

According to Edwards and Duplesis (2001, as referenced in Shokouhian et al., 2007), climate can be described as the temporal integration of the physical condition of atmospheric environmental variables within a certain geographical area. Buildings are constructed edifices that serve as human-made structures providing protection from the various atmospheric elements. Prior to commencing the architectural design process, it is imperative to get a comprehensive understanding of the climatic conditions prevalent in the specific geographical region where the building is intended to be situated. The energy consumption associated with providing thermal comfort within a structure can be influenced by its design. This thesis aims to investigate a geographical area characterized by a semi-arid climate, commonly referred to as semi-desert or BSK in accordance with Koppen's classification.

This section provides an overview of the evolution of climate design methodologies. According to Broadbent and Brebbia (2006), climate-responsive design is an approach that aims to optimize the favorable climate characteristics of a specific area, while mitigating any negative traits that could compromise comfort or escalate energy use (p.

99). According to Pourvahidi and Ozdeniz (2013), the term "bioclimatic design" is used to describe design approaches that take into consideration the climatic requirements of individuals.

The concept of climatic design predates the advent of contemporary technology. Ancient architectural designs were primarily focused on creating thermally comfortable surroundings without relying on modern technologies for comfort provision. Historically, the absence of air conditioning was prevalent. Engineers and architects were required to demonstrate ingenuity in ensuring a pleasant indoor environment through the utilization of natural methods, such as including effective ventilation systems and maximizing sunshine penetration throughout all areas of the structure. Through a process of experimentation and refinement, individuals discovered methods for constructing edifices that effectively harnessed the advantages offered by their specific climatic conditions. These constructions were designed to optimize the creation of a naturally conducive and comfortable living environment.

For example, builders had to consider which form would allow the greatest natural daylight and ventilation to the inside.

Consequently, each temperature location exhibits its own distinct architectural style, as designers have been compelled to address the individual climatic requirements of each locale. The efficacy of conventional architectural structures in fulfilling the specific climate and occupant comfort requirements has inspired modern architects to explore passive strategies for creating thermally comfortable settings.

2.3.1. Elements that affect climatic design

According to Douvlou (2003), designers who aspire to create energy-efficient and comfortable buildings, as well as climate-responsive designs, must consider the subsequent measures.

a. Comprehend the climatic zone.

b. Gain a comprehensive understanding of fundamental principles related to human thermal comfort.

c. Enhance the level of comfort by effectively utilizing thermal mass as a means of temperature regulation.

d. One objective is to improve visual comfort while simultaneously managing the impact of solar heating.

e. It is imperative to meticulously choose a method that effectively caters to space conditioning needs while being responsive to the prevailing environment conditions.

According to Douvlou (2003), the elements influencing climatic design can be categorized into two main groups: site-related factors and architectural factors.

The initial group conducts an examination of the regional microclimate and the many site elements that may impact the environmental conditions of the construction. According to Douvlou (2003), the following are:

a. The presence of surrounding buildings can contribute to the ventilation quality in an open plan environment, as the vacant areas between blocks allow for improved airflow. This phenomenon occurs due to the presence of high-density blocks, which leads to a decrease in wind speeds at ground level and limited access to wind flow (Abdullah, 2007). Furthermore, according to Givoni (1976), several factors such as the interstitial spaces between buildings, the vertical dimension of structures, the arrangement of street networks, and the allocation and dispersion of gardens, play a significant role in shaping the design of a building that achieves a favorable internal atmosphere.

b. Vegetation, characterized by its growth pattern, spatial distribution, mass, and height, has the potential to enhance the microclimate of buildings through the provision of shading and the facilitation of fresh air circulation. According to Yeang (2006), trees additionally serve the purpose of air filtration and moisture provision. Furthermore, the presence of vegetation, either on its own

or in conjunction with water, has the potential to establish a favorable ambiance, hence reducing reliance on HVAC systems. This not only leads to cost savings but also mitigates the risk of overheating within built environments (Abdullah, 2007).

c. The topography of an area, including its ground surface conditions, hills and valleys, slopes, and elevation, can significantly impact the airflow and natural ventilation potential of buildings. For instance, structures situated on elevated terrain are more likely to benefit from increased wind exposure, facilitating better natural ventilation compared to those situated in valleys.

According to Douvlou (2003), the architectural design variables can be categorized into four primary groups: the geometry of a building, ventilation, the building's fabric or material, and its fenestration or glass. According to Brien, Pearsall, and O'Keefe (2010), orientation is considered to be one of the design variables that contribute to the creation of an effective passive low energy design, resulting in a naturally thermally comfortable atmosphere.

Therefore, the five distinct factors are:

1. *Structure Form and Shape (Height and Surface-to-Volume Ratio):* The efficiency of a structure can be influenced by its form, which is determined by various factors such as climate conditions (Rashdi & Embi, 2016), functional considerations, and socio-cultural requirements (Douvlou, 2003). Climate conditions play a crucial role in determining the necessity of cross ventilation in buildings. Consequently, it has been observed that narrow plan buildings are more effective than deep plan structures in facilitating cross ventilation for cooling purposes (Abdullah, 2007).

Moreover, the utilization of a flat roof configuration might offer certain benefits in specific geographical regions during the winter season. In such areas, the presence of snow coverage on the roof can serve as an insulating layer, thereby enhancing thermal insulation properties. According to Abdullah (2007), the presence of high ceilings offers a distinct advantage in regions with hot climates, as it allows for the dissipation of heat that tends to accumulate above head level. Furthermore, according to Rashdi and Embi (2016), it has

been suggested that a reduced surface-to-volume ratio can passively contribute to the reduction of cooling loads.

2. *Building Fabric:* Encompassing aspects like as materials and construction techniques, as well as the influence of thermal mass and thermal insulation.

According to Reardon, McGee, and Milne (2013), the utilization of thermal mass and thermal insulation has the potential to regulate the extent of heat accumulation and dissipation in walls, roofs, or floors. In the context of building construction, heavyweight materials, such as earth, stone, solid concrete, or brick, possess a notable thermal mass characteristic. This property enables them to effectively absorb and retain solar heat during daylight hours, afterwards facilitating a gradual release of this stored heat throughout the night. The rate of temperature exchange between the indoor and outdoor environments is inversely proportional to the mass of the materials involved. This characteristic is advantageous during winter as it reduces heat loss, while in summer it promotes gradual and slow heating. Conversely, lightweight materials exhibit rapid responsiveness to temperature changes, making them suitable for spaces requiring quick heating or cooling (Douvlou, 2003; Reardon et al., 2013).

Additionally, the utilization of materials possessing thermal insulation properties has the potential to influence the transmission of heat between interior and exterior environments. This characteristic can be advantageous if appropriately employed. For instance, the implementation of thermal insulation measures can contribute to enhancing thermal comfort and achieving substantial energy conservation. These measures prove efficacious in retaining heat within the structure during cold weather conditions and preventing heat ingress from the external environment during hot weather conditions, hence facilitating temperature regulation within the building. The heat gain is influenced by the fabric color of both the interior and outside facades. According to Yeang (2006), there is a positive correlation between the intensity of color and the amount of heat absorbed.

3. *Building Orientation:* The orientation of a building plays a crucial role in the context of climatic design. For instance, when a building is positioned towards the south in the northern hemisphere or towards the north in the southern hemisphere, it facilitates the optimal exposure to sunlight during winter while providing protection against excessive heat during summer (Abdullah, 2007). Moreover, in the event that the elongated elevation is oriented towards the sun, a greater amount of heat could be acquired compared to when a smaller facade is exposed throughout the winter season. During the summer season, the angle of the sun is rather high, making it advisable to incorporate smaller facades on the eastern and western sides of a building, where the sun's angle is lower. The reduction of cooling loads and the requirement for mechanical air conditioning devices, such as HVAC, can be achieved by using measures to prevent direct sunlight exposure to interiors. Hence, it has been suggested that a proper orientation of buildings can effectively regulate the temperature by managing the cooling and heating processes (Brien et al., 2010). In situations where achieving a suitable orientation is unfeasible, the utilization of devices, such as shades, may prove beneficial in mitigating the ingress of intense direct sunlight into the interior space.

4. *Glazing:* Encompassing window dimensions, placement, glass composition, and shading mechanisms, represents a viable approach for facilitating the ingress of sunlight, so affording both illumination and thermal comfort inside a given space. The quantity and placement of glazing play a significant impact in the energy consumption of buildings (Abdullah, 2007). According to Abdullah and Wang (2012), it is important to evaluate the balance between enough heat gain and appropriate natural ventilation during the design phase of a structure. This is because an increase in the amount of glass used in the building allows for a greater influx of sunlight, resulting in higher heat gain. The determination of such judgments will be contingent upon the climatic conditions of the specific region, as well as the consideration that buildings may require additional assistance in managing heating loads during colder

seasons or cooling loads during warmer seasons. Nevertheless, it is crucial to exercise caution when implementing shade measures in situations where excessive heat is undesirable.

According to Holford and Hunt (2003), the utilization of shades and solar blinds can effectively reduce the amount of heat absorbed. The provision of shade has held significant importance, particularly within the context of vernacular architecture in the Middle-East (Michell & Grube, 1995). According to Weyland and Oncu (1997), the vernacular constructions were specifically crafted to provide shade in various semi-open environments, including courtyards, bazaars, and narrow streets. Overhangs possess a beneficial property of obstructing the direct rays of the summer high angle sun. According to Abdullah and Wang (2012), this design feature serves the dual purpose of preventing overheating and facilitating the penetration of low angle sunlight during winter, hence facilitating solar heat gains to assist with heating loads.

5. *Natural Ventilation:* As previously discussed, significantly impacts the initial architectural configuration of the building. According to Abdullah (2007), it is recommended that architects and engineers prioritize the selection of an option that optimizes the provision of adequate natural ventilation to meet the prospective needs of inhabitants in buildings.

Various methods can be employed to achieve cooling in enclosed areas (Ghiabaklou, 2010; Salib & Wood, 2013). One approach involves cooling the building structure itself, while another involves the introduction of outdoor air to cool and refresh the indoor environment, particularly when the outdoor temperature is lower than that indoors. Additionally, occupants can be cooled directly through convection and evaporation. However, the effectiveness of the final alternative is contingent upon the velocity at which air is circulated, commonly referred to as the air flow rate. According to Salib and Wood (2013), it has been established that the utilization of the convection and evaporation cooling approach can effectively mitigate occupant discomfort at high

temperatures, even when accompanied by high air speeds ranging from 1 to 2 meters per second. According to Norton (1997), the process of cooling through convection is responsible for around 30% of body heat loss, whereas evaporation accounts for approximately 25% of heat loss under typical comfort settings.

According to the findings of Behbood, Taleghani, and Heidari (2010), the velocity at which warm air is removed from the body and the resulting body temperature are influenced by the interplay between air temperature and air movement. Furthermore, the utilization of nocturnal cooling to reduce the temperature of the bulk material contributes to the reduction of cooling loads on the subsequent day (Abdullah & Wang, 2012). According to Hussain and Oosthuizen (2013), the implementation of night time ventilation has been found to enhance thermal comfort and decrease cooling requirements.

According to Hussain and Oosthuizen (2013), numerous low energy passively cooled office buildings have demonstrated the effectiveness of this technology.

Additionally, he asserts that nocturnal ventilation demonstrates optimal cooling efficiency when there is a substantial disparity in temperature between daytime and nighttime. This phenomenon occurs due to its ability to expel the accumulated warm air within the building space and fabric, thereby reducing the temperature of the building fabric. This cooling effect allows the building fabric to function as a heat sink, facilitating its capacity to absorb and store heat for subsequent days.

2.4. Commercial Buildings and Bioclimatic Architecture

This section provides a comprehensive overview of the contribution of energy consumption and carbon dioxide production in commercial buildings. The chapter also introduces the concept of bioclimatic architecture, which focuses on designing buildings that are in harmony with their natural surroundings and utilize renewable energy sources. By the end of this chapter, readers will have a clear understanding of the environmental impact of commercial buildings.

2.4.1. Definition of commercial buildings and their importance in the built environment

Commercial buildings refer to structures that are primarily used for business purposes, such as offices, retail stores, malls, and bazaars (Zhu et al. 2021).

These buildings play a critical role in the built environment by providing spaces for economic activities such as offices, retail stores, and restaurants. They not only contribute to the overall development of cities and communities but also serve as hubs for business and social interactions. Additionally, the design and construction of commercial buildings according to the principles of climate architecture can have a significant impact on energy consumption and environmental sustainability, ensuring efficient use of resources and reducing carbon footprints. On the other hand, buildings that are built without considering these concepts can contribute to increased energy waste and environmental harm. They can also lead to negative impacts on ecosystems and human health (Yuan et al. 2017).

Additionally, buildings that disregard sustainable practices may hinder efforts towards achieving a greener future. For example, a poorly designed building with inadequate insulation and inefficient heating and cooling systems will require excessive energy consumption to maintain comfortable indoor temperatures (Taleb, 2014). This not only leads to higher utility bills for the occupants but also contributes to increased greenhouse gas emissions, further exacerbating climate change. Moreover, if the construction materials used in the building contain toxic substances or are not sustainably sourced, it can lead to pollution during the manufacturing and disposal stages, causing harm to ecosystems and posing health risks to those exposed (Sev, 2009).

2.4.2. Built according to the principles of Climate Architecture

Commercial buildings built according to the principles of climate architecture aim to minimize their impact on the environment and provide a comfortable and healthy indoor environment for occupants (Al Horr et al. 2016). By designing and constructing these commercial buildings according to the principles of climate architecture, energy efficiency

can be maximized, reducing both operating costs and environmental harm. This can be achieved through strategies such as proper insulation, efficient HVAC systems, natural lighting, and renewable energy integration.

2.4.3. Built without considering the concepts of Climate Architecture

Commercial buildings that are built without considering the concepts of climate architecture often contribute to increased energy waste and environmental harm (Ibn-Mohammad et al. 2013). These buildings typically lack features such as efficient insulation, solar panels, or natural ventilation systems, which can lead to higher energy consumption and greenhouse gas emissions. Additionally, inadequate consideration of climate architecture principles may result in poor indoor air quality and uncomfortable working conditions for occupants (Al Horr et al. 2016). Furthermore, it can lead to increased health risks and reduced productivity levels.

2.4.4. Environmental Impact of Commercial Buildings

Commercial buildings have a significant environmental impact due to their high energy consumption and carbon emissions. The lack of sustainable design and construction practices in these buildings leads to increased resource depletion and pollution. Inefficient heating, ventilation, and air conditioning systems, as well as excessive use of artificial lighting, contribute to higher energy consumption and greenhouse gas emissions. Additionally, the improper disposal of construction waste and the absence of green spaces further degrade the environment surrounding commercial buildings.

Evaluation of the environmental impact of commercial buildings on energy consumption and greenhouse gas emissions is essential for developing sustainable solutions (Le et al. 2018).

This evaluation can help identify areas for improvement and potential strategies for reducing the negative impact on building occupants at risk.

Analysis of sustainable design strategies and technologies that can minimize the environmental impact of commercial buildings includes incorporating renewable energy sources, implementing energy-efficient systems and appliances, optimizing building orientation for natural lighting and ventilation, and utilizing green materials and construction practices (Omer 2008). Additionally, adopting green building certifications such as LEED (Leadership in Energy and Environmental Design) can ensure that commercial buildings meet strict sustainability standards (Leskinen et al. 2020). By implementing these strategies, commercial buildings can not only reduce their environmental footprint but also create healthier and more comfortable spaces for occupants.

2.5. Energy Consumption and Carbon Emissions

Buildings consume energy throughout their operational lifespan. The operational phase of a building's life cycle plays a crucial role in energy consumption. The key features encompassed within a building's infrastructure include heating, ventilation, air conditioning (HVAC), lighting, and appliances (Alzazmeh & Asif, 2021). According to empirical data, the energy consumption attributed to buildings and their associated activities throughout their life cycle accounts for over 40% of the total global energy demand (Hyde et al. 2013). Approximately 50% of the total energy consumption is allocated to heating, ventilation, and cooling (HVAC) systems (Spitler & Gehlin, 2019).

The energy consumption in question pertains to carbon dioxide emissions, which have exhibited an annual growth rate of 6.83% over the previous decade. The total emissions of 881 megatons (Mt CO2) reported in 2018 show that the rate of growth of this phenomenon is increasing. According to their overall performance, mercantile edifices are currently the most frequently used buildings in the realm of existing structures (Zhang et al, 2021).

Hence, the imperative to mitigate carbon dioxide emissions resulting from the utilization of fossil fuels to generate energy for pre-existing commercial structures has become a crucial matter of policy and design for governments globally (Hyde et al. 2013). Consequently, a considerable body of research, investment, technological advancements,

and regulatory efforts are directed toward reducing energy consumption in HVAC systems through the implementation of sustainable building practices (Spitler & Gehlin, 2019).

According to the definition provided by the US Environmental Protection Agency (2012), green construction refers to the practice of designing and implementing environmentally responsible structures and processes while also ensuring the efficient utilization of resources throughout the entire life cycle. A Green Building (GB) can also be referred to as a High-Performance Building or a Sustainable Building. There are two distinct categories of GB design, namely new design (ND), which pertains to the construction of new buildings, and reinforcement design (RD), which focuses on enhancing the structural integrity of existing buildings (Bu & Shen, 2013). Studies have demonstrated that the energy consumption of newly constructed buildings often exceeds the initial projections made during the design phase, despite the utilization of architectural elements such as Green Building practices. This disparity is frequently denoted as the "performance gap" (Spitler & Gehlin, 2019).

A study conducted in 2013 (Huang et al. 2013), examined the annual energy consumption per unit area (square meter or square foot) of building infrastructure in a sample of 953 properties located in New York City. The researcher observed a lack of substantial energy conservation in LEED-certified buildings compared to non-LEED-certified buildings. The US Green Building Council established LEED, which stands for Leadership in Energy and Environmental Design, as a widely accepted certification standard for environmentally friendly construction (Scofield, 2013).

In a study conducted in 2014, a comprehensive analysis was carried out on 51 buildings that were previously classified as "high performance" in the United States, Europe, and Asia (Li et al, 2014). It is noteworthy that a considerable proportion, roughly 50%, of the structures examined failed to comply with the ASHRAE Standard 90.1-2004 Energy Standards, as established by the American Society of Heating, Retrofitting, and Air Conditioning Engineers (Agopian, 2014).

A separate study conducted in 2019 (Geng et al. 2019) examined the operational efficiency of green buildings, with a particular focus on China and the United States. A comprehensive review of the literature identified a total of 106 studies that included

substantial quantitative data analysis. A comparison was conducted between the energy intensity of 121 high-performance certified buildings from the United States and 31 buildings from China. According to the study, there has been a marginal improvement in the overall performance of the building.

In conjunction with the considerable energy consumption exhibited by contemporary commercial buildings constructed in accordance with the Green Building Rules, as previously delineated, a more disconcerting reality pertains to the majority of commercial buildings in prominent urban centers worldwide, which were erected prior to the advent of energy efficiency measures and are currently 20 to 30 years old. The primary issue at hand pertains to the fact that the majority of these structures are anticipated to be in use until the year 2050. Hence, as a result of their elevated energy consumption, current commercial buildings exert added strain on the emission of carbon dioxide derived from fossil fuel sources (Huang et al. 2013).

Due to its perceived comparative advantages in terms of energy-saving potential, the construction sector occupies a prominent position in addressing global energy and environmental concerns, surpassing other sectors such as industry and transportation. The existing structure serves as the backbone of the construction sector, making it imperative to enhance its performance in order to ensure stability. Therefore, it is crucial to enhance the energy efficiency and environmental impact of existing commercial buildings in industrialized nations (Alzazmeh & Asif, 2021).

2.6. Definition of Bioclimatic Architecture

Bioclimatic architecture is founded upon a sustainable approach to design, taking into account various natural elements such as climate, fauna, flora, and topography. These factors are considered variables in the development of design solutions, with the aim of achieving a harmonious relationship between the natural environment and the built environment. This is achieved through the careful selection of design solutions that utilize renewable energy sources, prioritize energy efficiency, and employ building materials and systems with minimal environmental impact. The primary objective of bioclimatic design is to mitigate the adverse environmental impacts associated with construction

activities, thereby enhancing societal well-being through improved comfort and quality of life (Bestara, 2022).

The concept of bioclimatic design, also referred to as passive solar architecture, is centered around the objective of optimizing energy efficiency, mitigating environmental impacts, and improving hygrothermal comfort. In order to achieve this, architectural structures must take into account the natural features of the surrounding terrain, such as the topography, vegetation, prevailing winds, and weather patterns (Bodach, 2014).

Using design methods that make the most of the building's site's natural features helps create a strong link between the built environment and its natural surroundings. By carefully selecting design strategies that prioritize energy efficiency, use renewable energy sources, and use building materials and systems that have minimal negative effects on the environment, it is possible to achieve bioclimatic architecture (Pacheco, 2012).

Several design characteristics can be employed to attain bioclimatic architecture. These include optimizing building orientation, incorporating appropriate apertures, utilizing light and thin wall materials, incorporating semi-outdoor spaces, and maximizing the presence of flora (Aghimien, 2021).

Bioclimatic design is an approach that focuses on optimizing the building's relationship with its natural surroundings and climate to create comfortable and healthy indoor environments (Beccali, 2018).

This design strategy takes into account factors such as solar orientation, natural ventilation, and insulation to minimize energy consumption and greenhouse gas emissions. By integrating these principles into the building's design, bioclimatic design can help improve indoor air quality and create a more pleasant and productive work environment for occupants (Abazari, 2022). It not only reduces the negative impact on the environment but also enhances the overall well-being and performance of the building's users. It is a win-win situation for both the planet and the people.

2.6.1. Connection between climate architecture and bioclimatic design

Climate architecture and bioclimatic design are closely connected, as both aim to create sustainable and energy-efficient buildings that are in harmony with the natural environment (Nguyen et al. 2019). Climate architecture considers the local climate and weather conditions to design buildings that can withstand and adapt to these factors. Bioclimatic design takes this a step further by utilizing passive design strategies such as natural ventilation, daylighting, and thermal insulation to reduce the reliance on mechanical systems and minimize energy consumption (Mushtaha, 2021). Together, these approaches contribute to reducing greenhouse gas emissions and creating a more sustainable built environment.

2.7. Bioclimatic Design

Only primitives and barbarians lack knowledge of houses turned to face the winter sun.

Aeschylus (c. 525/524–c. 456/455 BCE)

The aforementioned citation attributed to Aeschylus, the renowned ancient Greek dramatist sometimes referred to as the "founder of tragic drama," effectively exemplifies the fundamental concept of Passive Solar Architecture (PSA). In the realm of PSA engineering, the architectural design of a building is strategically devised to optimize the utilization of solar energy readily accessible on-site for the purpose of meeting the heating requirements of the structure. Similarly, the design of photovoltaic solar arrays (PSA) can also be aimed at mitigating the issue of excessive heat generation caused by solar radiation (Manzano-Agugliaro et al., 2015).

Consequently, the architectural design of the building incorporates features that optimize the consumption of solar energy in accordance with the building's energy requirements (DeKay and Brown, 2014; Szokolay, 2014). This implies that PSA endeavors to incorporate design measures for enclosure systems, namely at the level of the building envelope, to promote passive solar heating and minimize overheating. These measures are primarily aimed at achieving these goals without relying on active methods such as mechanical heating and cooling.

The idea of bioclimatic design is frequently employed to refer to the practice of enhancing the energy efficiency of buildings and building envelopes, as discussed earlier (Almusaed, 2011). Nevertheless, it might be contended that a subtle yet significant distinction does really exist between the two. The design of PSA is mostly influenced by technology applications that attempt to decrease a building's energy consumption by utilizing solar energy passively, taking into consideration the climate conditions. In contrast, bioclimatic design encompasses a broader perspective that takes into account the needs, desires, and socio-economic circumstances of the occupants, as seen in Figure 2 Bioclimatic design is a prevalent engineering approach in building design that aims to tailor buildings to the specific climatic conditions of a particular area, taking into account the requirements and preferences of the occupants.

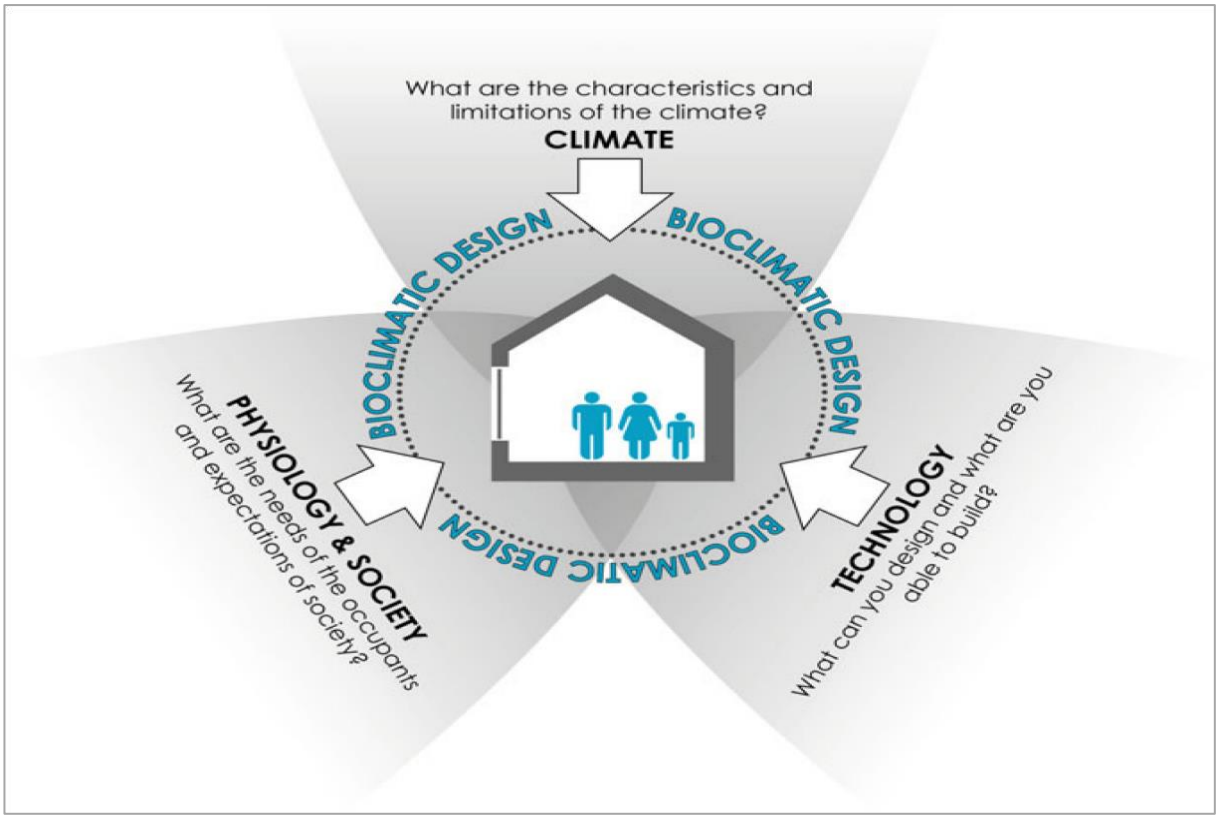


Figure 2: The three basic constituents of bioclimatic design. (Image source: Košir, 2019)

This practice also emphasizes the optimization of energy consumption (Olgyay 1963; Pajek and Košir 2017). For instance, consider a structure (see Figure 3) situated in a region characterized by a moderate temperature, such as Central and Western Europe.



Figure 3: Traditional building (British Isles) expressing bioclimatic adaptation on the level of building design, material use and aesthetic expression. (Image source: Košir, 2019)

A residential building constructed according to bioclimatic design principles would be adapted to the climatic specifics of its location via elongated floorplan with longer side facing south (i.e. equatorially oriented), south oriented rooms with substantial area of glazing to facilitate passive solar gains primarily during spring and autumn. To mitigate thermal losses during extended periods of cold weather, the implementation of a low thermal transmittance envelope is employed.

Additionally, shading techniques are employed on transparent building envelopes to minimize excessive heat gain during the summer months, hence obviating the necessity for mechanical cooling systems. Concurrently, the utilization of thermal mass would offer a sufficient time delay by storing solar energy received, so ensuring the provision of thermal comfort to the inhabitants throughout the nights, which correspond to the primary occupancy period of the residential structure. Furthermore, the integration of socio-economic and cultural elements would be achieved through the utilization of locally sourced materials, implementation of local construction methods and engagement of regional contractors, as well as adherence to established regional building customs (see Figure 3).

The concept being discussed gained significant recognition through the influential contributions of Victor Olgyay in his foundational publication titled "Design with Climate: Bioclimatic Approach to Architectural Regionalism" (1963), as well as Baruch Givoni's subsequent work "Man, Climate,

and Architecture" (1969). The underlying concept of bioclimatic design is inherently evident in its nomenclature, which comprises the prefix "bio" denoting the connection to human biological requirements and the broader realm of ecology, and the term "climatic" signifying the association with the climatic characteristics of a specific geographical area. The term "eco climatology" is derived from the scientific discipline of ecology, which pertains to the study of the interconnectedness between climatic patterns and the behaviors and geographic patterns of living creatures.

The ultimate objective of bioclimatic building design and, by extension, of PSA, can be attained through a variety of ways, such as the implementation of diverse passive solutions or the combination of active and passive measures. Nevertheless, when considering the objective of reducing the environmental effect of buildings, passive solutions implemented at the building exterior level are deemed more favorable. By implementing suitable bioclimatic techniques, it is possible to optimize the performance of buildings in relation to anticipated or projected climatic conditions (Olgyay, 1963; Pajek & Košir, 2018).

The latter phenomenon is manifested in a decreased requirement for operational energy, such as heating, cooling, artificial lighting, and so on. As a result, this allows for improved indoor conditions and subsequently leads to elevated levels of comfort. The achievement of fully passively conditioned structures is seldom feasible, so the ultimate objective of bioclimatic engineering frequently involves achieving a harmonious interaction between active elements (i.e., service system) and passive building components (i.e., enclosure system). One could hypothesize that these structures possess an extended lifespan and are more likely to be favored by their inhabitants. Nevertheless, it is imperative to emphasize that the attainment of enhanced indoor comfort necessitates the proper implementation of energy efficiency measures, as it is not uncommon for conflicting requirements to arise between comfort and energy efficiency. For instance, demands for daylighting and energy efficiency often clash. The importance of prioritizing comfort and wellbeing in indoor environments while minimizing energy consumption has been emphasized by Košir et al. (2012).

It is crucial to design indoor spaces with the intention of promoting comfort and wellbeing, rather than focusing just on energy efficiency. Hence, it is imperative to use bioclimatic design in a manner that maximizes its potential to facilitate a comprehensive approach to building design. There has been a noticeable trend in recent years towards the adoption of the aforementioned

concept in the field of integrated building design. This trend involves the simultaneous optimization of several performance criteria (Gagnon et al., 2018; Ferrara et al., 2018).

Hence, designers consider many design objectives like as daylighting, indoor air quality, energy performance, and material durability, among others. They strive to identify synergistic solutions that address these objectives, while also resolving conflicts through compromise and optimization. Undoubtedly, this task is challenging. Nevertheless, it is of utmost importance to consider the design of "improved" structures, especially when it comes to bioclimatic design. This approach aims to optimize buildings based on the requirements and preferences of the occupants, as well as taking into account various factors such as climate, social dynamics, and technological constraints (see Figure 2).

The nomenclature of bioclimatic design and Passive Solar Architecture may be historically attributed to the United States throughout the late 1960s and early 1970s. At that location, a group of scientists, engineers, and architects endeavored to construct off-grid structures that exclusively relied on solar energy sourced from the immediate surroundings (Butti and Perlin, 1980). From a cultural perspective, it may be argued that these pursuits are, to some extent, influenced by the hippie subculture of the 1960s (Britannica Academic 2018a), which was characterized by a desire to create an alternative societal framework in opposition to the prevailing materialistic values.

Simultaneously, the commencement of the 1970s oil crisis initiated a contemporary global fascination with the energy efficiency of buildings. There were two significant events that led to oil price increases. The first occurred in 1973 when the Organization of Arab Petroleum Exporting Countries (OAPEC) imposed an embargo on Western countries in retaliation to their backing of Israel during the Yom Kippur War. The second event took place in 1979 following the Iranian Revolution (Britannica Academic 2018b). Inevitably, later, with stabilized energy prices and current improvements in HVAC technology, the attraction in building and refurbishing in line with the bioclimatic design paradigm faded. However, it was not until the late 1990s that the issue resurfaced, driven by growing awareness of energy shortages, resource depletion, and the recognition of the significant human impact on the environment, particularly in relation to climate change (Houghton, 2015).

Hence, the current upsurge in fascination in the bioclimatic paradigm can be attributed to the recognition that the optimal approach to constructing buildings in a sustainable manner involves aligning them with the surrounding environment and accommodating the requirements of their

inhabitants to the greatest extent feasible (see Figure 1). Contrary to popular belief, bioclimatic design is not a recent design paradigm but rather has roots in early human communities and buildings, as evidenced by studies conducted by Olgyay (1963 a), Zhai and Previtali (2010), and Szokolay (2014). This phenomenon can be comprehended as a result of the overwhelming influence of envelope design, namely its climate responsiveness, on the performance of buildings prior to the advent of the industrial period. It might be contended that bioclimatic design represents the most ancient approach to architectural design. However, the historical practice of incorporating climatic considerations into architectural design has exhibited cycles of heightened attention followed by times of apathy (Haggard et al., 2009).

The historical significance and evolution of bioclimatic design in architecture can be observed by examining a range of vernacular buildings (Zhai & Previtali, 2010). Traditional architecture frequently demonstrates distinct bioclimatic attributes that are purposefully tailored to certain climates, resulting in enhanced efficiency in achieving optimal indoor comfort in accordance with the unique qualities of the given site. The process of adapting to local climatic conditions was mostly accomplished by a trial and error methodology, refined during centuries of bioclimatic evolution (Zhai and Previtali, 2010; Desogus et al., 2016).

Hence, it is commonly posited that the examination of vernacular architecture in the specific region where a newly built bioclimatic building is to be constructed is vital. Due to its inherent simplicity and ability to reproduce established solutions, this strategy is commonly employed by architects seeking to align their designs with climatic conditions. Nevertheless, it is necessary to assess the efficacy of these design solutions through the application of scientifically grounded engineering methodologies to substantiate their performance and credibility (Zhai and Previtali, 2010; Pajek and Košir et al., 2018). The subsequent sections will examine two potential methodologies for the construction of modern bioclimatic structures. The first approach is defined by the replication of vernacular solutions, whereas the second approach is grounded in the analytical analysis of climate peculiarities.

2.8. Two Approaches to Bioclimatic Design

The bioclimatic design paradigm has an extensive historical background, encompassing thousands of years of human architectural progress. It is primarily characterized by the

incorporation of climate adaptation techniques in vernacular building. Bioclimatic design has emerged as a topic of contemporary scientific and technical research and practical implementation during the past six decades. This development has been particularly driven by the growing concern for the sustainability of buildings, with bioclimatic design playing a significant role in this context (Lechner, 2014).

The previous section presented a concept regarding the evolutionary adaptation of structures, with a particular focus on traditional architecture, to suit various climatic conditions (Zhai & Previtali, 2010; Fernandes et al., 2014). Based on the aforementioned premise, it is posited that vernacular buildings have undergone a process of optimal adaptation to the particular climatic conditions that prevail within a certain geographical region, spanning several centuries or even millennia (Pajek and Košir, 2017).

The evolutionary process under consideration has been influenced not just by climatic conditions, but also by advancements in technology, the availability of materials, and many social and economic considerations. The aforementioned process is believed to have undergone a significant culturally transmitted feedback loop, in which climate-adapted features of building envelopes, which are essentially technological solutions, have been integrated into the aesthetic language of a regional architectural style. Consequently, these features have been further disseminated over time as a cultural entity (Zhai and Previtali, 2010). This implies that the integration of technical solutions for climate adaptability has transformed into a visual component within the architectural discourse of traditional buildings (see Figure 2), potentially obscuring their original technological underpinnings from the builders who include them.

The aforementioned proposed evolutionary progression of climate-adapted vernacular buildings leads to a clear and logical conclusion that the utilization of vernacular buildings as a reference point can serve as a valuable source of pre-existing and evolved solutions for the design of contemporary bioclimatic buildings, specifically those that prioritize energy efficiency (Manzano-Agugliaro et al. 2015; Pérez Galaso et al. 2016; Montalbán Pozas and Neila González 2016). Hence, the conceptual design approach illustrated in Figure 4 would have three fundamental stages.

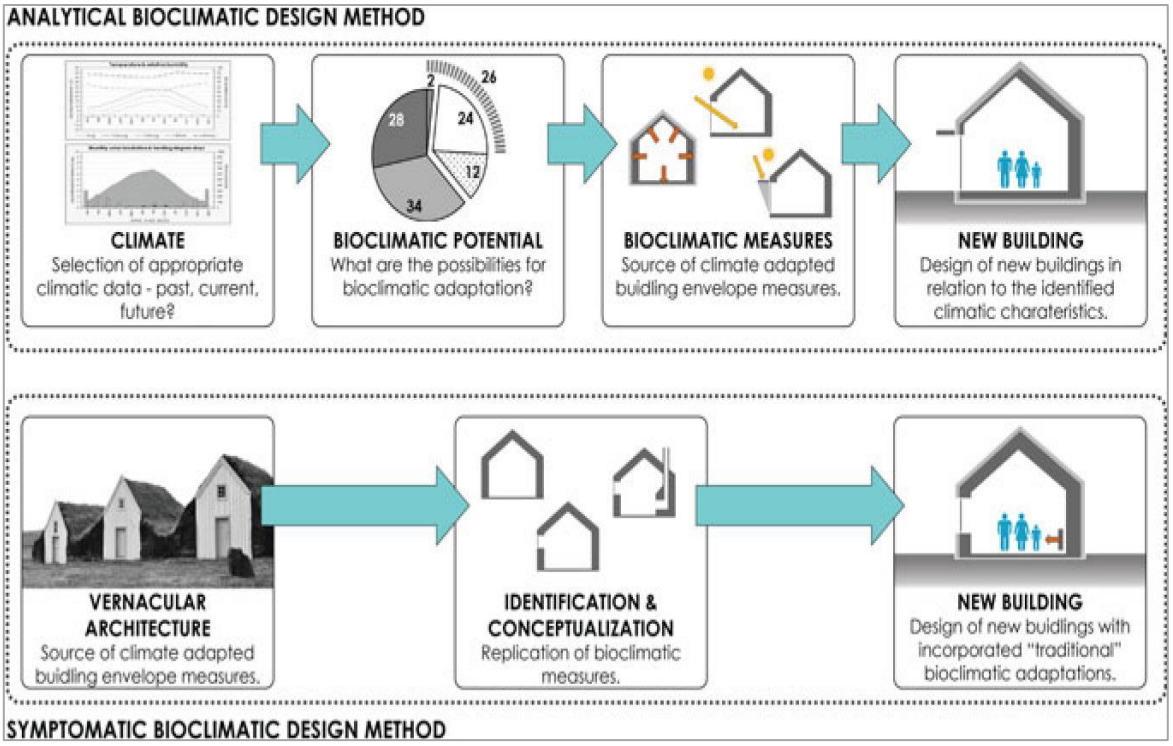


Figure 4: Schematic representation of design process for symptomatic (bottom) and analytical (top) method of bioclimatic design.

The initial stage involves the identification of suitable vernacular examples, necessitating caution to accurately discern buildings that exhibit adequate climatic adaptation and can serve as sources of inspiration.

Furthermore, it is important to analyze the chosen example or examples of traditional buildings in terms of their predominant bioclimatic strategies, such as thermal mass, equatorially oriented windows, and compact building forms.

By identifying and conceptualizing these measures, it becomes possible to develop precise approaches for Public Service Announcement (PSA) campaigns aimed at promoting adaptation to the local climate.

The conception phase is of utmost importance and represents the most challenging aspect of the process. This phase allows the designer to distinguish the technological aspects from the aesthetic or practical sacrifices made by the builders. The last phase entails the implementation of the identified Public Service Announcement (PSA) measures in a suitable manner, using contemporary technology and design methodologies, with the ultimate goal of attaining climate-adapted structures that align with present-day standards.

The aforementioned notion of evolutionary adaptation to the environment has led to the widespread adoption of this technique by architects and engineers worldwide, since it is considered suitable in their field of work.

Košir (2019) posits that bioclimatic architecture encompasses two distinct methods;

a) analytical bioclimatic design

b) symptomatic bioclimatic design

The initial analysis involves the examination of the regional climate, the assessment of the bioclimatic capacity, and the identification of appropriate bioclimatic strategies. The second approach examines vernacular structures that have already implemented bioclimatic strategies and seeks to reproduce these strategies (Košir, 2019).

The first approach, known as climatic design, focuses on understanding the unique characteristics of the regional climate and how they can be utilized to create comfortable living spaces. This involves studying factors such as temperature, humidity, wind patterns, and solar radiation. By doing so, designers can determine the most effective ways to regulate indoor temperatures, maximize natural ventilation, and optimize the use of natural light. The second approach, known as symptomatic bioclimatic design, takes inspiration from vernacular structures that have successfully implemented bioclimatic strategies. These structures, which are often traditional or indigenous, have evolved over time to adapt to their local climate and provide comfortable living conditions. Symptomatic bioclimatic design aims to replicate the principles of these structures by incorporating features such as thick walls, small windows, and shaded outdoor spaces. This approach relies on an understanding of local weather patterns and the use of materials that can effectively insulate against extreme temperatures. By studying and implementing the strategies employed by vernacular architecture, designers can create sustainable and energy-efficient buildings that prioritize human comfort while minimizing their reliance on mechanical systems.

The current study has examined both approaches.

The focus of this study is to commercial buildings, which predominantly consist of structures that are over 20-30 years old. These buildings were constructed prior to the

consideration of energy-related concerns. It is anticipated that these buildings will continue to be utilized until the year 2050. In light of this rationale, in order to conduct a comprehensive analysis, specifically pertaining to commercial structures, it becomes imperative to identify viable strategies for retrofitting these buildings in accordance with bioclimatic principles.

In order to investigate this aspect of the research, a comprehensive analysis was conducted on all publications available in the Scopus database from 2008 to 2022. The findings of this analysis will be thoroughly addressed in the subsequent section.

In order to examine the second approach, a comprehensive analysis was conducted on a longstanding bazaar situated in Arak, Iran. This ancient marketplace has a history spanning over a century and encompasses a vast area of around 140,000 square meters. The study focused on the examination of 320 individual stores and 22 caravanserais within the bazaar. The construction of this marketplace adheres to bioclimatic design principles. In this particular segment, a comprehensive investigation was conducted on the bioclimatic elements employed within the Nowzari Caravanserai market complex. To facilitate this study, a specific portion of the market complex, spanning an area of 5480.93 square meters, was simulated using Design Builder software. Subsequently, each individual element was thoroughly scrutinized and assessed. The comprehensive details of this investigation are provided in the subsequent section.

3. Chapter 3

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Analytical Bioclimatic Design

The initial analysis involves the examination of the regional climate, the assessment of the bioclimatic capacity, and the identification of appropriate bioclimatic strategies.

The year 2008 witnessed a notable paradigm shift in the international community's attention toward the concept of sustainability. In accordance with the declaration made by the United Nations, the year 2008 was designated as the International Year of Planet Earth, with a primary focus on highlighting the imperative of sustainable development (Richards, 2008). During this particular era, there was a notable surge in scholarly attention towards investigating energy efficiency and sustainability, encompassing the field of bioclimatic retrofitting (Ascanio-Villabon, 2021).

The period from 2008 to 2022 was characterized by notable progress in the field of technology, particularly in the domain of bioclimatic retrofitting. This period witnessed the emergence and enhancement of various tools and methodologies pertaining to this field (Ascanio-Villabona, 2021). Hence, this particular timeframe holds significant importance in comprehending the development and influence of these technologies.

During this period, numerous countries implemented policy changes aimed at enhancing energy efficiency and promoting sustainability (Blumberga et al. 2021). Gaining an understanding of the prevailing research trends during this specific period can yield valuable insights into the potential ramifications of these policies.

The selection of a 15-year timeframe enables a thorough examination of the existing body of scholarly works. The temporal scope of this study allows for the identification of trends and patterns while simultaneously ensuring the contemporaneity and applicability of the obtained findings.

While some manual assessments of commercial buildings have been conducted, the content analyzed in this chapter is one of the first compound procedure qualitative scientometric study analyses linking bioclimatic retrofitting and energy savings in commercial buildings. It also aims to improve on previous manual assessments by resolving errors and filling in knowledge gaps.

The chapter's objectives are as follows: (i) to critically assess and recognize the maximum influence of issuing venues, papers in climatology retrofitting in commercial buildings, and study keywords utilizing science topography; (ii) to recognize the composition of scheming studies on climatology retrofitting; and (iii) to identify knowledge gaps in the bioclimatic retrofitting domain. The study results contribute to the expansion of existing knowledge by delivering an exhaustive review of the present condition of climatology retrofitting in commercial building studies, scheming study compositions and collections, and suggesting positions for prospective research.

3.1. Bioclimatic Retrofitting Approach

In the 1950s, Olgyay (1963), identified bioclimatic concerns in architecture and, in the 1960s, established a design approach. This design process integrates building physics, climatology, and human physiology and has recently been considered a cornerstone for achieving more sustainable buildings and included within the building design professions in the framework of regionalism in architecture (Hyde et al. 2013).

Vernacular architecture is the cornerstone of climatology construction (Manzano-Agugliaro et al. 2015). Cruz et al. believe that this includes evaluating historical design in relation to the climate and culture of a place, as well as providing inactive alternatives to construction and architecture (Cruz et al. 2011).

The interest in vernacular architecture has been prompted by instances when HVAC and lighting systems failed to solve cooling and lighting problems (Cruz et al. 2011). The technologies used are adapted to the bioclimatic conditions in the area, and the indigenous benefits are unique due to the location of the building. Thus, soil or wood is used as a building material in local architectural designs (Manzano-Agugliaro et al. 2015).

Vernacular structures take advantage of natural resources such as the sun and wind, and research has shown that they have superior thermal execution. As a result, vernacular architecture and bioclimatic architecture are inextricably linked (Aghimien et al. 2021).

Because low- and medium-scale buildings are simple to make climatically interactive, with the form and fabric of the building matched to human and climate elements to

increase climate reaction, the research that led to the development of bioclimatic design regulations was mainly focused on these types of structures (Hyde et al. 2013).

Large-scale buildings have largely been overlooked because of the complexity of the process, the dense urban fabric in which these structures are generally found, and the availability of inexpensive energy for cooling. Bioclimatic factors have been largely overlooked in design concepts for large-scale buildings, with a good internal environment being instead achieved by employing energetic mechanical systems to restore comfort. Most commercial buildings in major cities around the world were built before energy efficiency became a goal and are between 20 and 30 years old, and these buildings will be operational until 2050. Thus, bioclimatic retrofitting of existing commercial buildings to increase energy efficiency and the environment is important (Hyde et al. 2013).

The bioclimatic retrofitting approach uses passive low-energy techniques that relate to and are borne by the site's climate and meteorological conditions. The approach focuses on providing high-quality passive changes in buildings through a high-performance envelope, form, and fabric (Aghimien et al. 2021). This results in a building that is climate-responsive and environmentally interactive with reduced energy consumption in operation and embodiment. A bioclimatic retrofitting approach gives a clear triple bottom line. The most convincing justification for the bioclimatic retrofitting for high-rise buildings is perhaps an economic one: the savings from lower consumption can be as much as 30–60% of the overall energy costs of the building (Hyde et al. 2013).

A further justification is that bioclimatic retrofitting affords a more human experience of a commercial building. Bioclimatic retrofitting promotes better natural ventilation and awareness of place, resulting in healthier internal environments and increasing overall business productivity. A further and essential justification is the ecological rationale. By using passive devices to achieve thermal comfort, climatically retrofitted buildings have lower total carbon dioxide emissions, lowering overall air pollution, and help minimize global warming (Hyde et al. 2013).

The growing demand for energy-efficient structures has resulted in a significant upswing in scholarly investigations pertaining to the application of bioclimatic retrofitting, with a specific focus on commercial edifices. Despite the extensive body of research on this

subject, there exists a dearth of comprehensive literature reviews that amalgamate the outcomes of these studies and discern areas of knowledge deficiency.

This chapter employs an innovative methodology to investigate the concept of bioclimatic retrofitting and its impact on energy conservation within the context of commercial buildings. This preliminary and extensive analysis of scientometric data in this field rectifies inaccuracies and fills in gaps in current knowledge. The present chapter undertakes an analysis of bioclimatic retrofitting in the context of commercial building research, thereby contributing to the existing body of global knowledge on this subject. The text provides an overview of research clusters and proposes potential avenues for future research.

The combined approach to periodic reviews was utilized to achieve the chapter's objectives. The combined approach to periodic reviews mixes qualitative and quantitative information to produce conclusions that are more comprehensive than either quantitative or qualitative analyses could produce on their own (Malina et al. 2011). The subjective bias associated with manual systematic reviews was also removed by this method (Ghosh et al. 2020). The study methodologies and instruments employed in this section:

3.2. Scientometric Analysis and Review of Scientific Maps

In analyzing the massive amounts of data available in the bibliographic literature, scientific topography may help to show basic trends and patterns (Donthu et al. 2021). This technology emphasizes keywords in contrast to the manual assessment process, which emphasizes researchers, publication outlets, and countries, to be linked in a study domain (Su & Lee, 2010). Bibliographic data were analyzed using scientometric investigation, a quantitative scientific mapping process.

This procedure requires the presentation of thought trends and the sketching of structural patterns in a research topic to visualize and analyze a large number of publications (Saka & Chan, 2019).

Scientometrics has also been used in this research. With applications in various fields (Manzano-Agugliaro et al. 2015), scientometric analysis is one of the most widely utilized methodologies for research development analysis (Olawumi & Chan, 2018*)*.

3.2.1. Science Mapping Software Selection

The map visualized in this study was created using the textualization tool VOSviewer 1.6.17 (Visualization of Similarities), expanded by Ludo Waltman and Nees Jan van Eck (2009). Open-source software has been selected because of its ease of use when displaying massive networks based on distance techniques (Van Eck & Waltman, 2009).

The connections among journals, researchers, and individual articles within ex-tensive networks are established through citations, bibliographic references, or shared authorship (Wuni et al. 2019). Studies of building control, construction management, public–private partnerships, building information modeling (BIM), and on-site construction have all made use of VOSviewer. As a result, to achieve the objectives of the study, VOSviewer is suitable.

3.2.2. Bibliographic Data Extraction

The selection of the Scopus database as the primary source of the literature for this study was based on multiple factors. Scopus provides extensive coverage across a wide array of academic disciplines. The database comprises a collection of over 22,000 titles sourced from more than 5000 publishers worldwide, thereby offering a diverse range of research materials. The selection of Scopus was influenced by the considerable importance placed on the quality of its content.

Scopus exclusively incorporates publications from publishers that are widely recognized for their credibility and reliability. This rigorous selection process serves to uphold the integrity of the research by ensuring that it is derived from reputable and dependable sources. One additional benefit of Scopus that was taken into account is its capability for tracking citations. The comprehension of the influence of a specific piece of work and the interconnections among various works is essential for conducting scientometric analysis (Chadegani et al, 2013).

In addition, Scopus provides sophisticated tools for literature search and analysis. These tools facilitate the identification of trends, the discovery of pertinent studies, and the execution of a thorough literature review on the subject of bioclimatic retrofitting in commercial buildings.

Although Scopus is widely acknowledged as a valuable resource, it is important to note that it is not the sole database accessible for academic research. In addition to PubMed, Web of Science, and Google Scholar, there are several other databases that provide comprehensive repositories of scholarly literature.

The selection of a database is contingent upon various factors, including the particular research discipline, the ex-tent of the research endeavor, and the unique requirements of the researcher. Due to the inevitable occurrence of duplicate publications when merging multiple databases, the decision was made to utilize a single database (Darko et al. 2020).

Scopus was selected in this instance due to its extensive coverage of the construction engineering and architecture domain, its high-quality content, and its sophisticated search and analysis capabilities.

Nevertheless, it is acknowledged that the exclusive reliance on a solitary database could potentially constrain the thoroughness of the literature review, as certain pertinent studies may not be contained within the Scopus database. The aforementioned constraint has been duly considered in the study. Published journal articles, review papers, and conference proceedings were used to con-duct the literature search. Zheng et al. believe that journal articles and review articles are preferred because they are reliable sources of information that are accurate and precise (Zheng et al, 2016).

As a result, the source discussed above has been designated as a trustworthy resource for preparing a literature review (Watson & Webster, 2020).

As shown in Figure 5, the keyword "**Commercial Buildings**" was used to find publications. These keywords were derived from the titles of publications.

The time frame for the search was 2008 through 2022. Furthermore, only papers in English were considered. There were 1301 publications in total.

The keywords "**Retrofitting**" OR "**Bioclimatic**" OR "**Green Buildings**" were used to further narrow these publications. These terms were chosen for their relevance to the

subject of research. A total of 414 linked publications were obtained at the end of the refinements consisting of 253 journal articles, 140 conference papers, and 21 review papers. The catalog information was downloaded in CSV format (comma separated values).

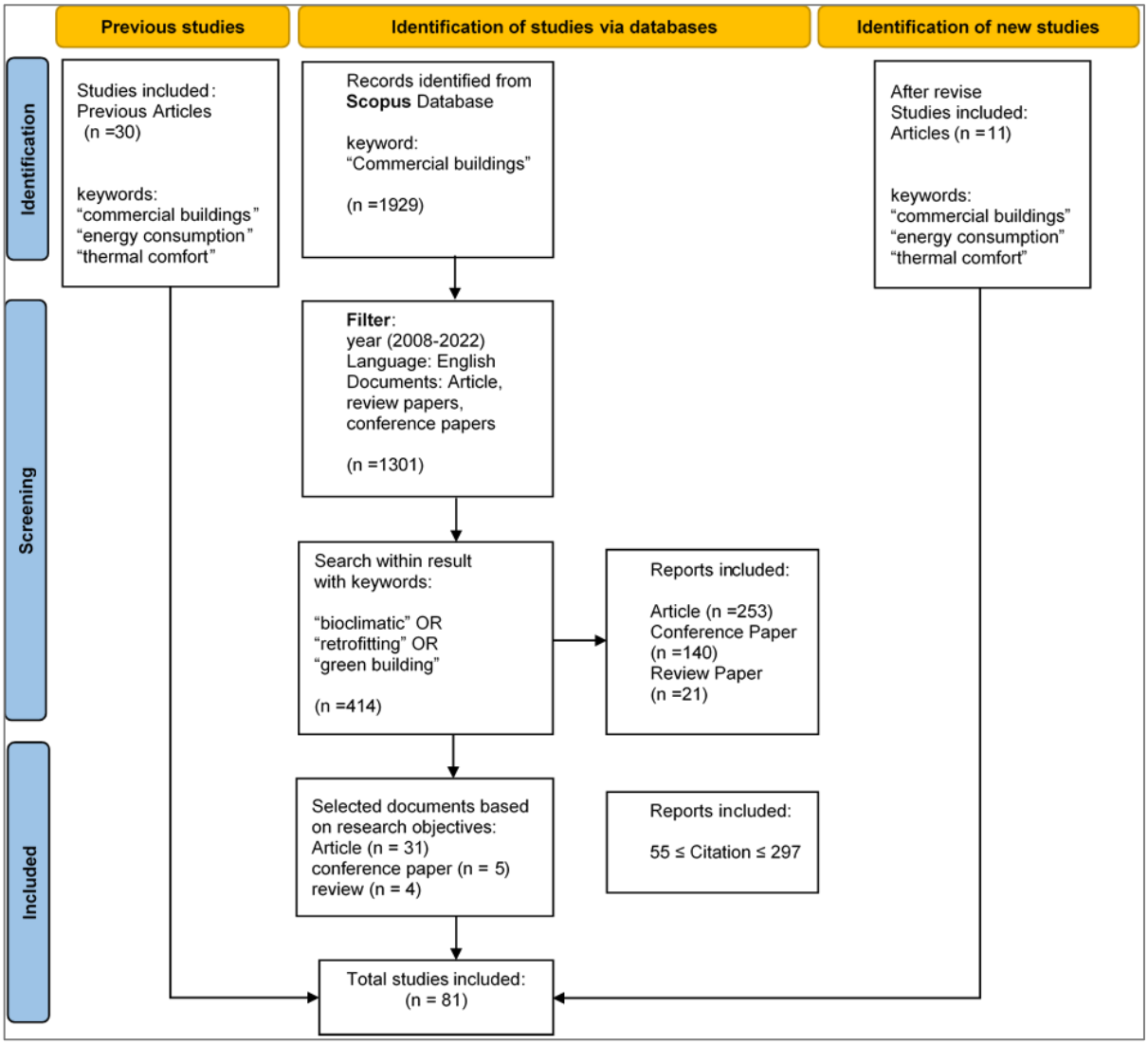


Figure 5: PRISMA (Page et al, 2021), flow diagram for the systematic review process, which included searches of the Scopus database and previous studies.

3.3. Scientometric Method

The downloaded bibliographic information was entered into the VOSviewer software (Figure 6). Network critique and visualization of those locations were performed. For

network construction, network analysis including source investigation, citation investigation, keyword event investigation, and cluster investigation were used. Data congregation is an info-extracting process that uses similarity measurements to identify natural groupings in a multidimensional dataset (Jain et al, 2000). Because it specifies and analyses the connections among concepts and recognizes patterns, an essential part of the scientometric investigation is cluster analysis. Data related to research subject clusters are provided by VOSviewer. Objects of the same color belong to the same collection and are characterized by a mark in the keyword network investigation scheme. The relationship of the keyword to the distance between the circles is shown. Ultimately, tables and maps were prepared to show the networks and statistically describe their criteria.

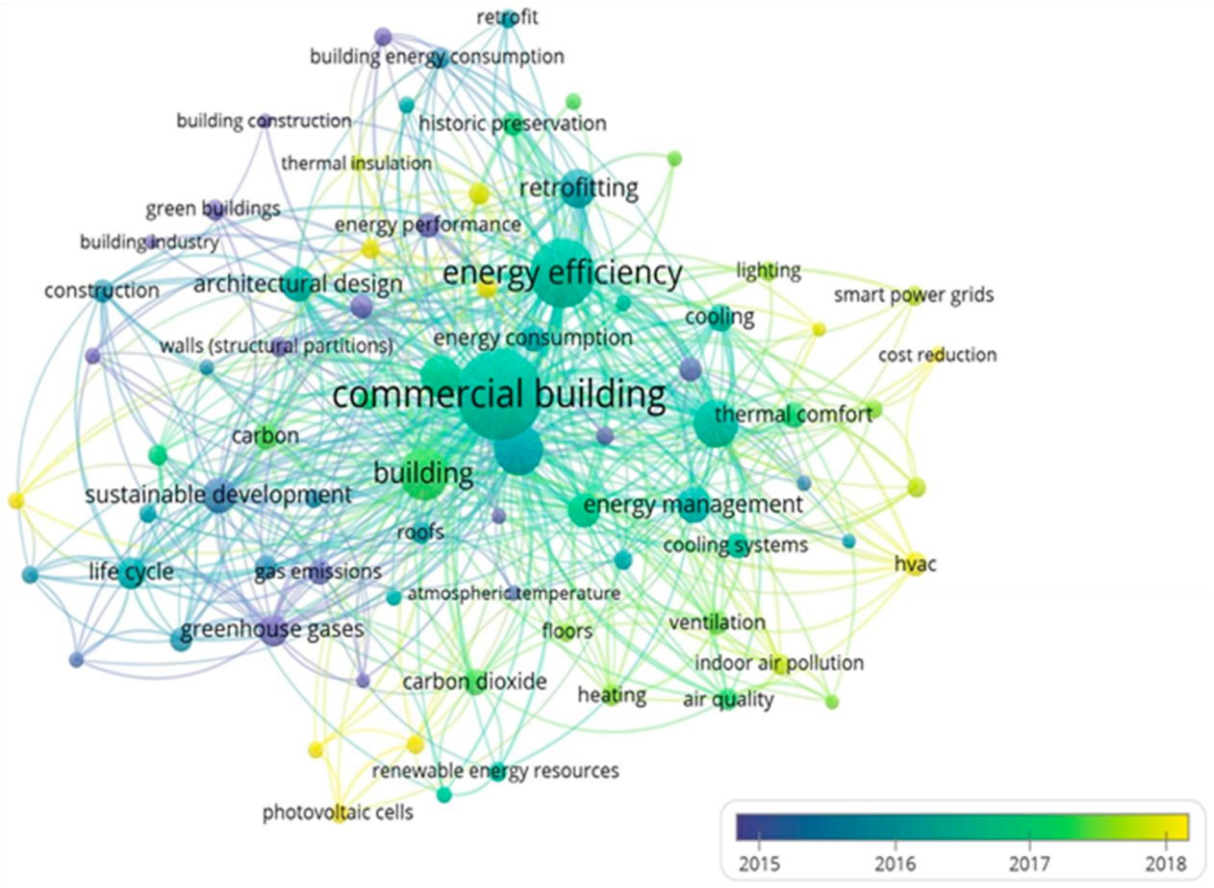


Figure 6: Overlay visualization map of co-occurring keywords (2008–2022). (source: VOSviewer software)

3.4. Quantitative Analysis

A transition was made to a more data-driven process in the first quantitative analysis section. In this part, studies conducted in the field of commercial buildings over a 15-year period were statistically analysed to find patterns and trends. During the period 2008 to 2022, a significant global shift towards sustainability took place. Scholars' focus was directed towards energy efficiency and bioclimatic retrofitting, resulting in significant advancements in technology. Policy adjustments were implemented in order to promote and support sustainability. Therefore, this 15-year timeframe is of great importance in understanding the development and influence of these technologies and policies (Ascanio-Villabona, 2021)

This quantitative analysis could be utilized to ensure that the results of the qualitative analysis have quantitative significance and validity. The research was taken to a higher scientific and logical level by this quantification method. VOSviewer software was used in the second half of the study to display a scientific map of the investigations, and the results and discussion are presented here.

3.4.1. Keyword Analysis and Areas of Research Focus

For scientometric analysis, keywords must be determined and a map visualization must be provided. Keywords describe the most important aspects of a study and reveal the domain's focal regions (Su & Lee, 2010). To construct the co-occurrence map based on the bibliometric data, a minimal number of co-occurrence keywords is needed. This enables proper study theme clustering (Aghimien et al. 2021).

A total of 133 of the 3581 keywords were discovered using "Author Keywords" and "Index Keywords," as well as at least seven simultaneous repetitions of keywords, using VOSviewer. Table 1. summarizes the top 30 keywords in detail.

Table 1. Qualitative Summary of Most-Cited Publications.

Keywords	Avg. Citations	Occurrences	Total Link Strength
Commercial building	20	251	2120
Energy efficiency	23	146	1436
Energy conservation	29	106	1181
Air conditioning	23	70	749
Retrofitting	21	46	502
Sustainable development	22	39	446
Energy management	20	39	369
Architectural design	15	38	374
Intelligent buildings	18	36	400
Greenhouse gases	28	31	390
Life cycle	28	30	338
Cooling	29	23	296
Thermal comfort	16	22	223
Carbon dioxide	19	22	240
Energy performance	11	20	193
Ventilation	22	19	237
HVAC	32	18	179
Sustainability	18	18	142
Climate change	22	18	200
Climate control	33	18	169
Solar buildings	18	16	196
heating	31	15	188
Air quality	21	15	172
roofs	33	15	190
Environment management	5	14	153
Indoor air pollution	11	14	147
lighting	32	13	114
Solar energy	28	13	163
Walls	20	13	143
Floors	23	11	114

Table 1. is in a standard output format from VOSviewer, which provides quantitative information about each keyword. Below is an explanation of each column:

Keywords: These are the words that have been frequently used in the articles, abstracts, titles, or other textual data under analysis. These words usually represent key themes or topics in the set of documents.

Avg Citations: This column shows the average number of times the papers associated with each keyword have been cited. This gives an idea of the impact or influence of the

work associated with that keyword. A higher average citation count might indicate a keyword associated with high-impact or influential work.

Occurrences: This is the total number of times each keyword appears in the dataset. A higher occurrence typically indicates a more common or important topic in the research field under investigation. However, a high occurrence does not always mean high importance, as it could also result from a large number of less significant papers mentioning the keyword.

Total Link Strength: This measure provides an overview of the interconnectedness of each keyword with all other keywords. It is calculated by adding up all the weights of the links connected to a particular keyword. The strength of a link between two keywords usually represents the number of documents in which these two keywords co-occur. A higher total link strength indicates that the keyword is strongly associated with many other keywords, suggesting that it might be a central or foundational topic in the research field.

This table provides valuable information about the most commonly occurring and influential keywords related to “Commercial Buildings”.

Frequency of occurrence: “Energy efficiency” is the most commonly occurring keyword, followed by “Energy conservation” and “Air conditioning”. This shows that these are the most often discussed subjects in the commercial building context.

Average citations: The keywords with the highest average citations are “Climate control”, “HVAC”, and “Cooling”. This suggests that articles on these topics are mentioned more frequently, implying that they are significant topics in the area. They could be linked to major works or significant advances.

Total link strength: “Energy efficiency”, “Energy conservation”, and “Air conditioning” have the highest total link strength, indicating that they have strong links with many other terms.

Although these metrics provide some insight into the importance and influence of certain topics, it is also worthwhile to examine keywords that are less frequently mentioned. For example, “Environmental management” and “Indoor air pollution” have low occurrences and total link strength, but they may reflect growing or specialist themes. Significantly,

"Environmental management" has a notably low average citation count, indicating that it may be an understudied issue worthy of more inquiry.

Investigating the correlations between distinct keywords offered further insights. For example, "energy efficiency" and "retrofitting" both have high occurrences and overall link strength, indicating that they are not just important issues in their own right but are also tightly related to other topics.

Retrofitting and Energy Efficiency: Given the relatively high frequency and total link strength of both "Retrofitting" and "Energy efficiency," it appears that these two topics have a significant connection. This shows that retrofitting commercial buildings for energy efficiency is a priority. It may be worthwhile to look into how these areas interact, such as researching the most effective retrofitting strategies for increasing energy efficiency or comprehending the hurdles and enablers of energy-efficient retrofitting in commercial buildings.

Intelligent Buildings and Energy Management: Both "Intelligent buildings" and "Energy management" have a moderate frequency but a comparatively high link strength. This could imply an increase in interest in the intersection of these areas. For example, research might look into how intelligent building technologies can be utilized to improve energy management, as well as the function of AI and machine learning in energy management inside intelligent buildings.

Greenhouse Gases, Carbon Dioxide, and Climate Change: Because they all have an impact on the environment, the intersection of "Greenhouse gases," "Carbon dioxide," and "Climate change" could provide fascinating results. For example, studies might look into how commercial buildings contribute to greenhouse gas and CO_2 emissions, as well as the implications for climate change.

Architectural Design and Sustainable Development: These two terms have a moderate number of occurrences and a pretty high link strength, showing that they are related. Research could look into how sustainable development ideas can be incorporated into the architectural design of commercial buildings. This could include investigating how to use sustainable materials, create energy-efficient structures, or incorporate biophilic design aspects.

3.4.2. Keyword Maps of VOSviewer

Keyword maps are a popular type of visualization offered by VOSviewer that illustrate which terms are frequently related to one another in the literature.

Each circle (or node) in the VOSviewer map in Figure 7 indicates a keyword. The size of the circle usually corresponds to the keyword's weight. In a keyword map, for example, a larger circle could signify a keyword that is used more frequently. The lines (or edges) connecting the circles represent the entities' relationships or links.

In VOSviewer maps, the color of the circles represents clusters. A cluster is a group of entities that are tightly connected. Keywords that frequently appear together in the same papers would create a cluster in a keyword map. The colors are assigned by the software and serve no use other than to distinguish distinct clusters.

Clusters in VOSviewer can help researchers in a variety of ways:

Identifying research trends: researchers can identify current trends and popular topics in their field by monitoring which terms are closely connected (i.e., belong to the same cluster).

Identifying gaps in the literature: isolated or less connected clusters may suggest unexplored themes or research gaps.

Understanding the structure of a research field: clusters can indicate how different subtopics within a research field are related, which can aid in the organization of literature reviews or the development of new research lines.

In Figure 7., the 133 keywords identified in the analysis are organized into five groups. Each cluster is made up of related keywords. The clusters are:

Cluster 1—*Thermal Comfort in Energy Management*: this is displayed in red and includes 23 keywords such as "air quality", "temperature control", HVAC, "lighting", "cooling", "heating", "ventilation", and so on.

Cluster 2—*Architectural design sustainability*: this is displayed in green and comprises 20 keywords. "Green structures", "building materials", "life cycles", and so forth are examples.

Cluster 3—*Commercial Building Retrofitting*: the 19 keywords in this cluster are displayed in blue in Figure 7. “Energy efficiency”, “energy performance”, “solar buildings”, “walls”, and other terms are among them.

Cluster 4—*Carbon dioxide*: this is displayed in yellow and includes 11 keywords including “renewable energy resources”, “solar energy”, “greenhouse gases”, and so on.

Cluster 5—*Commercial Building Energy Savings*: this is shown in purple and is made up of four terms linked to “atmospheric temperature”, “building energy simulation”, “roofs”, and “building energy”.

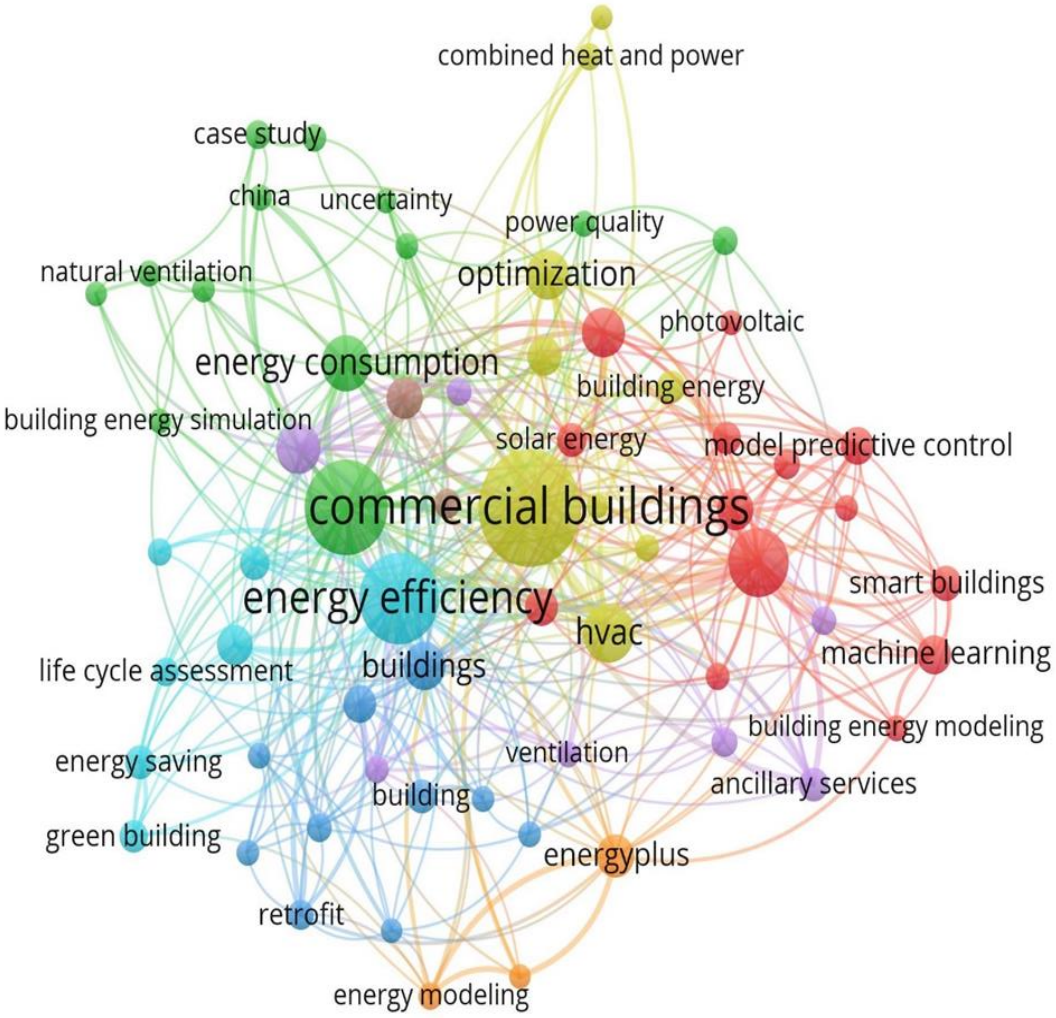


Figure 7: Network visualization map of co-occurring keywords. (source: VOSviewer software)

In Figure 7., the map's connection lines also depict the relationship between two keywords. As portrayed, retrofitting is linked to energy efficiency and performance, carbon dioxide is linked to renewable energy resources and solar energy, and thermal comfort is linked to HVAC, air quality, climate control, and lighting, while thermal comfort is linked to HVAC, air quality, and climate control.

3.5. Qualitative Analysis

The qualitative analysis sought to identify the most-cited documents' primary findings, conclusions, and consequences. The results of the investigations were consistent with prior studies (Ghosh et al, 2020). This approach allowed for a deeper understanding of the research topics and their significance in the field.

3.5.1. Summary of Most-Cited Articles

The most frequently mentioned documents were gathered and evaluated hermeneutically. Table 3.2. shows the results of the qualitative review of the most-cited documents.

One of the growing interests in commercial buildings sustainability research is building carbon emission analysis (Onat et al, 2014). Evidence of these studies can be observed in the study by Kneifel (2010), which uses an integrated design method to estimate life-cycle energy savings, carbon emissions reduction, and the cost-effectiveness of energy efficiency measures in new commercial buildings, as well as to assess the consequences of the cost of energy-based carbon emissions. This study carries out a total of 576 energy simulations for 12 archetypal structures in 16 cities, with three building designs for each building–location combination (Kneifel, 2010).

The findings reveal that traditional energy efficiency measures can reduce energy consumption in new commercial buildings by 20–30% on average, and by more than 40% in specific building types and locations. These upgrades save money and energy while lowering a building's carbon footprint by an average of 16%. Because greater efficiency allows the installation of smaller, less expensive HVAC equipment, these savings can sometimes be accomplished at a negative life-cycle cost (Balaji et al. 2013).

Balaji et al. (2013), point out that 39.6% of energy consumption in commercial buildings is related to HVAC systems.

Indeed, adhering to these guidelines in the construction of new buildings has been shown to effectively mitigate energy consumption. However, it is imperative to acknowledge the significant challenge associated with the task of diminishing energy consumption in existing buildings. The significance of this matter is of considerable magnitude, as evidenced by the dedicated efforts of the REHVA (The Federation of European Heating, Ventilation, and Air Conditioning) task force (History–Rehva, 2023), comprising representatives from nine European nations. Their primary focus lies in the refurbishment of existing structures, with particular emphasis placed on the modernization of heating, ventilation, and air conditioning (HVAC) systems (History–Rehva, 2023).

The role of HVAC systems in the deep renovation of existing buildings is crucial as it can help achieve significant energy savings when operated properly. The building envelope is also considered an essential aspect in initial efforts to reduce energy demand.

But renovation should not be limited to the building envelope; energy savings can be maximized, and payback time reduced by also focusing on HVAC systems and energy education of building occupants. Adapting HVAC systems to varying building energy demands can improve indoor environmental quality (IEQ) and occupant satisfaction (Cholewa et al. 2022).

Prior studies have advocated employing wireless occupancy sensors or even cameras for occupancy-based actuation to reduce HVAC energy use, with energy savings of up to 42%. However, most of these solutions necessitate the design, deployment, testing, and maintenance of these sensors and their accompanying networks within existing buildings, which is prohibitively expensive. Conversely, Balaji et al. (2013), present Sentinel, a system that uses existing WiFi infrastructure in commercial buildings, as well as smartphones with WiFi connectivity carried by building occupants, to offer fine-grained occupancy-based HVAC actuation. Similarly, Lawal & Rafsanjani (2022), present a comprehensive review of research work on the existing technologies and applications of Internet of Things (IoT) technologies in residential and commercial buildings.

As shown in Table 2., the paper with the third highest number of citations is (Robinson et al. 2017), published in the Applied Energy Journal. By teaching machine learning models using national data from the study of energy consumption of commercial buildings, this research proposes a new technique for estimating the energy consumption of commercial buildings from several building

characteristics (CBECS). Their findings show that gradient amplification regression models are the most accurate models in predicting the energy consumption of a commercial building, with predictions that are often in the coefficient of two real values (with an r2 score of 0.82).

Urban and rural temperatures have diverged in recent decades. The urban heat island (UHI) effect—caused by urban design, human heat, air pollution, sun intensity, wind speed, and anticyclone conditions—is well documented. UHI increases greenhouse gas emissions and air conditioning energy demand. Human comfort and climate change mitigation requires UHI solutions. One of the best passive cooling solutions is increasing the building's exterior albedo, especially in relation to its roofs (Ferrari et al. 2016).

Table 2. Qualitative Summary of Most-Cited Publications.

Authors	Year of Publication	Aim
Kneifel	2010	Estimate life-cycle energy savings, carbon emission reduction, and cost-effectiveness of energy efficiency measures
Balaji et al.	2013	Propose strategies to reduce energy consumption in HVAC systems
Robinson et al.	2017	Introduce a new technique for estimating the energy consumption of commercial buildings with machine learning models
Levinson et al.	2010	Weathered cool white roof
Haq et al.	2014	Automatic lighting control system
Onat et al.	2014	Analyze building-related carbon emissions
Hong et al.	2015	Introduce a toolkit of Commercial Building Energy Saver (CBES), that includes a web app for integrating CBES with other energy software tools
Lazos et al.	2014	Analyze the dependence of various building components on weather conditions

The majority of roofing materials absorb solar radiation and reflect only a small part of it. In warmer areas, for example, solar heat gain through the building's facade accounts for a significant part of the total heat gain. The energy entering a structure through its walls, floors, and ceilings is

equally significant. Although a traditional dark-colored roof's total heat gain can be as high as 366 kJm2, the heat loss through the same roof is only around 4.2 kJm2; heat gain is the major process for these roofs throughout the day. On hot summer days, dark roofs can achieve temperatures of over 60 degrees in many regions, allowing significant heat transfer into the building through roof insulation. Any alteration to a building's roof that reduces solar heat gain will save the building owner money on energy costs and reduce the property's overall environmental impact (Jo et al. 2010).

Green roofs and facades have high installation and operation costs, while solar reflecting materials like "cool roofs" can reject solar radiation over the visible and invisible solar spectrum. Solar reflectance (300–2500 nm) and thermal emissivity (4000–40000 nm) are high. White cool roofs were introduced (Ferrari et al. 2016).

Cool roofs are designed to minimize the absorption of solar energy and maximize the emission of thermal energy, resulting in reduced heat transfer from the roof to the building. This, in turn, decreases the demand for space-cooling energy in air-conditioned buildings (Levinson & Akbari, 2009).

The cool roof system yields indirect environmental benefits, primarily through reductions in environmental damage and peak-time electricity demand, resulting in electricity savings (Jo et al. 2010).

In cold climates, the implementation of cool roofs may potentially result in an increased demand for heating energy. In the context of commercial buildings, it is commonly observed that the reduction in the annual cooling load tends to surpass the corresponding increase in the annual heating load (Page et al, 2021).

However, in a study conducted by Hosseini & Akbari (2016), the DOE-2.1E software was employed to model and analyse the energy usage of various office and retail buildings in four cold-climate cities in North America, namely Anchorage, Milwaukee, Montreal, and Toronto. A function was defined to calculate the daily U-value and absorptivity of the roof in order to simulate the impact of snow on it. The findings indicated that the implementation of cool roofs in the simulated buildings led to significant reductions in annual energy expenditures across all cold climates Hosseini & Akbari, 2016).

The initial white and colored cool roof studies employed polymeric membranes and paints since these do not require long manufacturing cycles. Without maintenance, cool roofs last only a few years. Cool roofing in European towns using ceramic and clay roof tiles requires solar-reflective tile materials. This improves solar effectiveness and durability because tiled sloped roofs should not be cleaned. New glazed and engobed solar reflecting solutions are spreading this technology to ceramic and clay roof tiles. The use of ceramic glaze makes such objects weatherproof and durable. Traditional tile methods can improve solar reflection and insulation without changing the roof. Studies discuss the most often used pigments for external tile systems in ceramic glazes with gloss, matt, and Zirconium Silicate finishes and typical ceramics heating treatment, making first-generation glazed cool-colored tiles possible (Ferrari et al. 2016).

It is noteworthy to consider that the solar reflectance of cool roofs can be influenced by weathering, soiling, and biological growth. The solar spectral reflectances of 12 roofing membranes were measured in a study of Papadopoulos (2019). The measurements were taken before exposure and at various intervals of natural aging, specifically after 3, 6, 12, 18, and 24 months. The study was conducted in Rome and Milan, Italy. The findings indicated that the process of aging resulted in a decrease in the potential cooling load savings attainable from a new white membrane. Specifically, the reduction ranged from 14% to 23% in Rome and from 20% to 34% in Milan. Furthermore, in the case of Milan, there is evidence to suggest that an older, white roof with high insulation properties, possessing a solar reflectance value of 0.56, could potentially experience a surface temperature increase of 16 °C compared to a newer roof with a higher solar reflectance value of 0.80. Hence, with respect to the implementation of cool roofs in other urban areas, this aspect warrants due consideration (Paolini et al. 2014).

Lighting is another important factor in commercial building energy use (Haq et al. 2014). According to the Ferrari et al. (2016), artificial lighting is a large power consumer in commercial buildings, accounting for around 17% of overall electrical energy consumption. Therefore, intelligent control strategies are widely implemented to reduce lighting energy consumption (Rijal Wagiman et al. 2019). As a result, adopting intelligent lighting control systems, such as the combination of sensor technologies (occupancy and light sensors), advanced designs (wireless- and network-based architectures), and intelligent control approaches, has huge potential to minimize energy usage (artificial intelligence and optimization). Furthermore, an intelligent control system can improve visual comfort for occupants while lowering electricity usage and

greenhouse gas emissions. Lighting control systems can be divided into three types: controller, optimization-based control, and hybrid control (Wagiman et al. 2020).

The decarbonization of buildings is widely recognized as a significant challenge in the pursuit of achieving the United Nations' sustainable development goals by 2050. In conjunction with the objective of minimizing electricity usage, an equally significant concern in mitigating greenhouse gas emissions within the building sector pertains to the substitution of gas boilers. The potential of heat pumps, district heating, and hybrid solutions as alternatives has been highlighted by the REHVA task force. The aforementioned study has brought attention to the potential advantages of transitioning away from natural gas in buildings, including the reduction of greenhouse gas emissions, the enhancement of air quality, and the promotion of energy efficiency (Cholewa et al. 2022).

Also, computer simulation tools are an effective instrument for estimating building performance under various scenarios and giving a theoretical basis for retrofits that produce cost-effective energy savings. In their article, Hong et al. (2015), introduce a toolkit of Commercial Building Energy Saver (CBES) that includes a web app for integrating CBES with other energy software tools.

In addition, Lazos et al. (2014) and Huang et al. (2013), claim that the thermal performance of building envelopes is the deciding element of building energy consumption, and that envelope retrofitting is an extraordinarily successful technique for reducing energy consumption in existing structures (Table 3.2.). Because variables like temperature, humidity, and solar radiation directly affect heating and cooling in a structure, as well as the availability of solar and wind energy, multiple ideal retrofitting techniques may exist for different climates.

3.6. Conclusions

The implementation of bioclimatic retrofitting in commercial buildings is a nascent field, particularly in terms of its energy implications. In this chapter, the approach of bioclimatic retrofitting was examined as a vital strategy to reduce energy consumption and adapt to climate change.

A longitudinal examination of research publication patterns spanning from 2008 to May 2022 has indicated a discernible upward trajectory in scholarly investigations pertaining to the domain of

commercial buildings during this 15-year period. Nevertheless, research on the topics of bioclimatic design, retrofitting strategies, and green building practices in commercial settings exhibits a more gradual rise, displaying an almost linear trend between the years 2016 and 2020. The disregard for bioclimatic effects in commercial buildings may be attributed to factors such as the intricate nature of the process, the dense urban fabric typically surrounding these buildings, and the ready availability of cooling and comfort activation technologies. Moreover, the potential impact of bioclimatic design on commercial buildings may have been overlooked as a result of insufficient comprehension and awareness. However, scholarly investigations into the field of bioclimatic design, retrofitting, and green buildings within commercial contexts have revealed an emerging trend that extends beyond the year 2020. This observation suggests a growing recognition of the importance of incorporating sustainable and energy-efficient principles in the design and operation of commercial buildings.

4. Chapter 4

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Symptomatic Bioclimatic Design

This approach examines vernacular structures that have already implemented bioclimatic strategies and seeks to reproduce these strategies. By studying the successful implementation of bioclimatic strategies in vernacular structures, the approach of symptomatic bioclimatic design aims to replicate and adapt these strategies in contemporary architecture. This approach recognizes the effectiveness and efficiency of traditional methods and combines them with modern technologies to create sustainable and environmentally friendly buildings (Košir, 2019). By learning from the past and integrating bioclimatic principles into new designs, this approach offers a promising solution to address the challenges of climate change and energy consumption in the built environment.

In light of the contemporary era's focus on energy preservation and the implementation of passive systems to promote environmental cleanliness, it is deemed imperative to revisit the fundamental design principles and climatic regulations that underpin traditional architecture. Iranian architecture that adheres to traditional design principles is a prime illustration of climatic architecture. It showcases optimal solutions with regard to environmental preservation, human comfort, and the efficient utilization of natural energy sources (Sahebzadeh et al. 2017). Hence, through the identification of the underlying principles and regulations that govern this particular architectural style, coupled with the presentation of a model that takes into account the scientific comprehension of novel materials as well as the climatic and functional implications arising from technological advancements, it is indeed possible to apply the traditional architectural knowledge and process in novel constructions while still maintaining a contemporary outlook. For centuries, Iran's native architecture has offered its residents comfortable living conditions while consuming less energy, similar to numerous ancient civilizations (Varzaneh et al. 2014).

The implementation of a dual-layered dome ceiling and a domed roof with ventilation is a prominent feature of indigenous architectural design in the parched and sweltering regions of Iran. This technique has been widely utilized in the construction of diverse structures, including but not limited to mosques, mausoleums, bazaars, and residential

dwellings. Certain regions have managed to preserve valuable examples of constructions that have maintained their stability to date, owing to their superior design and construction quality (Sedighi et al. 2017). Mirzazadeh Akbarpoor (2021), conducted a study that demonstrated the potential of combining domed roofs with earth-to-air heat-exchanger systems to enhance their energy-saving capabilities. This study can be considered innovative. The integration of modern technologies with traditional architectural methods is a promising strategy for constructing environmentally friendly and energy-efficient structures, as evidenced by this innovative approach (Mirzazadeh Akbarpoor, 2021). Studying the structural characteristics of dome elements in traditional architecture is a complex area with abundant design variations, offering ample research prospects due to Iran's diverse architectural heritage (Yelkenci Sert et al. 2023).

The utilization of domed roofs—a traditional architectural element that is prevalent in the Middle East—has been observed to possess a noteworthy capacity to preserve energy and enhance the thermal comfort of occupants. The implementation of domed roofs in various settings, including bustling marketplaces, revered places of worship, and intimate residences, is notable due to their unique architectural features that contribute to efficient energy utilization and improved thermal comfort. According to Mahdavinejad's (2013) findings, the domes present on the historical mosques in Isfahan, Iran, served as thermal buffers that effectively reduced energy loss during the night. The architectural design and materials used in constructing the dome hindered the transfer of heat between the inside and outside of the structure, resulting in energy conservation and ensuring comfortable thermal conditions for the occupants (Mahdavinejad et al. 2013). The roof plays a crucial role in the building envelope as it is responsible for managing a significant amount of solar radiation. This can account for as much as 60% of the cooling energy used in a given space (Varzaneh et al. 2014; Rawat & Singh, 2022). The significance of roof design cannot be overstated in mitigating the discomfort of inhabitants, particularly in severe weather conditions (Elseragy & Elnokaly, 2007). Several prominent researchers, such as Runsheng (2003) and Fathy (2010), have advocated for the use of domed roofs instead of flat ones due to their superior ability to receive solar radiation. This results in lower indoor temperatures and improved thermal comfort.

Other researchers, including Faghih and Bahadori (2011) and Olgyay (2015 c), have also supported this approach. Research has demonstrated that the incorporation of the dome

structure and traditional materials such as adobe results in outstanding insulation, reduces heat transfer, and promotes thermal comfort. Moreover, domes have the potential to function as thermal buffers, thereby impeding nocturnal energy dissipation (Sedighi et al. 2017; Mahdavinejad et al. 2013). Due to their unique configuration, domed roofs serve as effective self-shading mechanisms. This is because half of the structure is exposed to direct sunlight while the other half remains in the shade. In their study, Soleimani et al. (2016), investigated the effects of wind and buoyancy-driven ventilation in a geodesic structure that was equipped with roof vents and open windows in a hot climate. The research results indicate that roof vents have the potential to serve as a passive strategy for ensuring adequate indoor thermal comfort and air quality throughout all seasons. Previous research has demonstrated the advantageous outcomes of employing dome roofs in conjunction with earth-to-air heat-exchanger systems, resulting in heightened energy-conservation capabilities. The aforementioned innovative methodology prioritizes the potential for amalgamating modern technologies with longstanding architectural traditions, thereby ushering in a novel epoch of environmentally conscious and power-conserving edifices (Yelkenci Sert & Yilmaz, Karaman, 2023).

Besides the aforementioned benefits highlighted in the research regarding domed roofs, certain studies have revealed the suitability of flat roofs when compared to domed roofs. The underlying reasons for these preferences will be elucidated below.

A few experts (Tang, 2003) have analyzed the thermal characteristics of curved roofs under hot and dry weather conditions using numerical calculations. They determined that the heat transfer and daily heat flow through curved roofs are hardly impacted by the roof's radius, thickness, and thermal properties. However, they are noticeably affected by the half-rim angle of both domed roofs (DRs) and vaulted roofs (VRs), as well as the ambient temperature. The findings also establish that domed roofs are unsuitable for regions with elevated air temperatures and high levels of diffuse sky radiation, which are commonly found in hot and humid areas. Another study (Faghih, & Bahadori, 2011) conducted numerical simulation on a simplified model of a domed roof in a paper titled "Evaluation of Thermal Performance in Domed Roofs". They demonstrated that the thermal performance of the investigated domed-roof building surpasses that of a building with a flat roof on hot days. However, in conditions where there is no wind flow, the flat-

roof building outperforms the domed structure. In addition, while taking into account both convection and solar radiation on the roofs, (Hadavand et al, 2008) examined the thermal efficiency of vaulted roofs and compared their heat transfer with flat roofs. These investigators clarified that the heat transfer to the building, based on a specific ceiling-design temperature, is significantly influenced by different wind patterns and vault shapes. Upon comparing the outcomes with those of a flat roof, it was discovered that the daily average heat flux of all vaulted roofs, except the one with a rim angle of 180°, was lower than that of a flat roof, and it diminished further with higher wind speeds.

It is important to mention that the majority of studies exploring the advantages of domed roofs have primarily concentrated on hot and desert regions characterized by consistently warm weather year-round (Reda et al. 2024). One such study was conducted within the arid and scorching areas of southern Egypt (Ayoub, & Elseragy, 2017). According to this research, domed-roof structures can have a significant impact on reducing the intensity of solar radiation received by maximizing the ratio between the height and radius of the dome. As a result, they decrease the energy required for cooling in hot climates and thereby enhance indoor thermal comfort.

Another study was carried out in Cairo, Riyadh, and Istanbul (Moustafa et al. 2018). This study reveals that pointed double-dome roofs are effective in Cairo and Riyadh's climatic conditions, while cases of half-circular/pointed domes and vaults yield similar outcomes in Istanbul's climate.

In Iran, as well as in the hot and dry regions of Egypt, North Africa, and Istanbul, traditional dome roofs have been widely utilized for their notable impact on enhancing internal thermal conditions over time. However, since some structures with domed roofs in Iran are situated in areas experiencing hot summers and cold winters, this study aims to address the following inquiries:

Do domed roofs, like those found in hot and dry regions, affect energy consumption for heating in areas with cold and dry winters?

Furthermore, by comparing the gas and electricity energy consumption for heating and cooling between a dome roof and two flat and sloping roofs throughout the year and across different seasons in these regions, what will be the resulting findings?

4.1. The Arak city

The city of Arak is situated on the central plateau of Iran, characterized by its significant mountainous terrain that encompasses a substantial portion of the region. The northeastern area of Stan Arak encompasses a substantial expanse of flat terrain that is encircled by mountainous formations. Fifty percent of the plain in question is situated inside the confines of Arak city, while the remaining portion is found within Tafresh city. Miqan Lake, spanning an approximate area of 100 square kilometers, is situated in the southernmost region of the plain within the city of Stan Arak, adjacent to the northeastern outskirts of Arak city (Karimi, 2009).

The city of Arak is situated in the southwestern region of the Arak plain. It is bordered by the Nazm Abad, Mount Sork, Mount Sheikh Ibrahim, Mount Darband to the south, Mount Chihak to the southeast, Mount Mustofi to the west, and the smooth plain of Farahan to the north and northeast. The conclusion is reached (Karimi, 2009).

The approximate distance separating Arak city and Miqan lake is approximately 15 kilometers. The city of Arak is situated in close proximity to the Zagros mountain range, which spans through the northwestern to southeastern regions of Iran (Karimi, 2009).

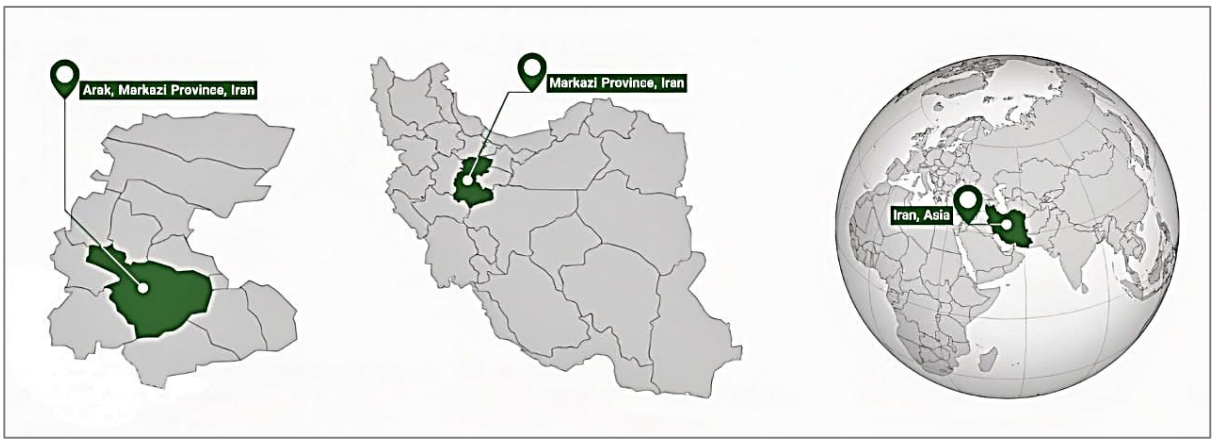


Figure 8: The location of the city of Arak in the country of Iran in the continent of Asia

4.2. The Meteorological and Natural Aspects of Arak city

4.2.1. Air masses

There are large bodies of air that have similar temperature and moisture characteristics throughout. They are typically several hundred kilometers in size and can cover vast regions of the Earth's surface.

The primary factors influencing the prevailing air currents over the Iranian plateau are the significant low pressure and high-pressure systems that impact the expansive geographical expanse of the plateau throughout the year. It is evident that the focus of this subject pertains to air currents on a macroscopic level. The air masses that exert a significant influence on the examined region can be classified into two distinct categories: those associated with winter and those associated with summer.

Winter Surface Currents: Typically, during the winter season, the surface currents of Iran are influenced by the high-pressure systems originating from Siberia and the Azores. The primary stream of this prevailing current, upon its ingress from the northwest and subsequent traversal of the western territories of the nation, proceeds in the direction of the aforementioned region. The second branch extends to the northeastern and eastern regions of the country.

Summer currents: The most important current of significance within the region is the North Atlantic current, which traverses Eastern Europe before reaching Iran. During the summer season, the prevailing wind patterns exhibit a distinct behavior characterized by early morning airflow that diverges into two primary directions, namely west and south-west.

4.2.2. Temperatures

The Arak station experienced an average annual temperature of 13.9 degrees Celsius throughout a 30-year period. The committee's average temperature was recorded at 7 degrees Celsius, while the average maximum temperature reached 20.8 degrees Celsius. Furthermore, the lower and upper limits of temperature are recorded as -28 and 44 degrees Celsius correspondingly. Additionally, the range of temperature fluctuations is The diurnal temperature range spans 13.8 degrees Celsius, with the coldest month

(December) seeing an average temperature of -1.3 degrees Celsius and the warmest month (July) experiencing an average temperature of 27.5 degrees Celsius.

Based on the provided definition, a frost day is defined as a 24-hour period wherein the minimum air temperature falls to zero degrees Celsius or below, excluding the months of October to April. It has been observed and documented numerous times at Arak station, while no such occurrence has been reported during the remaining months of the year. Based on a 30-year analysis, it has been shown that Arak experiences an average of 84 chilly days year. Notably, the months of December and January exhibit the highest average number of frosty days.

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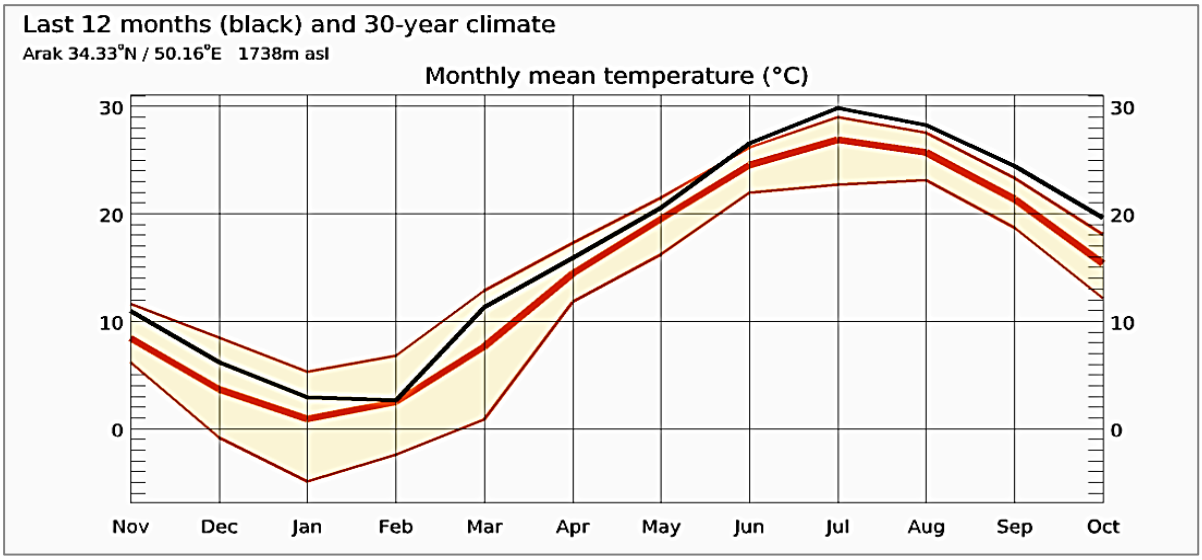


Figure 9: Comparison of the Monthly Temperature of the Last 12 Months with the 30-Year Pattern in Arak. (source: www.mateoblue.com)

4.2.3. Rainfall

Based on the available 30-year statistical data spanning from, Arak exhibits an annual precipitation of 377.6 mm, rendering it the region with the most substantial rainfall in comparison to other areas within the central province. Conversely, the Shams Abad station, situated in close proximity to Arak, experiences a more moderate level of precipitation. The measurement displayed on the shutter is 364.6 mm. Based on the

extant statistical data, precipitation is seen throughout the entirety of the year within the region, with January exhibiting the most amount of rainfall at 69.7 mm, while September experiences the lowest amount at 0.1 mm, rendering it the least precipitous month of the year.

The Arak station has a range of rainfall between 278 and 612 mm. In contrast, the Ahmadabad station, situated in the low rainfall regions of the northeastern province, records a maximum rainfall of 287 mm. This value is only marginally greater than the minimum rainfall observed at the Arak station. The minimum measurement is 71 mm. In relation to the seasonal distribution of precipitation, it is seen that winter receives the highest proportion of total annual rainfall, accounting for 47.3%. Following this, autumn and spring receive 30% and 22% of the total annual rainfall, respectively. Additionally, it should be noted that summer exhibits the lowest annual rainfall, accounting for a mere 0.7% of the overall precipitation.

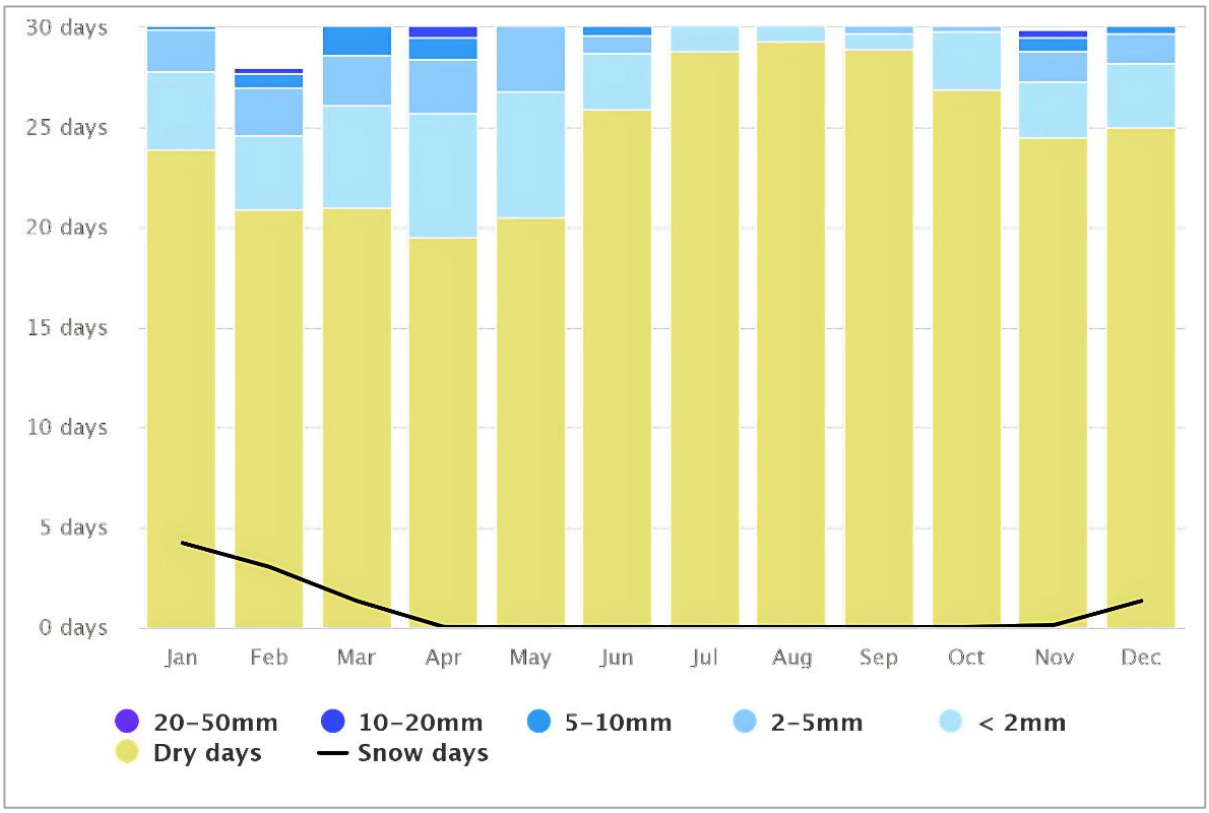


Figure 10: Graphical Representation of Monthly Precipitation Amounts and Number of Dry Days of Arak. (source: www.mateoblue.com)

4.2.4. Humidity

The climate in Arak exhibits variability. The duration of winters often spans a period of 4 to 6 months. Spring and fall are characterized by relatively brief durations. The summer season typically spans the months of July and August. The average relative humidity of the study area over the course of the past three decades has been recorded at 47%, suggesting the presence of a semi-arid climate in the region. The geographical presence of mountains in the western and southern regions has resulted in certain consequences. The presence of moisture persists, leading to a relative increase in air humidity and subsequent softening of the atmospheric conditions. The minimum relative humidity for the months of July and August is observed to be 28%. During this time period, the prevailing wind direction originates from the Miqan desert, predominantly from the northeast and east. Consequently, the prevailing wind brings with it dry air, resulting in arid conditions. The majority of atmospheric moisture is observed throughout the period spanning from November to March. The relative humidity exceeds 50% and attains its peak level of 72% throughout the month of January. The occurrence of hot weather in the region exhibits a fluctuation, with a recorded frequency of 45% in the month of April and a peak frequency of 77% in the month of January.

4.2.5. Major wind currents

The frequency of calm weather in the region exhibits variation, ranging from 45% in the month of April to 77% in the month of January. In the spring season, the wind exhibits a higher level of persistence compared to other seasons, resulting in a reduced frequency of quiet conditions. Winter exhibits the most tranquil climatic conditions in comparison to the other seasons. The region experiences southwest and west winds throughout the year, with the exception of August and July. These two wind directions are often regarded as the prevailing winds in the area during the remaining months. This observation suggests that the movement of Mediterranean currents is responsible for the prevailing wind patterns in this particular direction.

During the summer months, particularly in August and July, there is a prevailing shift in wind direction from the southwest and west to the northeast and east. The prevailing winds in question are located throughout the North Atlantic region, extending towards

the eastern and northeastern areas. The prevailing meteorological conditions, particularly during the final two months of the summer season, exert a notable influence on the wind patterns within the designated research region.

According to the Arak annual windfall data, it is seen that the occurrence of southwest and west winds is comparatively more frequent than other wind directions, accounting for 14.5% and 11.2% of the total wind occurrences, respectively. The mean wind speed ranges from 7 to 10 knots, with the average speed of westward winds being greater than that of southwestward winds.

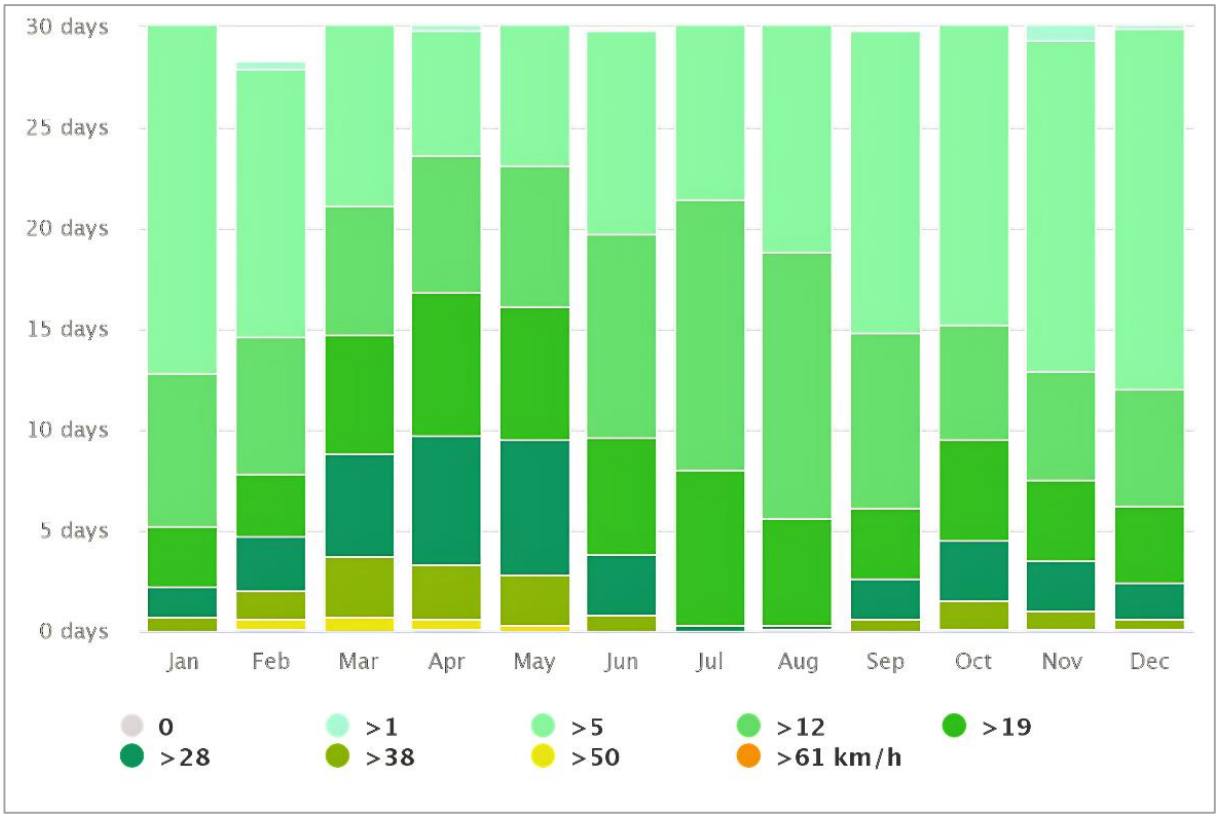


Figure 11: Wind Speed Distribution Throughout the Year. (source: www.mateoblue.com)

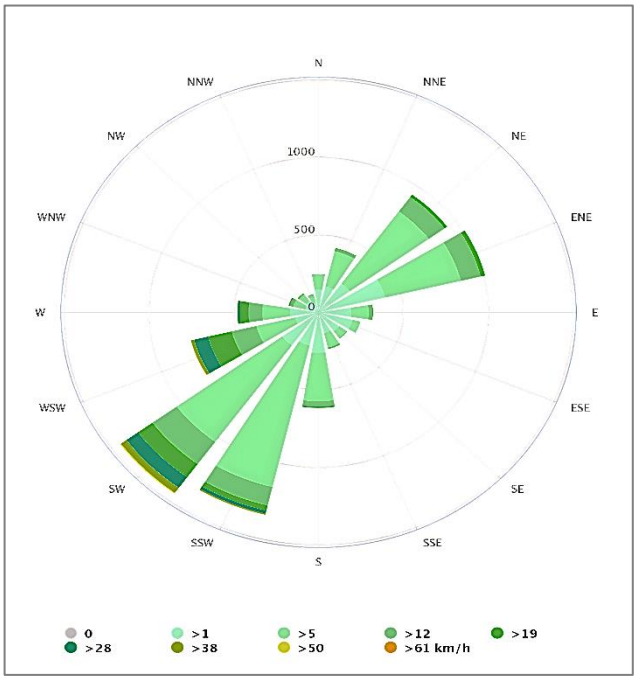


Figure 12: Wind Rose of Regional Wind Data of Arak. (source: www.mateoblue.com)

4.3. Spatial structure of Arak Bazar

The bazar in Arak adheres to a predetermined urban planning concept, which governs its initial location and further extension. This systematic approach ensures that all necessary features and components are included in a cohesive and continuous manner within the market (Karimi, 2009).

The marketplace is characterized by two longitudinal roads running in a north-south direction, as well as east-west pathways leading to the central area of Chahar Souq. These routes serve as connections between the city gates and the marketplace, allowing for entry into the city from four different directions (Figure 13). Consequently, the market serves as the starting point for accessing the city, as indicated by the presence of towers and fortifications surrounding it. The economic exchange core has been strategically built as the central axis of the city, so exerting dominance over the entire urban area while maintaining spatial independence (Haji Ghasemi, 2013).

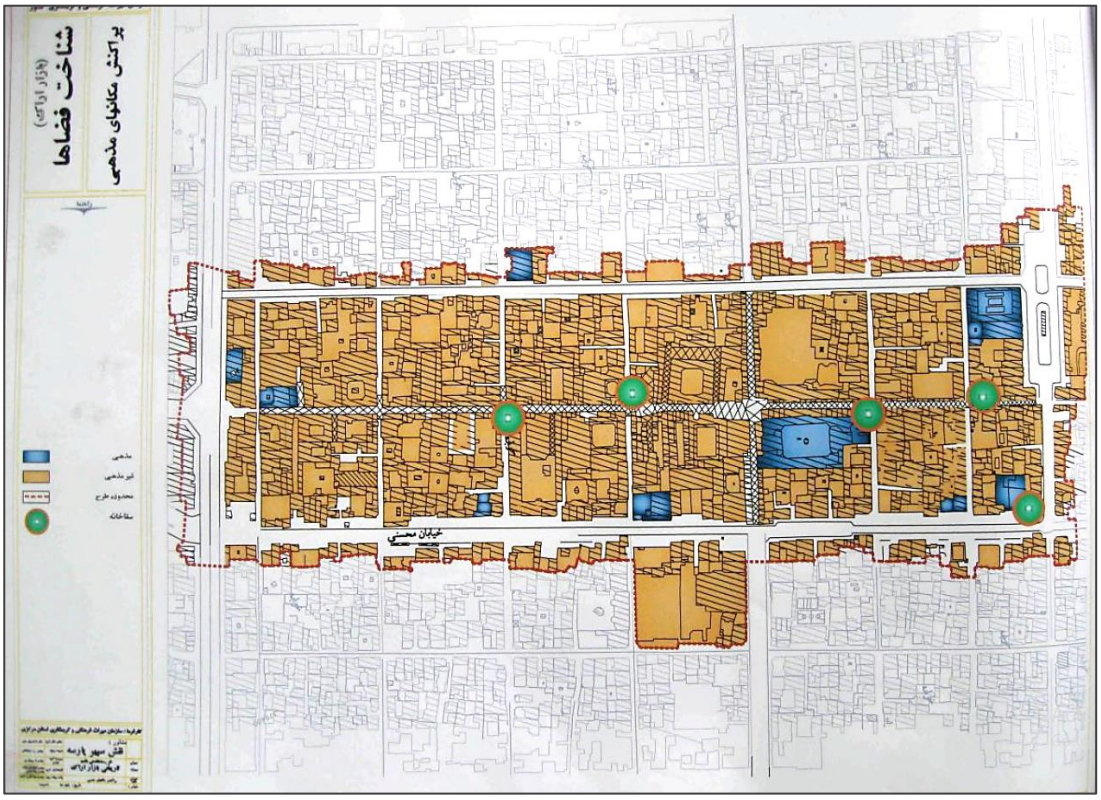
The Old Town Bazaar serves as a commercial hub that caters to the shopping requirements of travelers. It spans a considerable distance and offers a diverse range of

merchandise in all four cardinal directions. The presence of road intersections inside each sector of the market facilitates convenient access to essential amenities for residents (Figure 14), including bakeries, butchers, hair salons, and grocery stores, which are strategically located along the roads leading to residential areas (referred to as market passages) (Karimi, 2009).

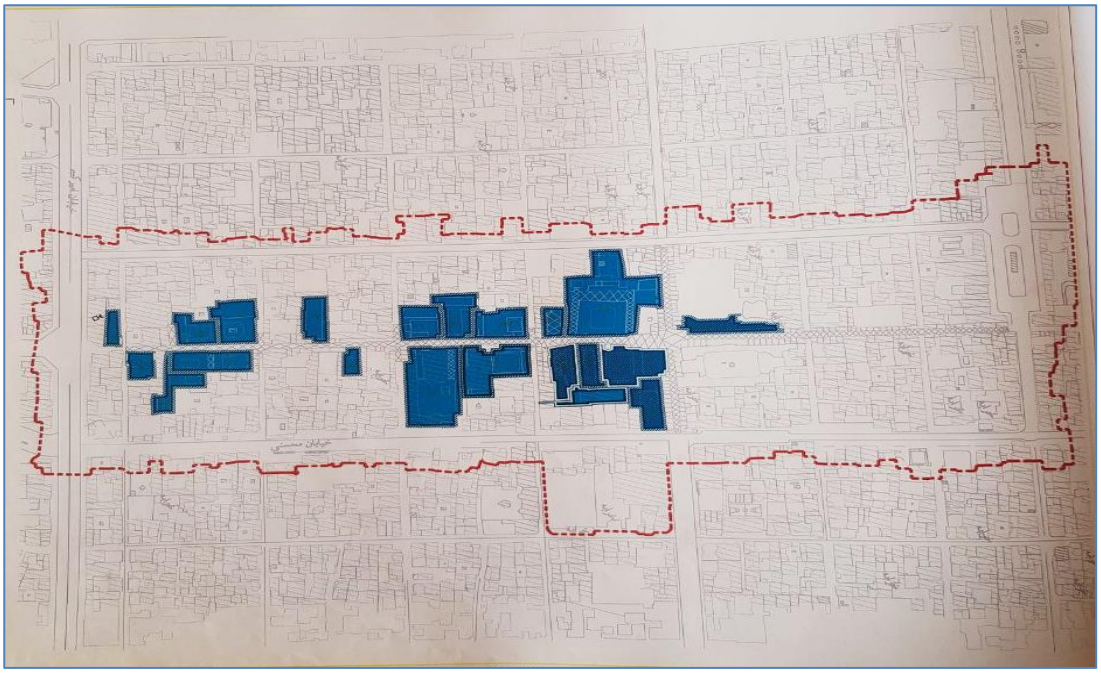
The architectural design of certain caravanserais' interiors gives the impression that, despite the passage of time, only a relatively short period of a few years or decades has elapsed since their original construction. Nevertheless, these structures have been neglected for almost a century, resulting in a lack of maintenance and refurbishment.

The arrangement of the historical Bazar of Arak, similar to many traditional Bazars in Iran, features a systematic organization of merchandise. Examples of individuals engaged in various occupations include cloth-dealers, tanners, cream merchants, and spice salespeople (Haji Ghasemi, 2013).

In caravanserais, commodities are typically sold in large quantities, while in marketplaces, they are offered in smaller, individual units. Certain caravanserais utilize for the purpose of carpet repair, while others dedicate to the spinning of yarn or wool.



(a)



(b)

Figure 13: Detailed Map of Arak Bazaar (a & b). (source: Ministry of Cultural Heritage, Tourism and Handicrafts of Iran)



Figure 14 : Map of Arak Bazaar. (source: Ministry of Cultural Heritage, Tourism and Handicrafts of Iran)

4.4. The defining attributes of several key components inside the bazaar framework:

4.4.1. Rasteh:

The Bazar route, also known as the Rasteh, refers to a lengthy passageway characterized by a network of interconnected stores that lining both sides. The primary segments of the streets are allocated for the establishment of retail establishments, while the adjacent and peripheral sections are designated for the operation of workshops belonging to skilled craftsmen and artisans.

Typically, these intersections serve as the pivotal link connecting the urban core with the adjacent thoroughfares and highways situated beyond the city limits. Furthermore, the ingress of establishments and other relatively secluded commercial and welfare sectors within the marketplace are frequently situated along one of these axes (Karimi, 2009).

4.4.2. Caravanserai:

The term "caravanserai" refers to a type of roadside inn or resting place that was commonly used by travelers.

In the realm of Iranian culture, which has flourished over the past three centuries, the terms "Sarai" and "Caravanserai" are employed to refer to the part of marketplace. The quantity and dimensions of caravanserais situated within the central marketplace or urban center serve as indicators of the economic significance and level of foreign commerce associated with the city. Sarai, akin to contemporary shopping malls, enhances the commercial capacity of the rows and serves as a means to address the limited length of the rows.

The caravanserai typically comprises a centrally located courtyard, encompassed by a series of interconnecting circular chambers. The dissimilarities of caravanserais mostly lie in the topographical configuration, the quantity of levels, and the architectural characteristics of the porches and corridors. The prevailing architectural design of caravanserais often consists of two levels (Karimi, 2009).

4.4.3. Chahar Souq:

The quadrilateral, also known as Chahar Souq (Figure 15), serves as a prominent hub where two primary routes intersect, resulting in a notable commercial center. Typically, this center features four main pathways that extend from it, and its architectural design surpasses that of other sections along the route, boasting more capacity and interior embellishments. The architectural design of all Chahar Souq features a dome-shaped roof. The utilization of high domes and the incorporation of ketch bar embellishments within its arches have resulted in a striking visual impact (Karimi, 2009).



Figure 15: A view of "Chahar Souq" of Arak bazaar with dome roof

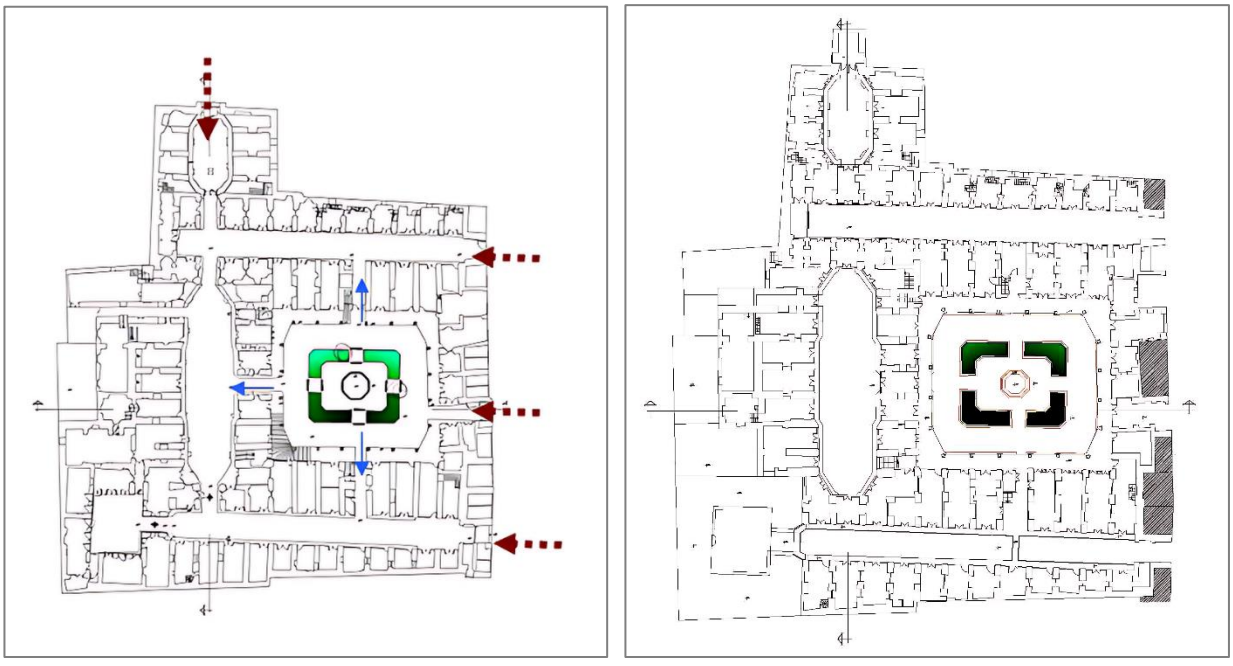
4.5. Arak Bazaar: A Journey through Unique Architecture and Timeless Traditions

As shown in Figure 13. the Arak Bazaar's primary axis, oriented in a north-south direction, spans approximately 722.52 m and accommodates roughly 320 stores and 22 caravanserai entrances throughout its expanse. The total area of the Bazaar amounts to 140,000 square meters. The principal marketplace is encompassed by a roofed edifice featuring a dome-shaped structure that incorporates apertures for ventilation. The architectural design of the caravanserais or passageways linked to this axis exhibits a distinctiveness that is noteworthy.

In general, caravanserais are comprised of a centrally located courtyard that is encompassed by interconnected stores (Haji Ghasemi, 2013). The majority of caravanserais are designed with a dual-level structure, featuring aesthetically pleasing brick and plaster roofs that are constructed with ribbed vaults, arches, and springs. The architect responsible for the design of the Arak Bazaar demonstrated a discerning approach by avoiding a monotonous and standardized layout for the 22 caravanserais. The arrangement of enclosed and open spaces in relation to the primary axis of the Bazaar exhibits remarkable diversity, resulting in a visually captivating and multifaceted Arak Bazaar.

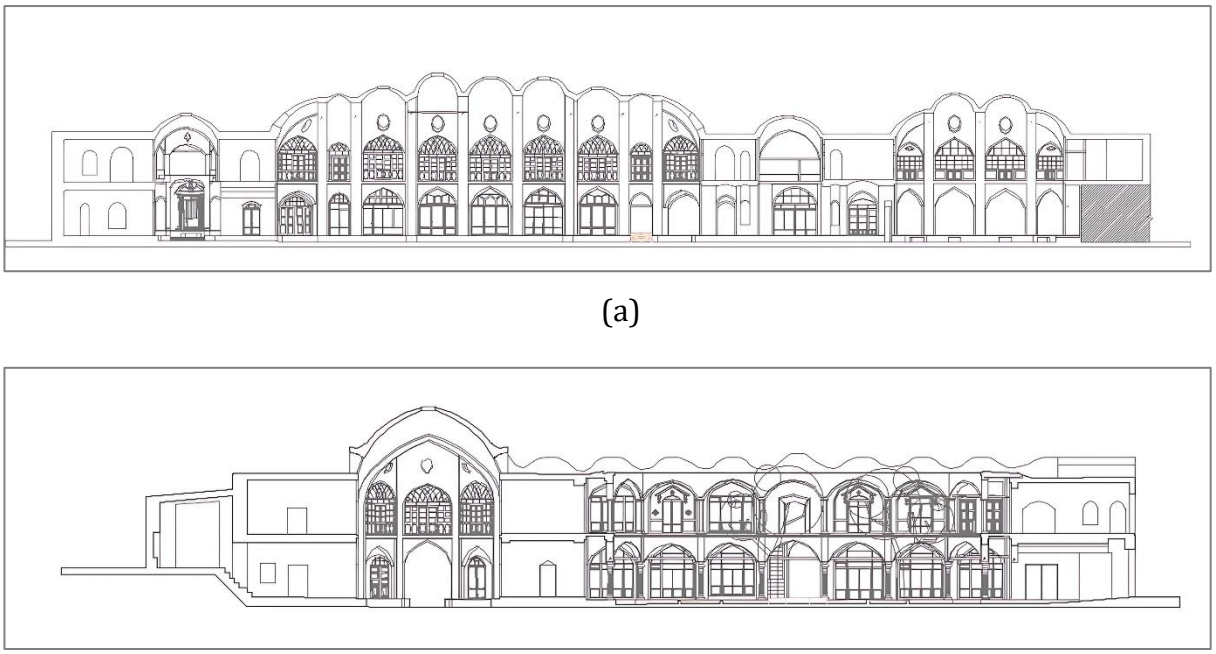
The Nowzari Caravanserai (Figure 16), situated within the Bazaar, is a notable example of a vast and complex structure. Covering an expansive area of roughly 5480.93 square meters, it stands as one of the largest caravanserais in the region. The caravanserai in question features a central courtyard, which is connected to three longs, covered corridors (known as Timchehs) that are easily accessible. Additionally, there are three entrances leading to the main axis of the Bazaar, as well as one entrance from the Chahar Suq passage (Karimi, 2009).

The paved flooring of the courtyard is adorned with stones, and a diminutive pool has been constructed at its focal point. Surrounding the area are multiple establishments featuring stone columns that uphold brick arches. A thoroughfare extends from the central shopping area to the adjacent corridors, facilitating seamless access between disparate sections. The entirety of the caravanserai is comprised of two levels. The retail establishments are involved in the sale of carpets, as well as the creation of carpet patterns (Ministry of Cultural Heritage, Tourism and Handicrafts of Iran, 2022).



(a) (b)

Figure 16: Plans of Nowzari Caravanserai. (a) Ground Floor (b) first floor (source: Ministry of Cultural Heritage, Tourism and Handicrafts of Iran)



(a)

(b)

Figure 17: Views of Nowzari Caravanserai. (a) East-west view (b) North-south view (source: Ministry of Cultural Heritage, Tourism and Handicrafts of Iran)

This particular caravanserai is distinguished by its extensive scale and comprehensive level of detail, making it one of the largest and most intricately designed structures inside the market. The total land area measures around 5480.93 square meters (Figure 17). The caravanserai in question is equipped with three entries that face the bazaar, as well as an additional entry from Chahar Souq. Moreover, it features a central courtyard that is accessible through three lengthy corridors, each of which serves as a connecting pathway (Karimi, 2009).

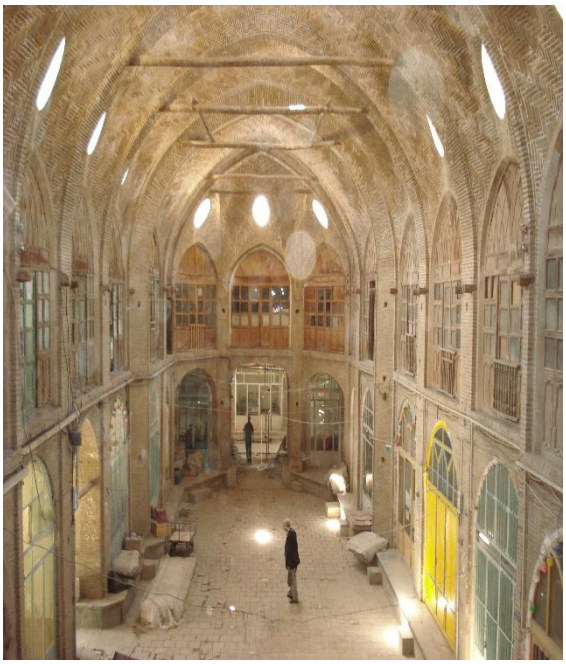
The yard is adorned with a paved floor, with a centrally located pond. Surrounding the area are a multitude of retail establishments, characterized by stone capitals that provide structural support for brick arches. A thoroughfare extends from the central area of the shops to the adjacent corridors, establishing a seamless linkage between the various areas. The caravanserai consists of multiple sections, each of which is arranged across two levels (Figure 18). Retail establishments are involved in the selling and drawing the pattern of carpets (Karimi, 2009).



(a)



(b)



(c)



(d)

Figure 18: Pictures of Nowzari Caravanserai located in Arak Bazaar. (a) Bazar route leading to Nowzari Caravanserai; (b) A view of the upper floor store; (c) The carpet sales department of Nowzari Caravanserai with a domed roof with ventilation holes; (d) A view of the central courtyard of Nowzari Caravanserai. (source: Ministry of Cultural Heritage, Tourism and Handicrafts of Iran)

5. Chapter 5

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Methodology

The primary research methodology employed in this study is simulation. Simulation studies employ computational models to replicate a given system or process, with the aim of forecasting outcomes under varying circumstances (Sailor et al. 2011). The present study employed Design Builder software V7.0.1.004 to conduct a simulation of the Arak market, utilizing varying roof forms (flat, sloped, and arched) and roof heights. The objective was to investigate the impact of these factors on the internal temperature and energy consumption for heating and cooling during the season. The seasonal variations in temperature were assessed.

The present study can also be categorized as quantitative in nature as it entails the collection and analysis of numerical data to comprehend the effects of alterations. Quantitative research employs statistical techniques to scrutinize data and typically entails impartial measurements and numerical outcomes (Goundar, 2012). This study involved the collection and analysis of data pertaining to indoor temperature and energy consumption across various scenarios. The aim was to draw conclusions regarding the impact of roof forms on these factors.

Thus, it can be posited that the methodology employed in this study is an experimental design conducted within a virtual environment. This methodology is frequently employed in domains such as architecture and construction, where conducting physical experiments can be prohibitively costly, time-intensive, or unfeasible. By means of this approach, it became feasible to employ a software application for the purpose of evaluating diverse architectural configurations and parameters, amassing relevant data, and deducing inferences from said data.

5.1. Design Builder Simulation Software Validation

In order to assess the accuracy and validity of energy-simulation software, researchers have introduced a range of methodologies. Broadly speaking, these methods can be

classified into three overarching categories: analytical, comparative, and experimental methods. Within the realm of building-energy software-validation research, two prevalent types of validation studies are experimental methods, which involve comparing simulation outcomes with field measurements, and comparative methods, which involve comparing the results of various energy-simulation software with one another. The objective of these studies is to elucidate the factors that contribute to the disparity between projected energy consumption and observed consumption, as well as to validate the software inputs in accordance with their respective application platforms. In developed countries, where simulation software is designed in accordance with established regulations and standards, several software programs have undergone validation (Judkoff et al. 2008). These include Ecotect Autodesk (Chung et al. 2013), Green Building Studio (Leng et al. 2012), IES (Qays Oleiwi et al. 2019), Energy Plus (Zhu et al. 2013), E-Quest (Rallapalli, 2010), and Design Builder (Zahiri, & Altan, 2012). The investigation of the validity of Design Builder software in Iran was conducted to align with the specific conditions and methodologies of construction and operation, as well as equipment and climatic factors. This investigation utilized two experimental and comparative approaches. The findings indicate that the Design Builder software exhibits favorable performance in accurately forecasting energy-consumption levels and internal temperature variations within spaces, considering factors such as construction conditions, equipment specifications, and climatic conditions (Zomorodian, & Tahsildoost, 2016).

In this research, to check the validity of the software in the study area (Arak City), we used the experimental method and compared the results of the simulation with field measurements.

5.2. Site Visit and Energy Survey of Nowzari Caravanserai

The desired information was collected through the utilization of existing maps of the Arak market, as well as the acquisition of additional information from the General Department of Cultural Heritage, Handicrafts and Tourism of Arak City; the Meteorological Organization of the province; and a field visit. Subsequently, a comprehensive and precise

documentation process was conducted, encompassing the verification and quantification of various elements such as dimensional and architectural data, executive particulars, specifications pertaining to walls, ceilings, doors, and windows, as well as general specifications concerning the mechanical and electrical systems of the building, including lighting. Additionally, meticulous records were compiled regarding the comfort conditions within the spaces, encompassing temperature and humidity values, as well as the conditions governing the utilization of the building. The quantification of electricity and gas energy consumption was derived from monthly billing records over the course of one year.

5.2.1. Dry Bulb Temperature of Arak

Figure 19 displays the temperature ranges for dry bulb conditions, encompassing the Recorded High and Low Temperature (shown by round dots), the Design High and Low Temperatures (indicated by the top and bottom of the green bars), Average High and Low Temperatures (represented by the top and bottom of the yellow bars), and the Mean or Average Temperature (represented by the open slot).

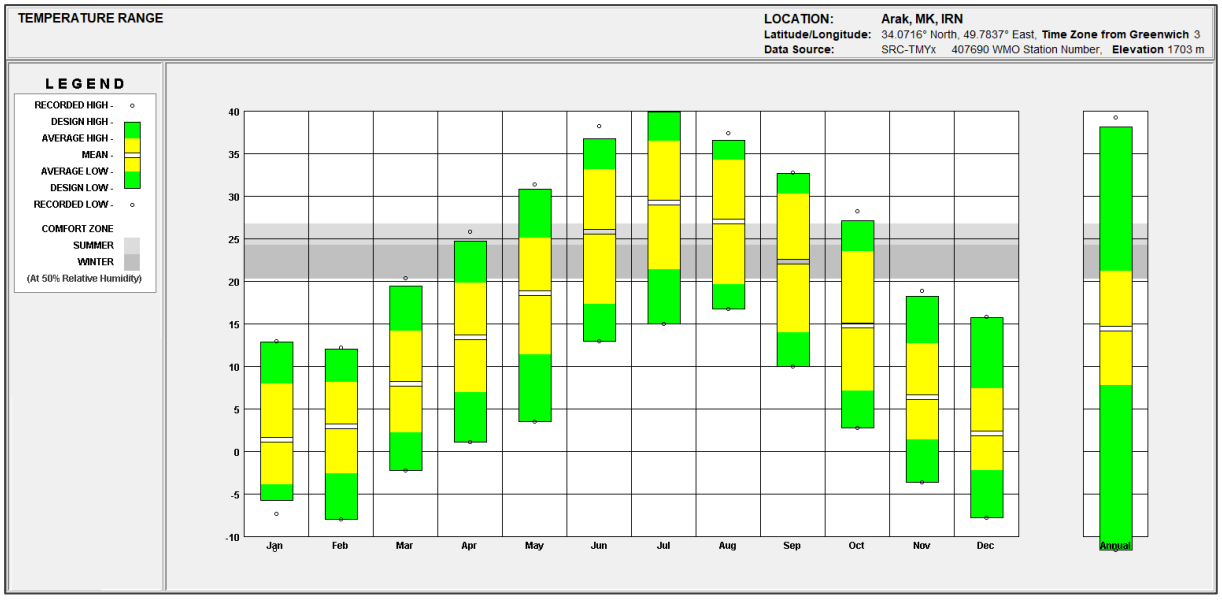


Figure 19: Diagram of dry bulb temperature of Arak city (Source: Climate Consultant software)

The weather data file of Arak contains the maximum and minimum dry bulb temperatures observed for each month and for the entire year. EPW files consist of selected months from various years, intended to create a typical or sample year.

The Annual Design Temperatures are used to compute the Heat Loss and Heat Gain of the structure, which is then employed to determine the appropriate size of the heating and cooling equipment. The design temperatures for each month are indicated using the same proportion of hours in that month.

The Design Temperature Range is the percentage of hours utilized to determine the outdoor design high and design low temperatures. The following temperatures are presumed to be the basis for determining the dimensions of a building's heating and cooling apparatus. As an illustration, the 2008 California Energy Code, which applies to both Residential and Non-Residential buildings, specifies that the Outdoor Heating Design Low temperature should be set at the median of the lowest temperatures seen throughout winter. Climate Consultant utilizes EPW data that is specifically curated to represent the average conditions seen over the past 30 years. Therefore, it considers that the lowest temperature recorded in the EPW file is equivalent to the median value of extreme temperatures over this time period.

The temperature referred to as the Recorded Low in Climate Consultant. This indicates that none of the hours in this file had temperatures below this value. However, in a real year, there would be a 50-50 probability of recording temperatures below this threshold. The design of outdoor cooling for high temperatures is somewhat intricate.

According to the 2008 California Non-Residential Energy Code, the temperature should not exceed 0.5% of the values for Cooling Dry Bulb and Mean Coincident Wet Bulb. This indicates that there is a 0.5% occurrence or 44 hours where the dry bulb temperature exceeds the wet bulb temperature.

According to the 2008 California Residential Code, the Outdoor Cooling Design High temperature should not exceed 1.0% of the Cooling Dry Bulb and Mean Coincident Wet Bulb values. Consequently, 1.0% or 88 hours exceed these temperatures. Naturally, in any given year, there is a 50-50 probability that the percentage of reported temperatures exceeding these levels will be higher.

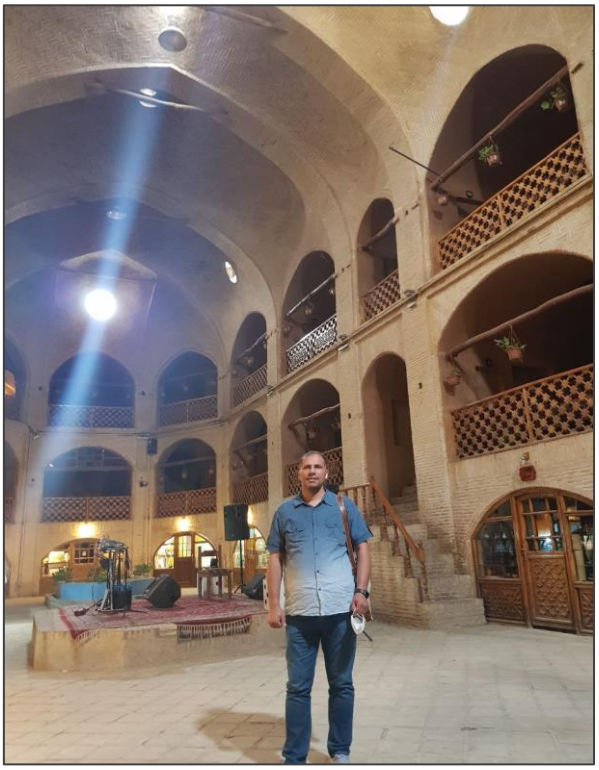
Climate Consultant will automatically compute these two temperatures, which are then presented as Design High and Design Low on the Annual bar graph of the Temperature Range Chart. The default values for defining the Design High and Low Temperatures are 1% for Design High and 0% for Design Low for Residential buildings, and 0.5% for Design High and 0% for Design Low for Non-Residential structures.

For this reason, as can be seen in Figure 19 (the left side of the image shows the settings considered for the design.) In this temperature simulation, the settings based on non-residential buildings are considered.

5.2.2. Measuring temperature at Nowzari Caravanserai

I measured the internal temperature of a store located in Sarai Nowzari (Figure 20 illustrates the area where the shop in question is situated) on 15 December 2022 (representing the coldest month of the year) and on 15 July 2022 (representing the hottest month of the year).

As shown in Table 3. the measurements were conducted over an 16 h period, starting from the early morning. During the cold season, the lighting and heating systems were turned off, and during the hot season, the cooling system was nonactivated. Furthermore, the windows were kept closed throughout the experiment. A TESTO DATA LOGGER device was utilized to record the temperature at specific time intervals. It is important to note that the first part of the experiment was conducted without the presence of users and customers, while the remaining hours involved the presence of residents and customers. The duration of one hour was measured at the central location within the store.



(a)



(b)



(c)



(d)

Figure 20 : The location of indoor temperature and humidity measurement in Nowzari Caravanserai. (a & b) in July; (c & d) in December

Table 3. Comparison of measurement and simulation temperature results in a store in Sarai Nowzari on 15 July 2022.

Date/Time (July)	Relative Humidity %		Outdoor Dry-Bulb Temperature °C		Indoor Air Temperature °C	
	Simulation	Field Measurement	Simulation	Field Measurement	Simulation	Field Measurement
06:00:00	36.04	35.0	23.00	23.2	26.03	25.7
07:00:00	36.76	36.5	23.41	23.9	25.40	25.1
08:00:00	37.36	37.0	24.35	24.6	24.62	24.3
09:00:00	38.39	38.0	26.15	25.4	24.47	24.0
10:00:00	39.73	39.3	27.95	27.4	24.30	23.6
11:00:00	40.81	40.1	30.13	29.0	24.16	23.4
12:00:00	41.36	41.0	32.35	31.5	24.04	23.0
13:00:00	41.70	41.5	34.63	33.5	24.03	22.6
14:00:00	41.94	42.0	36.03	35.0	24.03	22.3
15:00:00	42.49	42.5	37.20	36.0	24.00	21.9
16:00:00	43.18	43.0	38.33	37.0	24.05	21.5
17:00:00	43.69	43.5	37.33	36.0	24.40	22.0
18:00:00	43.73	43.8	35.55	34.6	25.02	22.5
19:00:00	43.52	43.2	33.83	33.3	25.77	23.0
20:00:00	34.52	35.9	33.03	32.2	26.42	23.5
21:00:00	34.03	33.1	32.45	31.5	27.35	24.0

The results revealed a discrepancy between 1 and 3 percent between the temperature obtained from field measurements and the results obtained from simulation. According to other validation studies of the Design Builder simulation software (Zahiri, & Altan, 2012; Zomorodian, & Tahsildoost, 2016), this discrepancy falls within the acceptable range, which is consistent with the reports reviewed in the previous sources.

In addition, Table 4 displays the internal temperature measurement of the Sarai Nowzari store on 15 December 2022 (the coolest month of the year) and the simulation data.

Table 4. Comparison of measurement and simulation temperature results in a store in Sarai Nowzari on 15 December 2022.

Date/Time (December)	Relative Humidity %		Outdoor Dry-Bulb Temperature °C		Indoor Air Temperature °C	
	Simulation	Field Measurement	Simulation	Field Measurement	Simulation	Field Measurement
6:00:00	20.27	20.6	−2.87	−2.85	15.46	15.28
7:00:00	19.35	19.5	−2.075	−2.10	16.96	16.48
8:00:00	17.94	17.5	−1.875	−1.85	19.26	18.87

9:00:00	17.76	17.1	1.03	1.03	19.87	19.63
10:00:00	18.34	18.0	1.525	1.55	20.27	19.78
11:00:00	18.97	19.3	2.025	2.05	20.65	20.21
12:00:00	19.43	19.8	2.45	2.55	20.87	21.13
13:00:00	19.62	20.2	2.875	2.90	21.11	21.49
14:00:00	19.79	19.6	3.025	3.00	21.27	21.10
15:00:00	20.13	19.8	2.75	2.80	21.33	20.90
16:00:00	20.30	20.4	0.825	0.82	21.44	21.18
17:00:00	20.27	20.3	0.25	0.25	21.51	21.77
18:00:00	19.53	20.0	−1.85	−1.90	21.72	21.43
19:00:00	18.80	18.5	−2.45	−2.52	21.80	21.40
20:00:00	21.59	21.0	−3.975	−3.90	20.27	20.69
21:00:00	22.26	22.0	−4.55	−4.58	19.26	19.45

The actual consumption of electricity and gas was extracted through monthly bills in a one-year period.

Using Equation (1), the information obtained from the monthly bills was compared to the results obtained from the case simulation.

Difference Percentage =

Equation 1

| (Actual Energy Consumption – Simulated Energy Consumption) | /

Actual Energy Consumption + Simulated Energy Consumption/ 2) × 100

The simulation engine of this software is Energy Plus, which was developed by the US Department of Energy in 2011 and is known as one of the most reliable energy modeling software. The validity of Energy Plus software 9.4, which is the simulation engine of Design Builder, was confirmed based on BESTEST and ASHRAE-14 standards (Casini, 2022). Energy Plus is among the dynamic energy software that have high flexibility, and the following factors are included within it:

- Geographic location and orientation of the structure;
- Specific local weather conditions;
- Intricate 3D geometry of the building, including shading from nearby structures and self-shading;

- Time lag in the response of the building envelope;
- Type and characteristics of utility systems (heating, ventilation, and air conditioning) installed in the building;
- Functioning of automated utility system controls during weather fluctuations;
- Building's operational schedule, accounting for varying usage throughout the day, week, month, and year;
- Nonlinear interconnection of utility system components within the building (Pukhkal, 2021).

Data on monthly gas and electricity consumption was obtained via the examination of electricity and gas invoices.

On the invoices, the monthly electricity consumption is detailed in kilowatt hours. But the gas meter consumption indicated in the bills was determined in cubic meters, which was subsequently converted to kilowatt-hours. (For additional details, consult the gas and electricity invoice included in the annexes on page 107).

Following the extraction of the bill data, a comparison was made between the obtained information and the simulation outputs generated by the Design Builder software.

As can be seen in Table 5., the percentage difference between the actual consumption of electricity and gas and the results obtained from the simulation shows an average difference of 1.6%, which is consistent with the results obtained in similar studies (Fathalian, & Kargarsharifabad, 2018).

Table 5. Comparison of the difference between predicted consumption with Design Builder software and actual consumption.

Date/Time Month	Dome Roof					
	Gas (kWh)			Electricity (kWh)		
	Simulation	Actual Consumption	Percentage Difference	Simulation	Actual Consumption	Percentage Difference
Jan	54,214.44	53,659.08	1.03%	219.52	216.18	1.53%
Feb	28,614.64	28,300.02	1.10%	576.78	570.50	1.09%
Mar	15,978.21	15,807.72	1.07%	2,045.48	2,016.20	1.44%

Apr	5,152.35	5,078.19	1.45%	8,003.49	7,895.96	1.35%
May	1,370.03	1,353.43	1.22%	22,415.59	22,041.87	1.68%
Jun	0.0	0.0	0.0	37,432.63	36,912.65	1.40%
Jul	0.0	0.0	0.0	56,717.68	56,127.20	1.05%
Aug.	0.0	0.0	0.0	49,798.81	49,334.53	0.94%
Sep	0.96	0.95	1.95%	31,352.17	31,038.26	1.01%
Oct	1,998.19	1,973.20	1.26%	12,761.63	12,592.13	1.34%
Nov	21,407.21	21,092.34	1.48%	852.08	842.69	1.11%
Dec	40,989.13	40,489.30	1.23%	377.12	372.48	1.24%

5.3. Initial Settings of the Software for the Simulation Process

In order to acquire valid and reliable results from simulation, it is necessary to take certain factors into account. Therefore, the information gathered from the Bazaar's site visit was used as simulation input data and initial parameters in the software. Table 6. provides an example of input data.

Table 6. Input data and initial settings of Design Builder software.

Wall **3 layers**	**Outermost layer** Brickwork outer Thickness (m)	0.10	
	Layer 2 Brickwork outer Thickness (m)	0.50	
	Innermost layer Gypsum plastering	0.10	
Wall & Roof **(Inner surface)**	**Radiative heat transfer coefficient** (W/m^2-K)	5.54	
	Surface resistance (m^2-K/ W)	0.13	
Wall & Roof **(Outer surface)**	**Radiative heat transfer coefficient** (W/m^2-K)	5.13	
	Surface resistance (m^2-K/ W)	0.04	
Roof **3 layers**	**External layer** Thickness (m)	**Tile** **Brick**	0.02 0.20
	Air gap Thickness (m)	0.30	
	Internal layer Thickness (m)	**Brick** **Plaster Board**	0.20 0.02
Convective heat transfer coefficient External Wall ($W/m^2/K$)		2.10	
Convective heat transfer coefficient External Roof ($W/m^2/K$)		0.49	

An extensive amount of information and configurations relevant to internal and external walls, internal floor, external floor, internal doors, external doors, and internal mass may be found in the annexes, which can be found on pages 19 to 34.

5.4. Simulation of Sarai Nowzari in Design Builder to Compare the Energy Consumption of Three Dome, Flat, and Sloped Roofs

In order to simulate the market conditions through the utilization of Design Builder software, it is imperative to initially establish the corresponding environment within the software.

The present study involves the simulation of “Sarai Nowzari”, a Caravanserai located in Arak Bazaar. The aforementioned caravanserai is characterized by an unroofed central area and enclosed compartments, featuring a sizable central dome and seven minor lateral domes. It is noteworthy that certain particulars have not been taken into account due to constraints in the software, which could potentially result in inaccuracies. The objective of this study was to examine the impact of different roof types on the reduction of energy consumption and enhancement of passive thermal comfort in Nowzari Caravanserai, which is situated in Arak Bazaar.

In order to guarantee the precision of the investigation, the simulation was meticulously crafted to closely emulate the present Bazaar reality, and pivotal parameters such as dimensions and materials were meticulously chosen to correspond with the factual Bazaar.

The present investigation involved the creation of three distinct models of Nowzari Caravanserai, involving dome, flat, and sloped roofing designs (As depicted in Figure 19) In the simulated scenario involving a sloped roof, the angle of inclination for the roof was uniformly established at 30 degrees across all orientations. The selection of a 30° roof pitch was based on its recommendation in the literature for the purpose of facilitating maintenance and promoting enhanced air circulation, as compared to alternative pitches (Ibrahim et al. 2018).

The objective was to conduct a comparative analysis of the parameters associated with thermal energy consumption (measured via gas consumption) and cooling (measured via electricity consumption) across the three distinct roof shapes. Furthermore, the present investigation was carried out with the objective of contrasting alterations in temperature

during the warmest and coolest months of the calendar year within the interior and exterior settings of the marketplace. The average monthly temperature of Arak City over a 10-year period was obtained from the Meteorological Department for the purpose of temperature analysis. This study aims to offer valuable insights into the potential advantages of utilizing domed roofs as a means of reducing energy consumption and enhancing passive thermal comfort in conventional marketplaces, such as Arak Bazaar.

5.5. Complex Building Design of Nowzari Caravanserai in Design Builder: An Exploration of Space and Functionality

The following pictures (Figure 21. a, b, c) show the architectural plan of Nowzari Caravanserai site, which show detailed information about the layout of the shops, access routes to the bazaar and spatial zoning. Here are the key components:

Spatial Zoning: Shops/spaces are labelled with a distinctive alphabet (A, A1, B, C, etc.), representing different areas or functions in the building.

Central Feature: In the middle of the plan, there is a square space with a complex design with a concentric pattern, which represents a special central courtyard. The symmetrical design in the middle is a special landscaping feature in the architecture of Arak market.

Circulation Paths: This design presents a network of routes, corridors and connections that allow movement between shops and different spaces. These circulation paths are critical to understanding flow and access within the market complex.

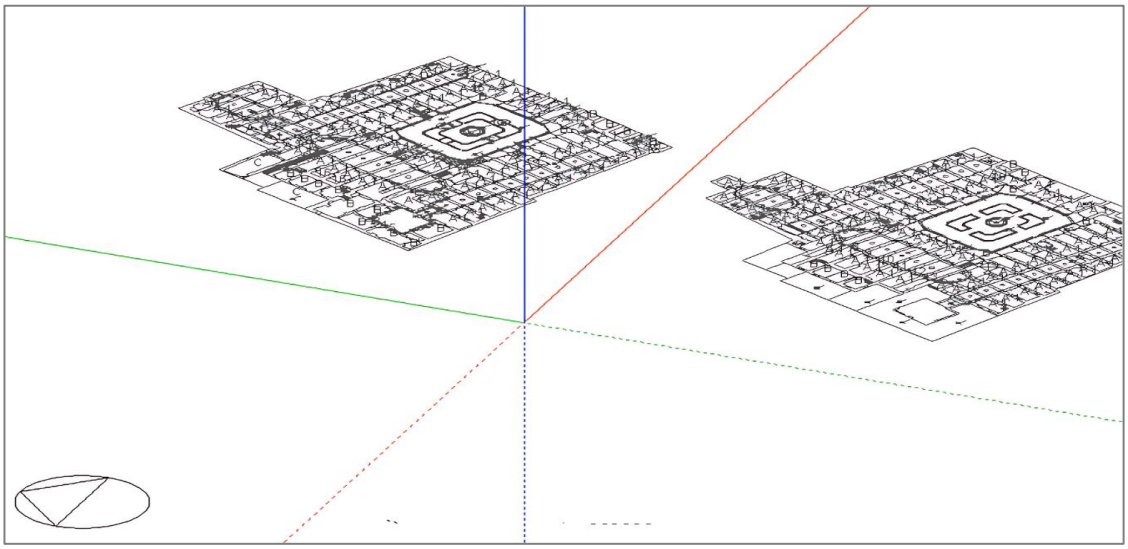
Cardinal Directions: In the upper right corner, there is a color-coded arrow diagram (red, blue, green) that represents the cardinal directions (north, east, west, south). This is essential for understanding building orientation, which plays an important role in aspects such as sunlight exposure, wind direction and general climate considerations.

Circular Diagram: This diagram, which is located at the bottom left, is a diagram of the path of the sun or the sun. Such diagrams are very important in the design of sustainable architecture to determine how the path of the sun affects the building in terms of lighting, shading and energy consumption.

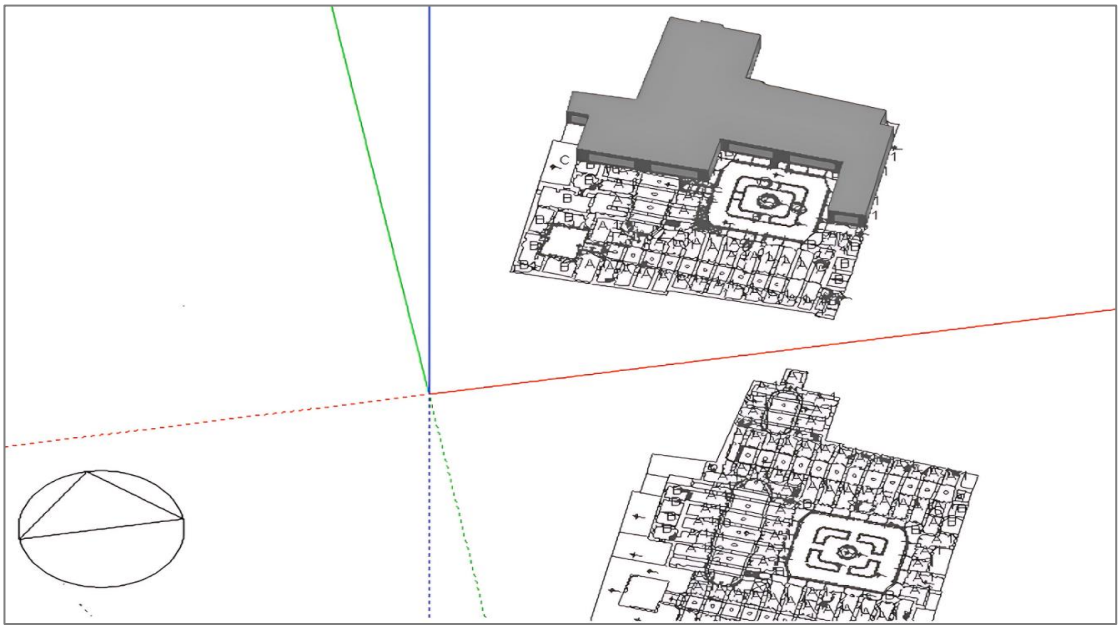
Annotations and Symbols: Throughout the diagram, various icons and symbols provide additional information. These include the location of doors, window locations, stairs and

other architectural features. Some spaces also have numerical annotations that refer to shop dimensions, references, or other relevant details.

These images reveal a comprehensive plan of the architecture of Nowzari Caravanserai, focusing on spatial zoning, circulation and design features. The integration of the sun path diagram represents a conscious effort for sustainable and energy-efficient design considerations. These designs have been simulated in Design Builder software to understand spatial relationships, functional zoning and to investigate the effect of changes in architectural elements on energy consumption.



(a)



(b)



(c)

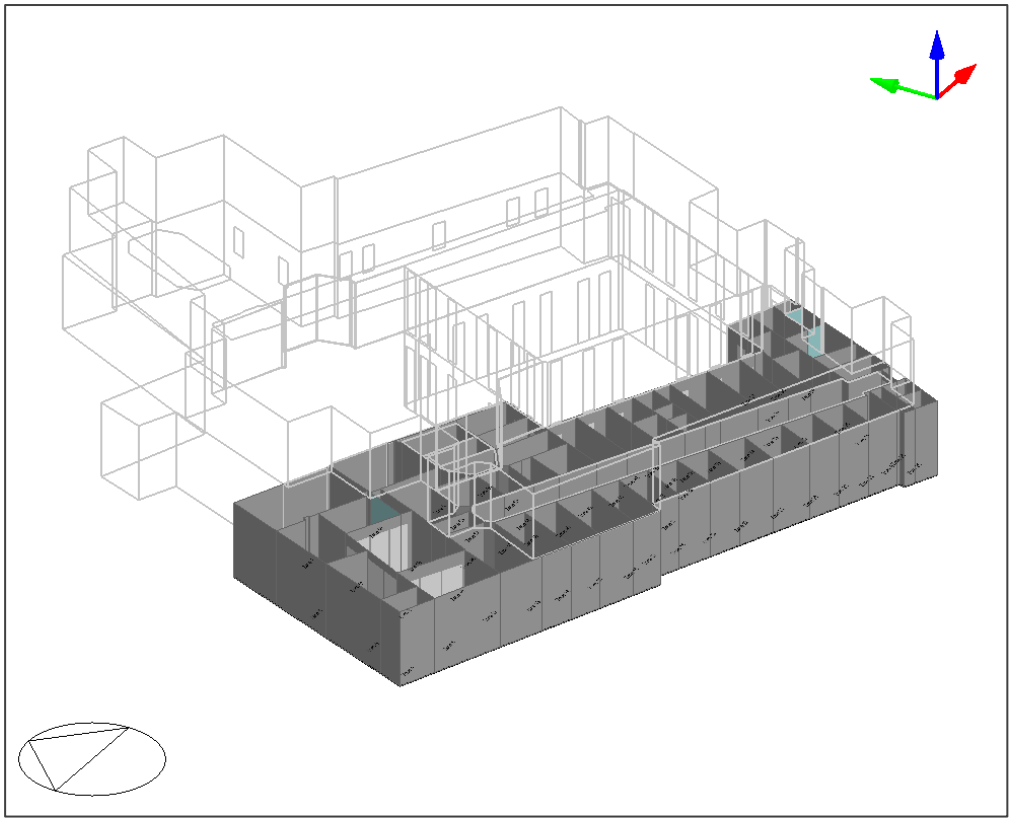
Figure 21: Design Builder plan of Nowzari Caravanserai. (a) plans of ground floor & first floor of Nowzari Caravanserai (b) simulate of flat roof (c) Space placement of doors, window locations, stairs and other features. (source: Design Builder software)

5.5.1. Floors modelled as separate blocks

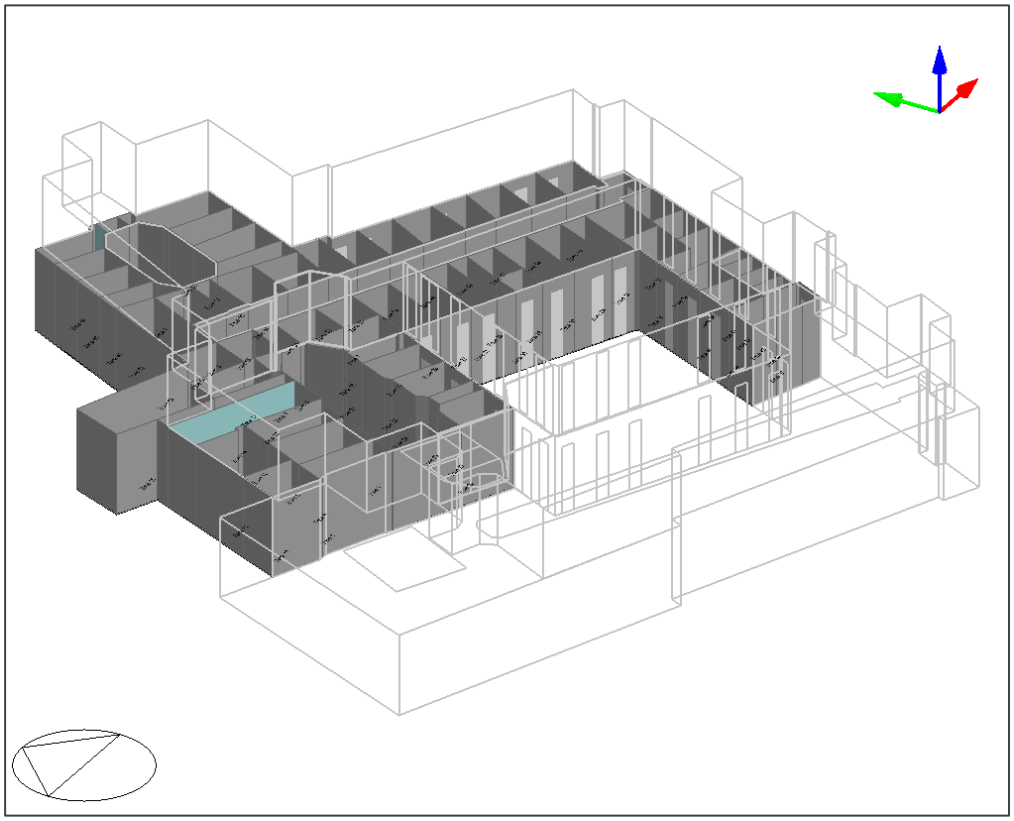
The floors are represented as distinct entities. Four distinct blocks were constructed in this modelling, which were then used to construct the primary layout of Nowzari Caravanserai.

Figure 22 (a) illustrates that Block 1 comprises a total of 55 zones. Every zone is meticulously crafted according to the initial AutoCAD blueprint of Nowzari Caravanserai.

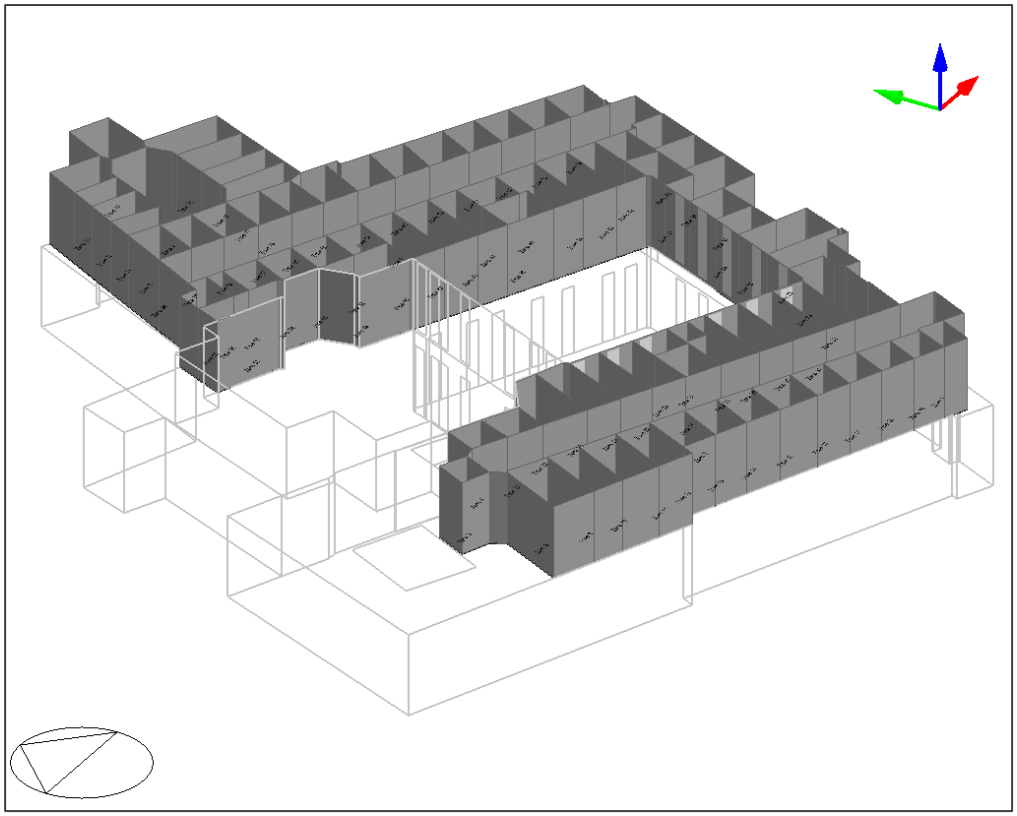
Figure 22 (b) displays Block 2, comprising a total of 64 zones. The graphic (c) also displays Block 3, which consists of 78 zones. The final image (d) displays block 4, which consists of 3 distinct zones.



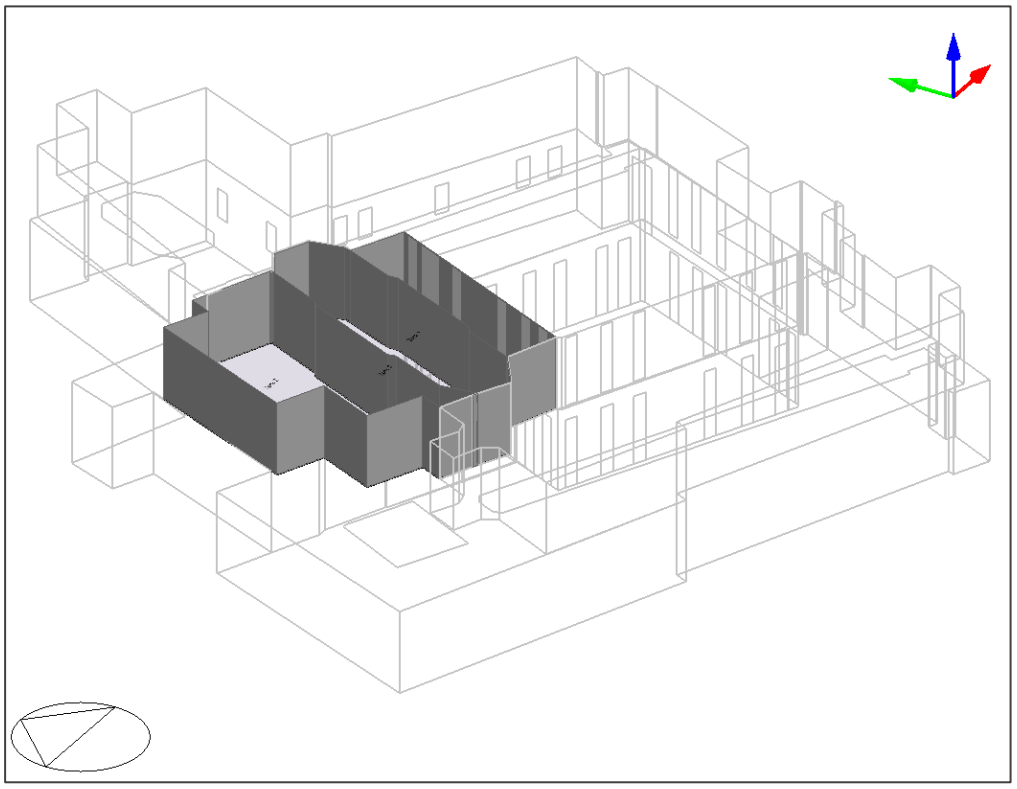
(a)



(b)



(c)



(d)

Figure 22: Nowzari Caravanserai floors modelled as separate blocks (a) Ground floor plan – block 1; (b) Ground floor plan – block 2; (c) First floor plan- block 3; (d) First floor plan- block 4

5.5.2. Dome Roof

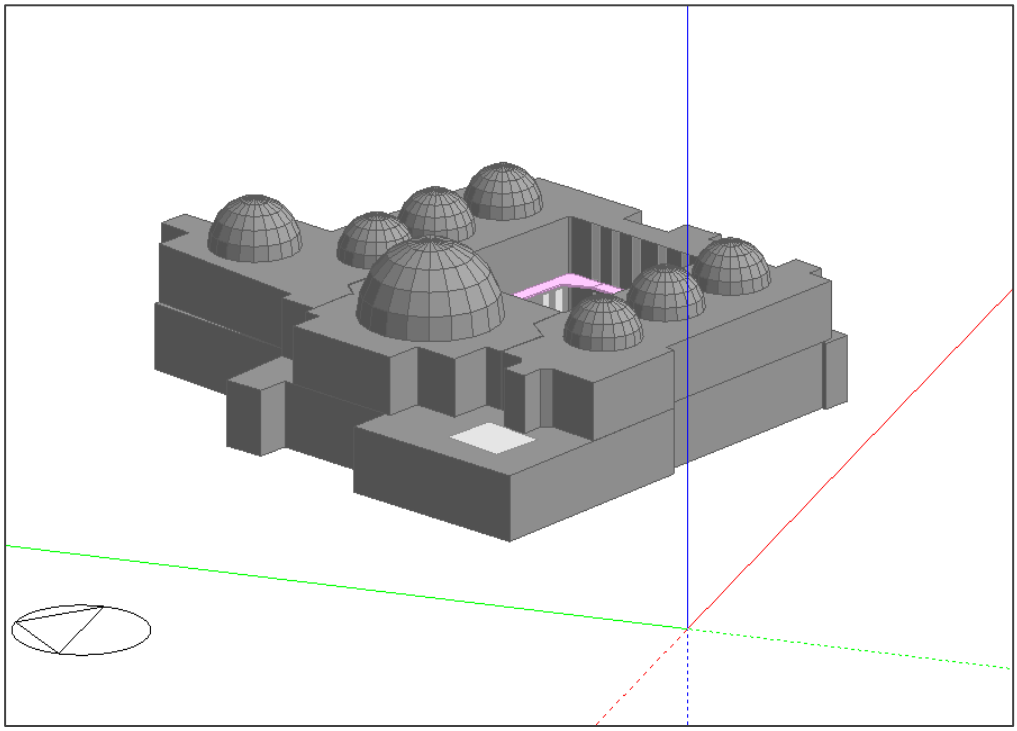
Three distinct sizes are used to model domes (Figure 23 a). For the dome roof, a total of 8 distinct blocks are created in the model (Additional details are provided in the annexes on page 39 - 41).

Block 5 is designated for the construction of the largest dome, which is highlighted in bold in Figure 23(b).

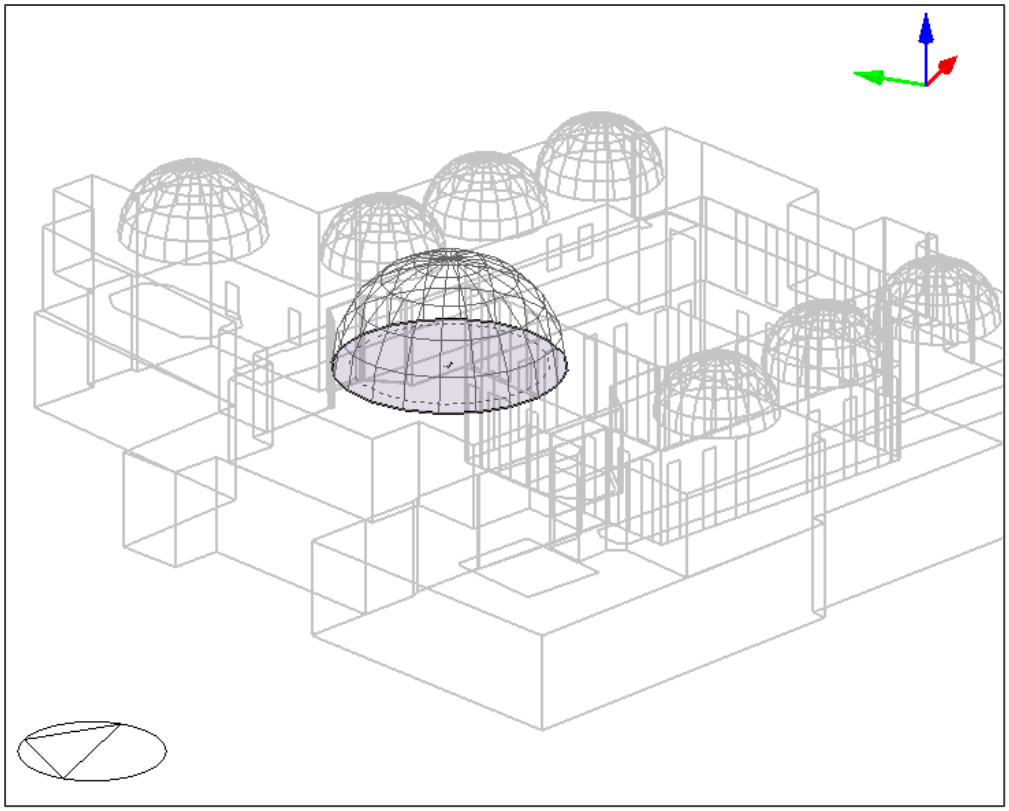
Block 6 is depicted in image (c) for the medium dome.

Blocks 7-12 are designated for small domes, with one dome highlighted in image (d).

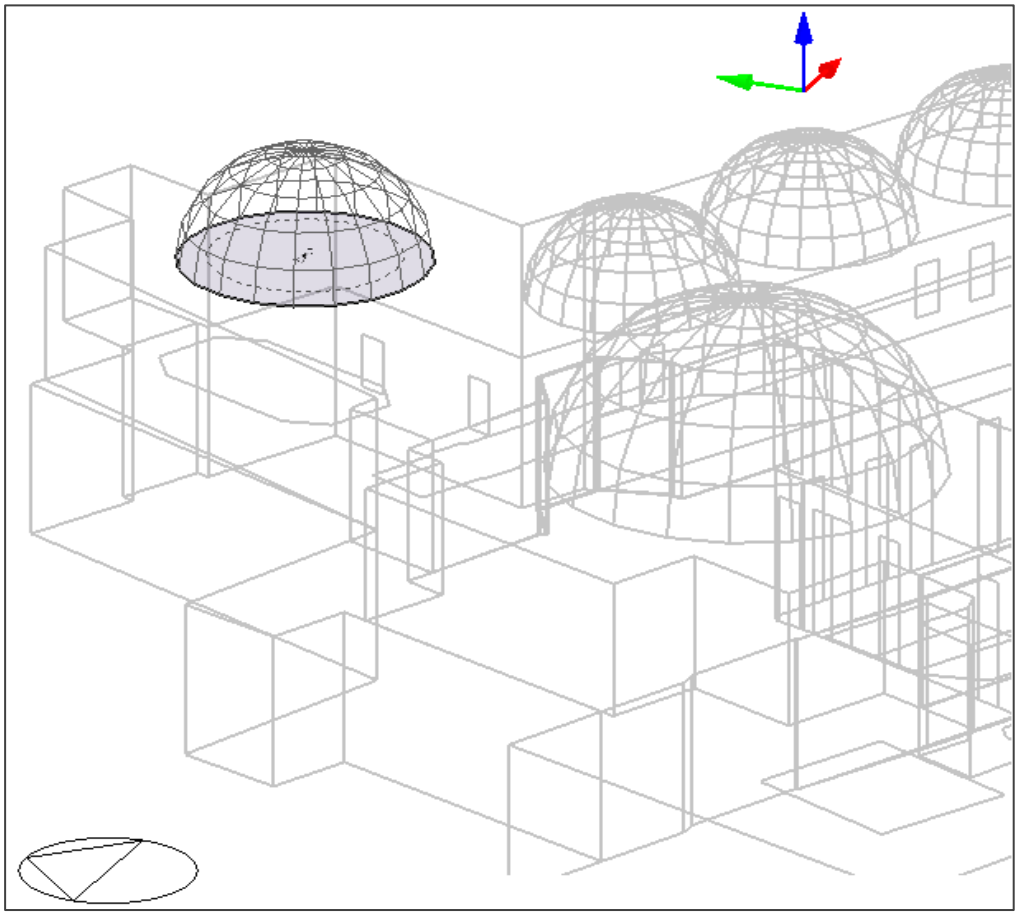
To access the specific information on each dome, please consult the annexes provided on the page 39 - 41.



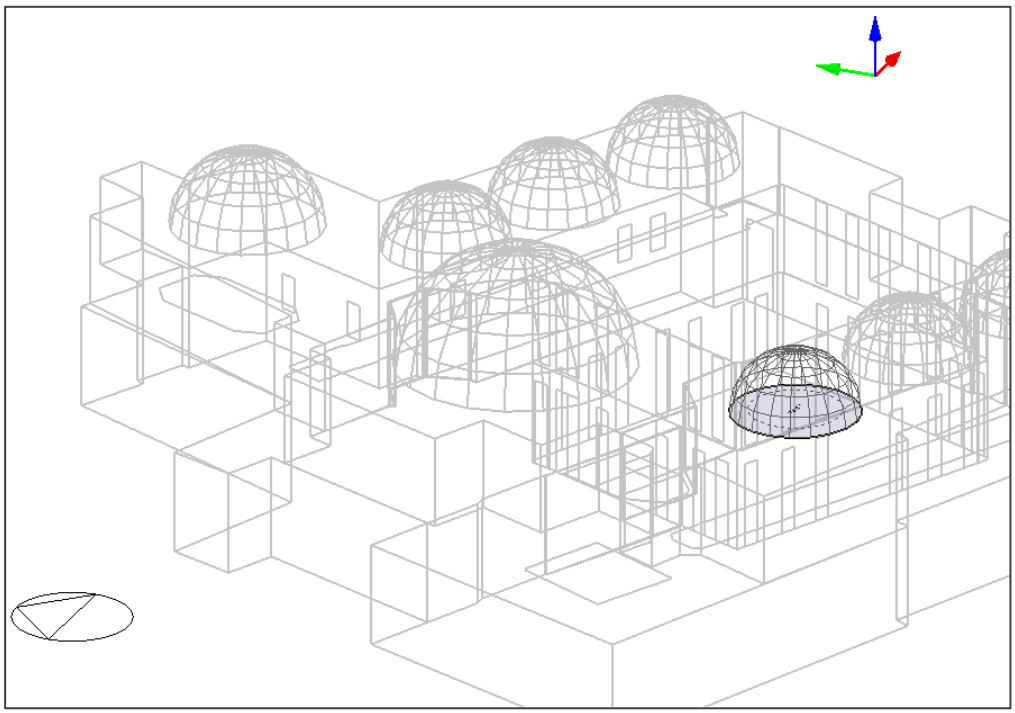
(a)



(b)



(c)



(d)

Figure 23: Three different sizes of simulated domes in Nowzari Caravanserai. (source: Design Builder software)

5.5.3. Flat Roof

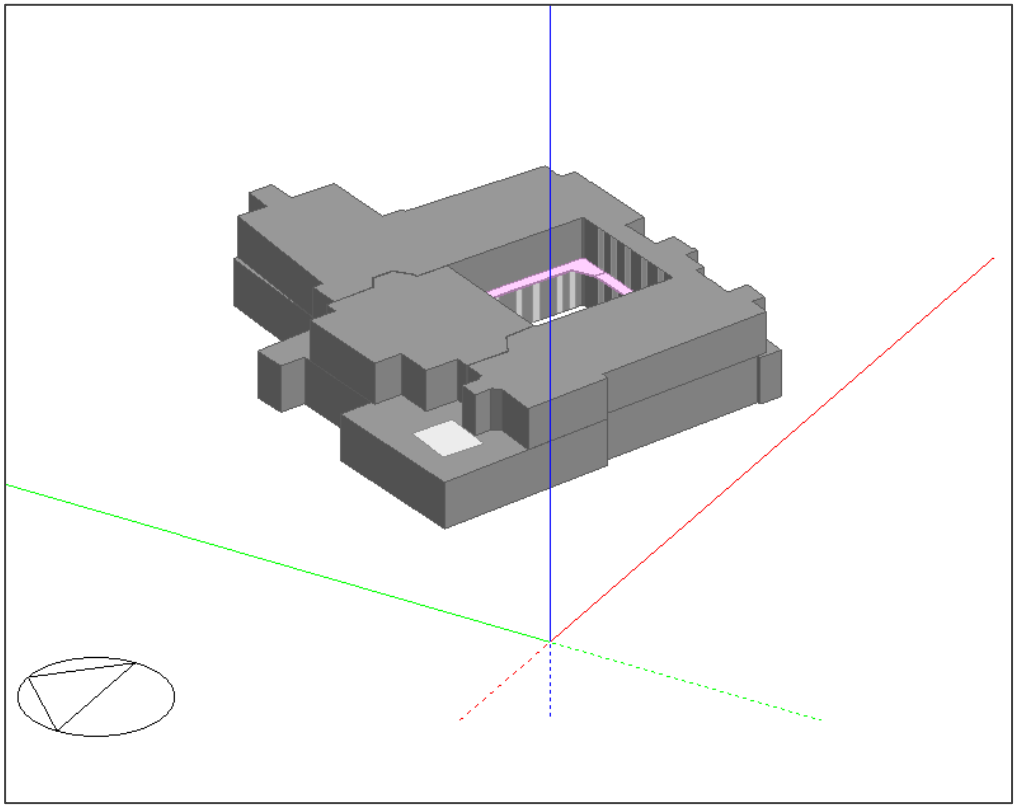


Figure 24: Simulation of Nowzari Caravanserai with flat roof. (source: Design Builder software)

5.5.4. Sloping Roof

Two roof components are defined for the modelling of the sloping roof (Figure 25).

The initial segment consists of 52 exterior divisions, each spanning an angle of 30 degrees.

The second component consists of 15 sections, each having an angle of 30 degrees.

(For further information, please refer to the annexes on page 42 & 43).

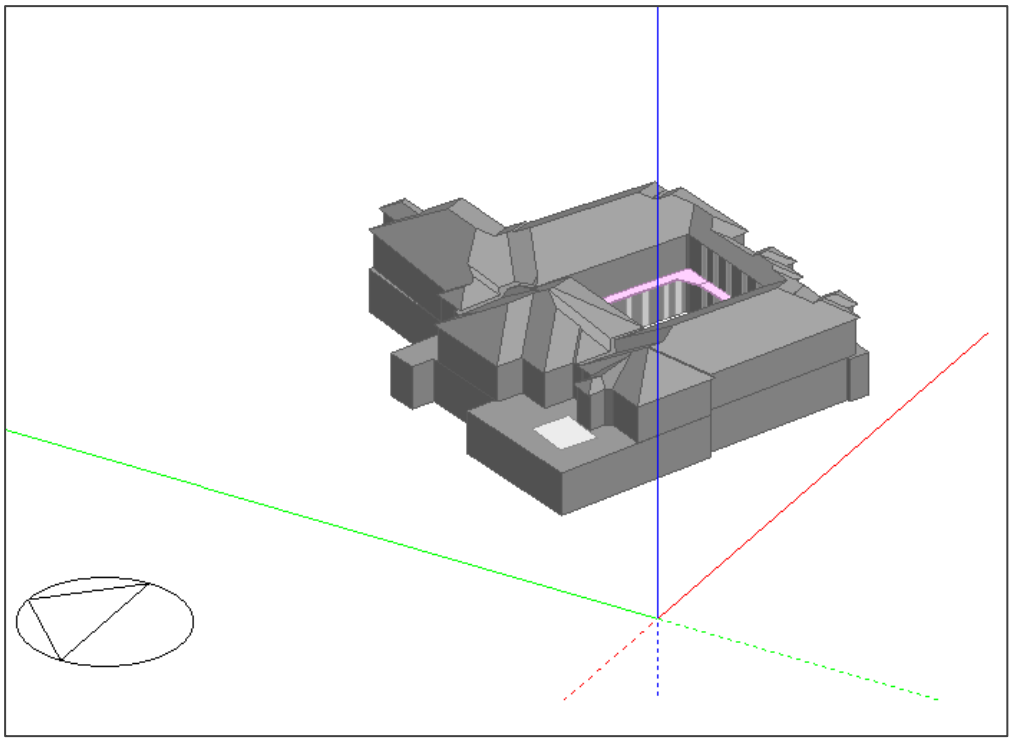
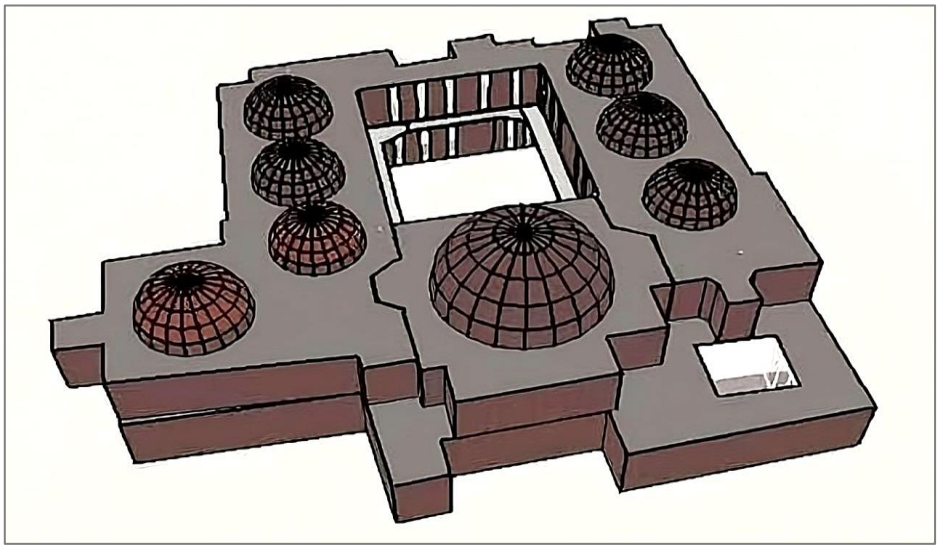
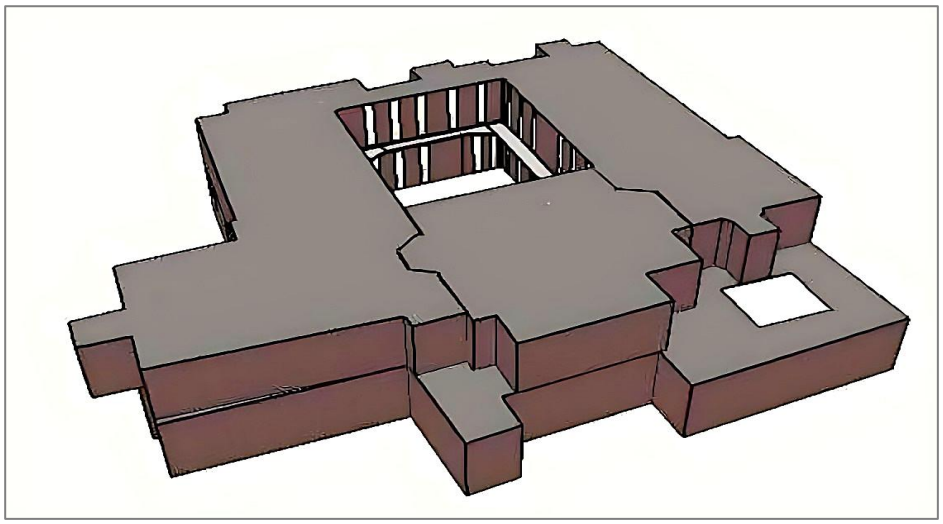


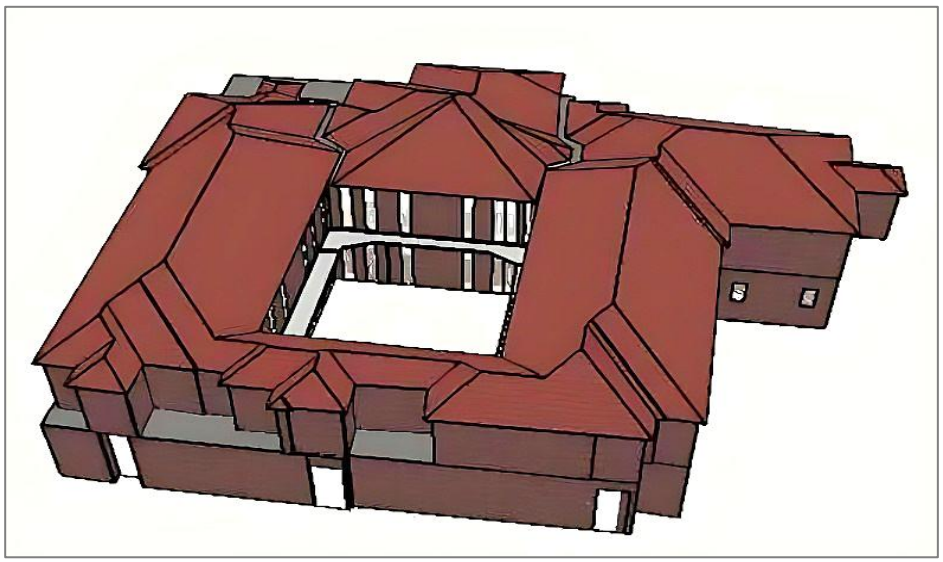
Figure 25: Simulation of Nowzari Caravanserai with sloping roof. (source: Design Builder software)



(a)

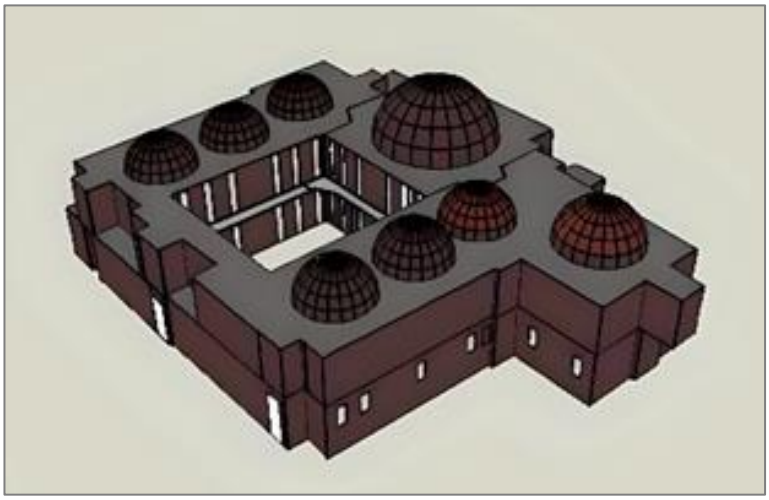


(b)

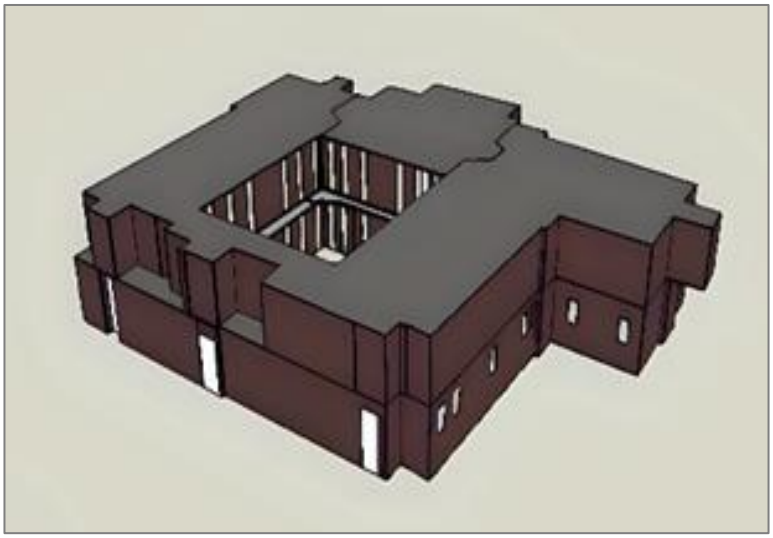


(c)

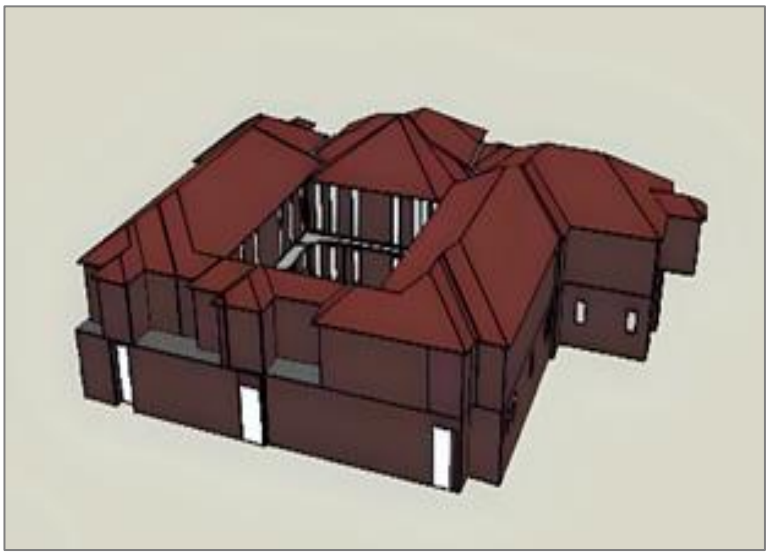
Figure 26: Simulation of Nowzari Caravanserai with 3 different roof models: (a) Dome roof (the original roof); (b) Flat roof; (c) Sloping roof. (source: Design Builder software)



(a)



(b)



(c)

Figure 27: Another view of the simulation of Nowzari Caravanserai located in Arak Bazaar. (a) Dome roof; (b) Flat roof; (c) Sloping roof. (source: Design Builder software)

6. Chapter 6

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Results and Analysis

6.1. Energy Analysis

In order to facilitate a meaningful comparison, it is necessary to first provide a summary of the aggregate simulated energy consumption for each category within every type of commercial structure for the given year.

A comparative analysis was conducted on the energy consumption of various types of roofs (For additional information, please consult Table 5). The annual energy consumption for heating (using gas) and cooling (using electricity) in a flat-roof structure were recorded as 189,649.95 kWh and 297,761.24 kWh, respectively. The aggregate energy usage of the flat-roof configuration over the course of a year amounted to 567,909.30 kWh.

On the contrary, the employment of a dome-roof structure resulted in reduced energy consumption. The recorded heating energy consumption was 171,525.12 kWh, while the cooling energy consumption was 271,874.11 kWh. As a result, the aggregate energy consumption of the dome-shaped roofing system was significantly lower, totaling 515,539.93 kWh on a yearly basis.

The energy consumption of the sloping roof structure was moderate. A total of 183,309.95 kWh was utilized for heating purposes, while 284,792.92 kWh was consumed for cooling purposes. The aggregate energy consumption of a slanted-roof configuration throughout the course of a year amounted to 540,243.57 kWh.

According to the data in Table 7, the percentage difference in total energy consumption between roof types during the coldest and warmest months was analyzed.

Table 7. Variations in simulated energy consumption (over the course of one year) of Nowzari Caravanserai with three distinct rooftops.

Date/Time	Flat Roof		Dome Roof		Sloping Roof	
	Heating (Gas)	Cooling (Electricity)	Heating (Gas)	Cooling (Electricity)	Heating (Gas)	Cooling (Electricity)
Month	kWh	kWh	kWh	kWh	kWh	kWh
Jan	60,147.94	277.65	54,214.44	219.52	57,595.19	270.97
Feb	31,765.94	771.80	28,614.64	576.78	30,499.19	648.96
Mar	17,657.38	2,254.17	15,978.21	2,045.48	16,742.15	2,181.43
Apr	5,451.338	8,130.32	5,152.36	8,003.49	5,383.95	8,098.80
May	1,425.13	23,978.4	1,370.03	22,415.59	1,400.37	23,161.36
Jun	0.0	40,649.91	0.0	37,432.63	0	38,801.34
Jul	0.0	61,990.3	0.0	56,717.68	0	59,805.05
Aug	0.0	54,601.4	0.0	49,798.81	0	52,211.26
Sep	1.45	34,317.98	0.95	31,352.17	1.10	33,159.65
Oct	2,048.21	13,820.44	1,998.19	12,761.63	2,025.54	13,182.91
Nov	23,408.87	1,000.92	21,407.21	852.08	22,795.53	978.36
Dec	45,140.59	573.38	40,989.13	377.12	41,367.28	466.39

The mathematical expression used to calculate the percentage difference between two values is:

Equation 2

$$Percentage\ Difference = (|X - Y| / ((X + Y)/2)) \times 100$$

The computations demonstrate the dissimilarity in energy usage across various architectural configurations, namely flat, dome, and sloping roofs, throughout the most frigid and sweltering periods of the year.

Highlighted by Table 8. during the month of December, the flat structure exhibits the greatest energy consumption, followed by the sloping roof and the dome, respectively. The flat type exhibits a notable dissimilarity from the other two variants, manifesting a higher energy-consumption rate of around 9.97% compared to the dome type and 8.95% in contrast to the sloping-roof type. Nonetheless, the energy usage of both the dome- and sloping-roof constructions exhibits a comparable pattern, with a marginal deviation of merely 0.97%.

Table 8. Variations in energy consumption (over the course of one year) of Nowzari Caravanserai with three distinct rooftops.

	Percentage Difference in December	Percentage Difference in July
Between Flat and Dome Roofs	9.97%	9.04%
Between Flat and Sloping Roofs	8.95%	4.26%
Between Dome and Sloping Roofs	0.97%	4.65%

During the month of July, which is typically characterized by high temperatures, it was observed that the flat structure consumed the highest amount of energy. However, the discrepancies in energy consumption between the various structures were comparatively smaller than those observed in the month of December. According to the data, the flat structure consumes 9.04% more energy compared to the dome, and a mere 4.26% more energy than the sloping roof. The energy consumption of the dome and the sloping roof exhibits a marginal variance of 4.65%.

Based on these findings, it can be deduced that:

The energy consumption of flat structures is higher for both heating and cooling, particularly during the coldest and hottest months, respectively. This implies that such structures may not be the optimal choice for extreme temperature conditions in terms of energy efficiency. This phenomenon may be attributed to various factors, such as an increased surface area that is subject to fluctuations in external temperature.

According to research, dome structures exhibit greater energy efficiency during colder months compared to flat- and sloping-roof structures, as they consume relatively lower amounts of energy. This phenomenon could potentially be attributed to the circular configuration of the object, resulting in a reduced surface area that is susceptible to colder temperatures and subsequently, a diminished amount of heat dissipation.

The structures with sloping roofs exhibit a commendable equilibrium in energy utilization under varying temperature conditions, consuming a lower quantum of energy than the flat structures but a marginally higher quantum of energy than the dome-shaped ones.

The data presented in Figure 28. indicate that:

During the month with the highest temperatures (July), the flat roof exhibits the highest electrical energy to provide cooling inside, while the dome roof displays the lowest energy usage. The electrical energy of the sloping-roof commercial structure is marginally higher than that of the dome roof, yet lower than that of the flat roof.

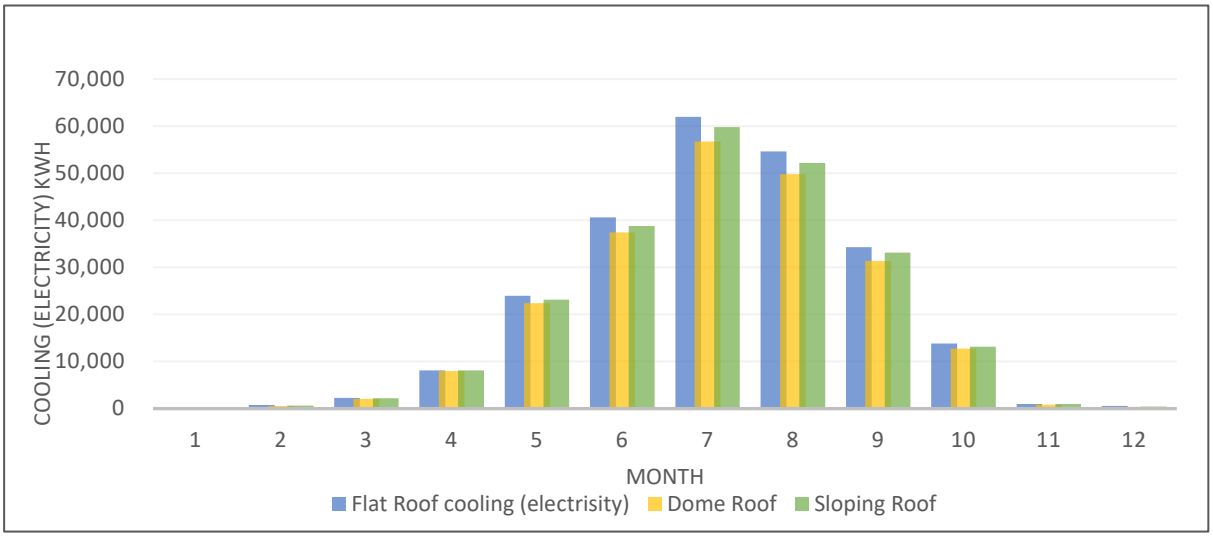


Figure 28: Comparison of electrical energy consumption for cooling purposes between two simulated roof models and the main dome-roof model of Nowzari Caravanserai during the hottest month of the year (July).

The Arak Bazaar's dome roofs feature ventilation holes. Using Design Builder software, two scenarios were analyzed: one with the presence of ventilation holes and one without. The study aimed to determine the amount of electrical energy consumption required for cooling and the amount of gas energy consumption required for heating in both scenarios. An analysis was conducted on the months of the year to gather additional insights into the impact of ventilation apertures on energy usage (As depicted in Figure 29.)

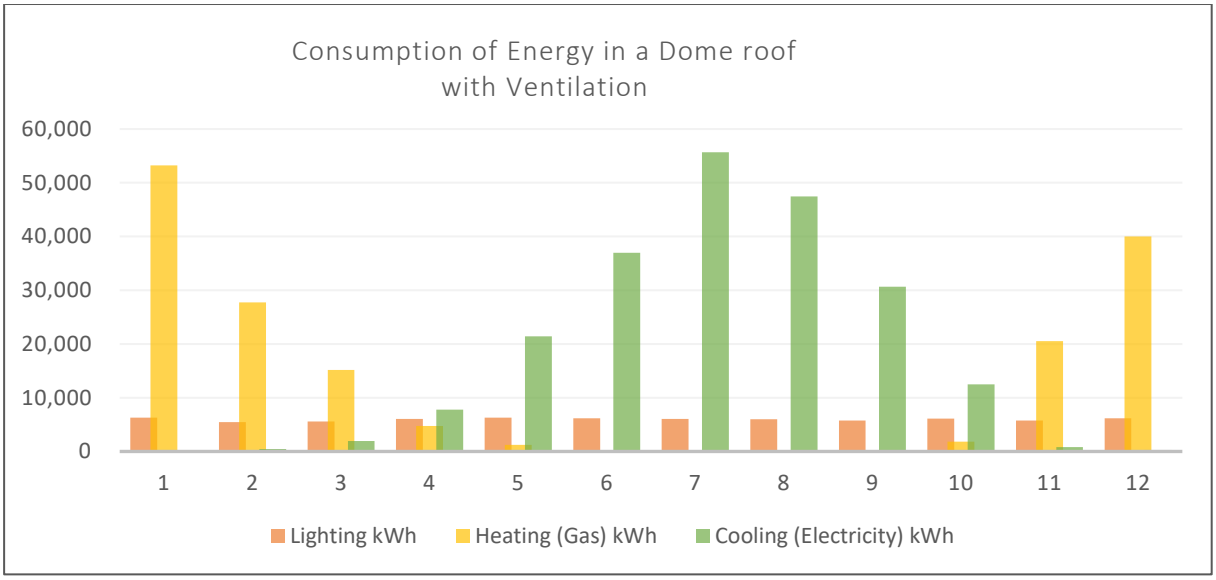


Figure 29: Diagram of consumption of energy in a dome roof with ventilation.

Upon comparing the data presented in Table 9. with those in Table 7., specifically in the domed-roof section, it is evident that the structure lacking ventilation exhibits higher energy consumption across all categories. The aforementioned statement suggests that the ventilation system within the edifice contributes to the mitigation of energy consumption by facilitating natural cooling and heating processes, thereby diminishing the necessity for artificial heating and cooling. (For more information about ventilation holes, refer to the annexes on page 45 & 46).

Table 9. Energy consumption (over the course of one year) of Nowzari Caravanserai with ventilation.

Date/Time	Heating (Gas)	Cooling (Electricity)
Month	**kWh**	**kWh**
Jan	53,260.5	239.74
Feb	27,724.76	479.99
Mar	15,192.91	1,943.61
Apr	4,728.50	7,786.68
May	1,205.98	21,437.55
Jun	0	36,991.23
Jul	0	55,685.85
Aug.	0	47,481.87
Sep	0.39	30,672.16
Oct	1,816.61	12,478.89
Nov	20,505.58	820.50
Dec	39,980.93	301.85

Upon analyzing the monthly data, discernible patterns can be observed.

In both configurations, the consumption of heating energy exhibits a peak during the colder months (January, February, November, and December) and diminishes to negligible levels during the warmer months (May through September).

The pattern of cooling energy consumption exhibits an inverse trend. The temperature exhibits a peak during the warmer months spanning from May to September and subsequently declines to a minimum during the colder months.

The energy usage for illumination appears to exhibit a degree of constancy over the course of the year in both edifices, with slight variations.

Typically, the energy consumption of a ventilated structure is lower than that of a non-ventilated structure.

6.2. Thermal Comfort

6.2.1. Weather of Arak city

The external weather information plays a crucial role in elucidating the internal temperature of spaces and determining the energy demand necessary to establish comfortable conditions. The climatic variables utilized in building-energy simulation, such as epw, wea, and TMY formats, are derived from meteorological station data and are employed while taking into account the environmental conditions surrounding the analyzed structure. The present study obtained weather data from the meteorological organization of Arak City, encompassing the average temperature, as well as the maximum and minimum temperatures, for the past decade. This information was subsequently utilized as input for the software, representing the weather conditions of the region.

The subsequent sections will present a series of diagrams that contain extensive meteorological information for Arak city. These diagrams are organized by month and cover the full year. These charts provide a visual representation of three important

meteorological factors: monthly air temperature, cumulative monthly rainfall, and average wind speed for each month. The data on the "Monthly Air Temperature" is clearly presented, supplying valuable information on the average, maximum, and minimum temperatures for each month. This data provides a view into the prevailing thermal conditions. The section titled "Monthly Rainfall" provides information on the cumulative amount of precipitation received in each month, providing insights into the occurrence of rainy and dry periods in the city. Finally, the part titled 'Wind Speed' presents the mean wind speeds, providing insight into the prevailing wind patterns. Collectively, these graphical representations intricately depict the climatic patterns and meteorological intricacies of Arak city, facilitating a full comprehension and facilitating a comparative analysis of the diverse weather variables throughout different months.

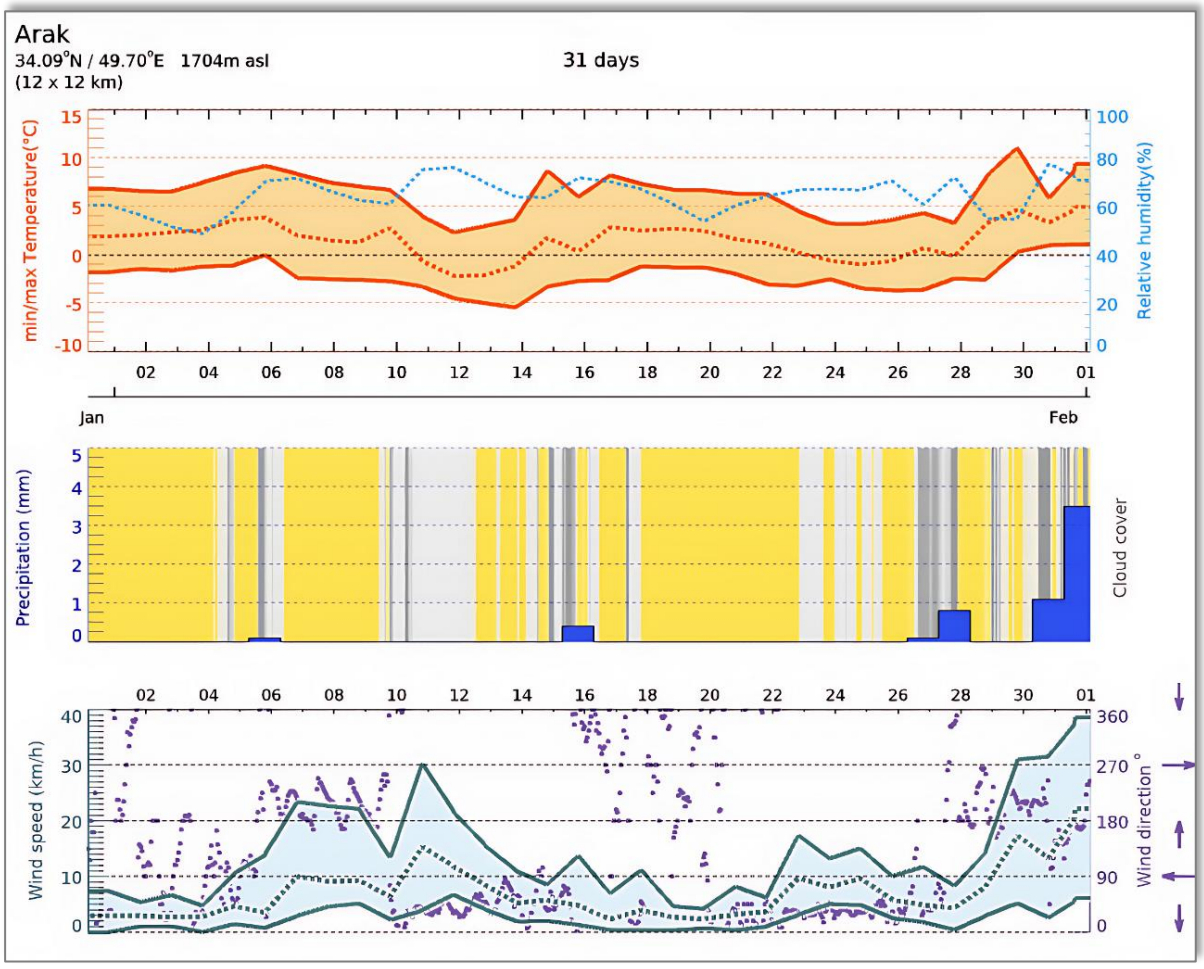


Figure 30: Diagram of air temperature, precipitation & wind speed in January

In the month of January in Arak:

The air temperature exhibits a range of variation spanning from around -10°C to 15°C, with the lowest temperatures occurring in the early days of the month and the warmer temperatures observed towards the middle of the month.

The occurrence of precipitation is irregular throughout the month, with significant rainfall events observed on around the 10th, 20th, and 28th days.

The velocity of wind exhibits fluctuations, reaching its maximum value of approximately 40 km/h towards the eighth day, while maintaining an average range of 10 to 20 km/h for the majority of the month.

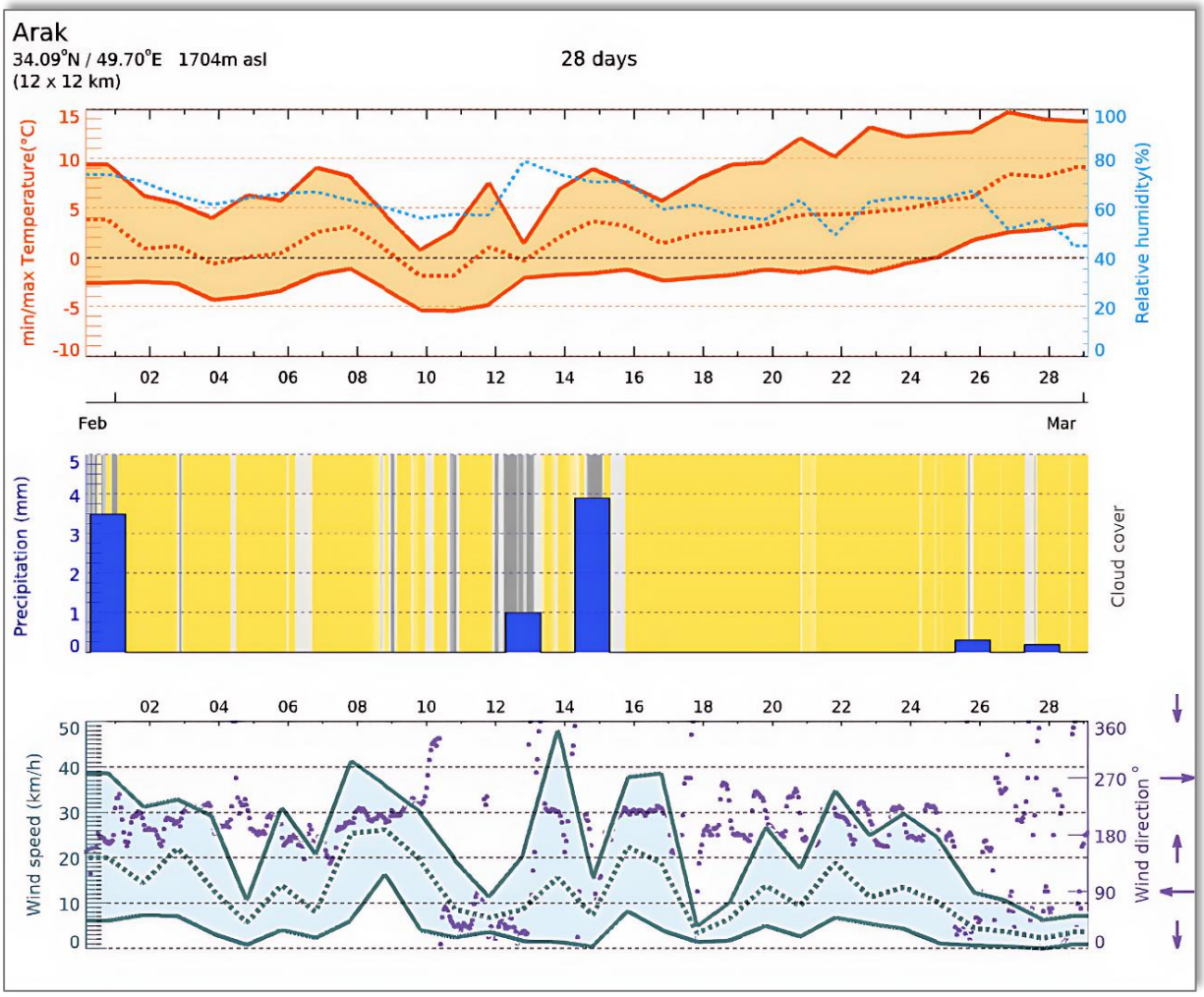


Figure 31: Diagram of air temperature, precipitation & wind speed in February

In the context of Arak, the month of February is of particular interest.

The air temperature normally exhibits a range of approximately -5°C to 15°C, with a discernible pattern of gradual warming as the month progresses.

The occurrence of precipitation is characterized by substantial rainfall at the commencement and conclusion of the month, accompanied by sporadic episodes of lighter rain in the between period.

The velocity of wind displays a dynamic pattern, characterized by intermittent surges of approximately 50 km/h around day 8, and sustained mean values ranging from 10 to 30 km/h over the course of the month.

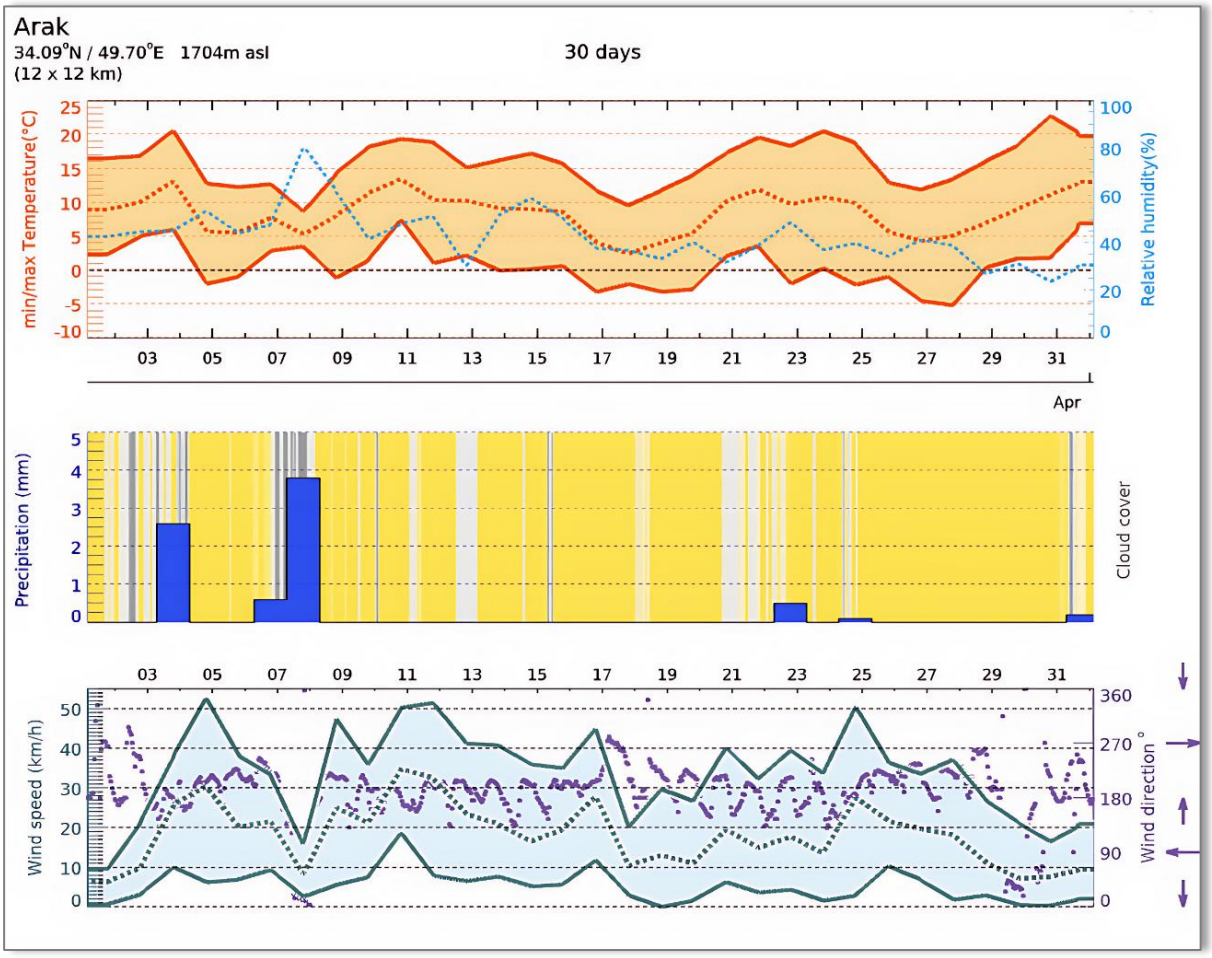


Figure 32: Diagram of air temperature, precipitation & wind speed in March

In the month of March in Arak:

The air temperature exhibits a cyclic pattern, fluctuating within a range of around -5°C to 25°C. Notably, there is a distinct cooling phase that occurs around the middle of the month, which is then followed by a period of warmth.

The occurrence of precipitation is characterized by substantial rainfall during the initial part of the month, followed by less intense and more sporadic rain events over the remaining days.

The velocity of the wind exhibits variability, characterized by a prominent maximum approaching 50 km/h on around the ninth day, followed by a consistent range of 10 to 30 km/h for the remainder of the month.

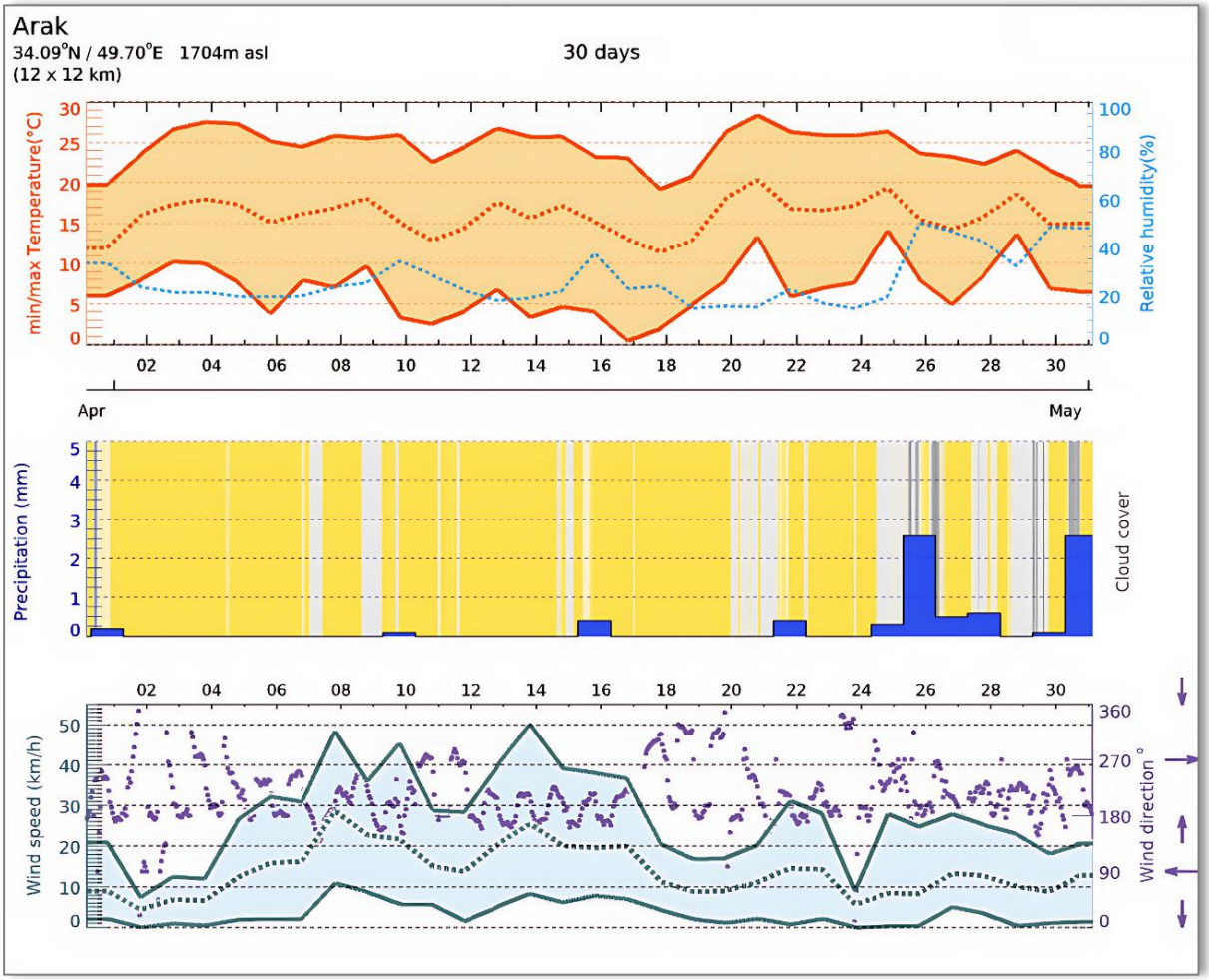


Figure 33: Diagram of air temperature, precipitation & wind speed in April

In the context of Arak, the month of April holds significance.

The air temperature exhibits a range of approximately 10°C to little below 30°C. The overall pattern implies warming as the month proceeds.

The month exhibits a relatively low level of precipitation, characterized by intermittent occurrences of small rainfall, particularly observed at the beginning and end of the month.

The velocity of wind exhibits variability, occasionally surging to nearly 40 km/h. Throughout the majority of the month, the velocity of the wind typically ranges from 10 to 20 kilometres per hour.

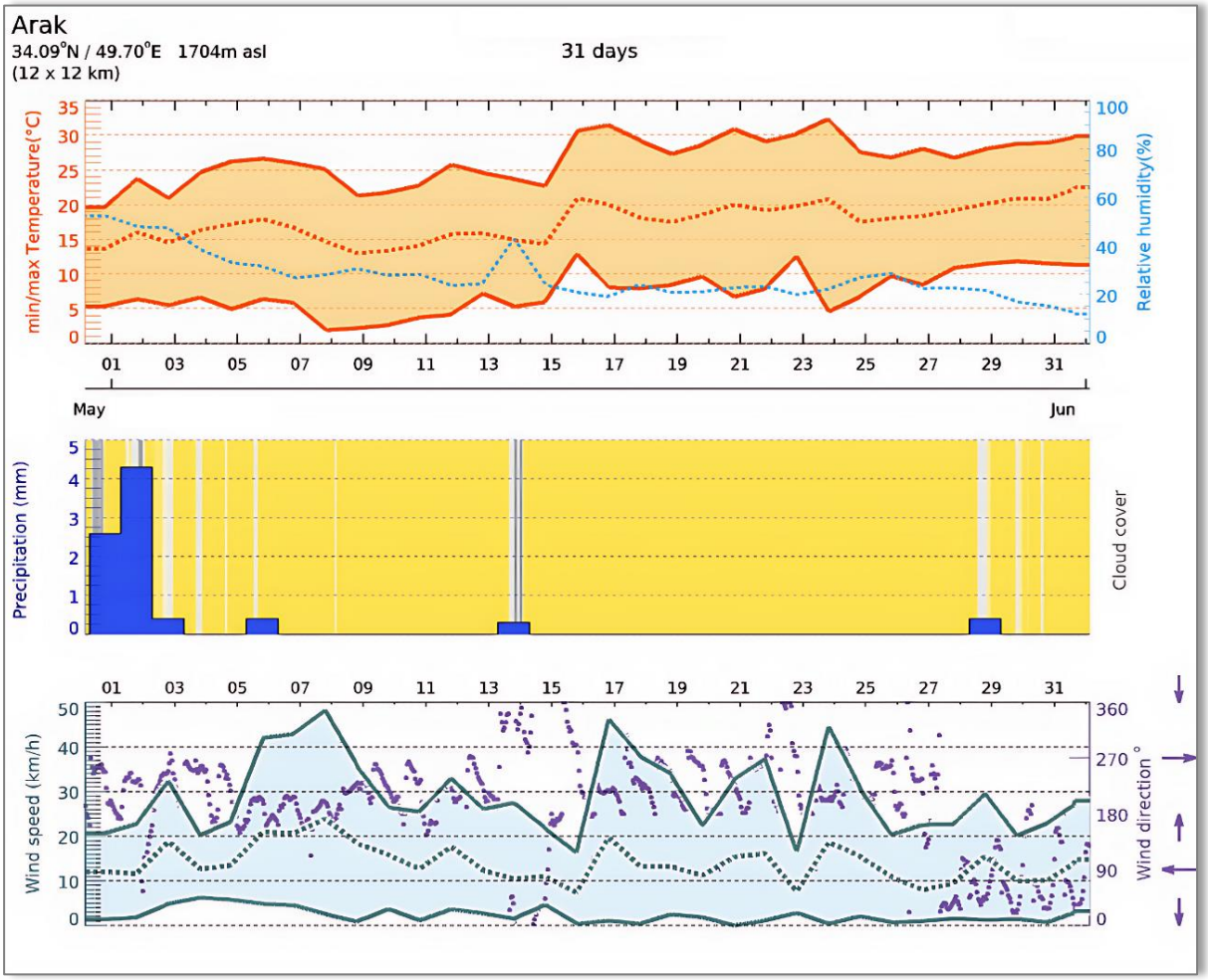


Figure 34: Diagram of air temperature, precipitation & wind speed in May

In the month of May in the city of Arak:

The ambient temperature typically spans from approximately 15°C to slightly above 30°C. The temperatures exhibit a pattern of reaching their highest point in the middle of the month, followed by a period of stabilization towards the end.

Precipitation occurrences during the observed period were infrequent, characterized by substantial rainfall towards the onset of the month and minor rainfall towards the conclusion.

The wind speed exhibits variability during the course of the month. The velocities primarily vary from 10 km/h to slightly over 30 km/h, with sporadic surges in wind intensity, notably during the middle of the month. The humidity levels exhibit a pattern of high relative humidity at the onset of the month, which is likely associated with the occurrence of precipitation. Subsequently, there is a gradual decline in relative humidity throughout the month, with the lowest levels observed towards the conclusion of the month.

Cloud Cover: Throughout the month, the prevailing weather conditions are characterized by predominantly clear skies and minimal cloud cover. However, towards the latter part of the month, there is a noticeable increase in cloudiness, which coincides with a light rain event.

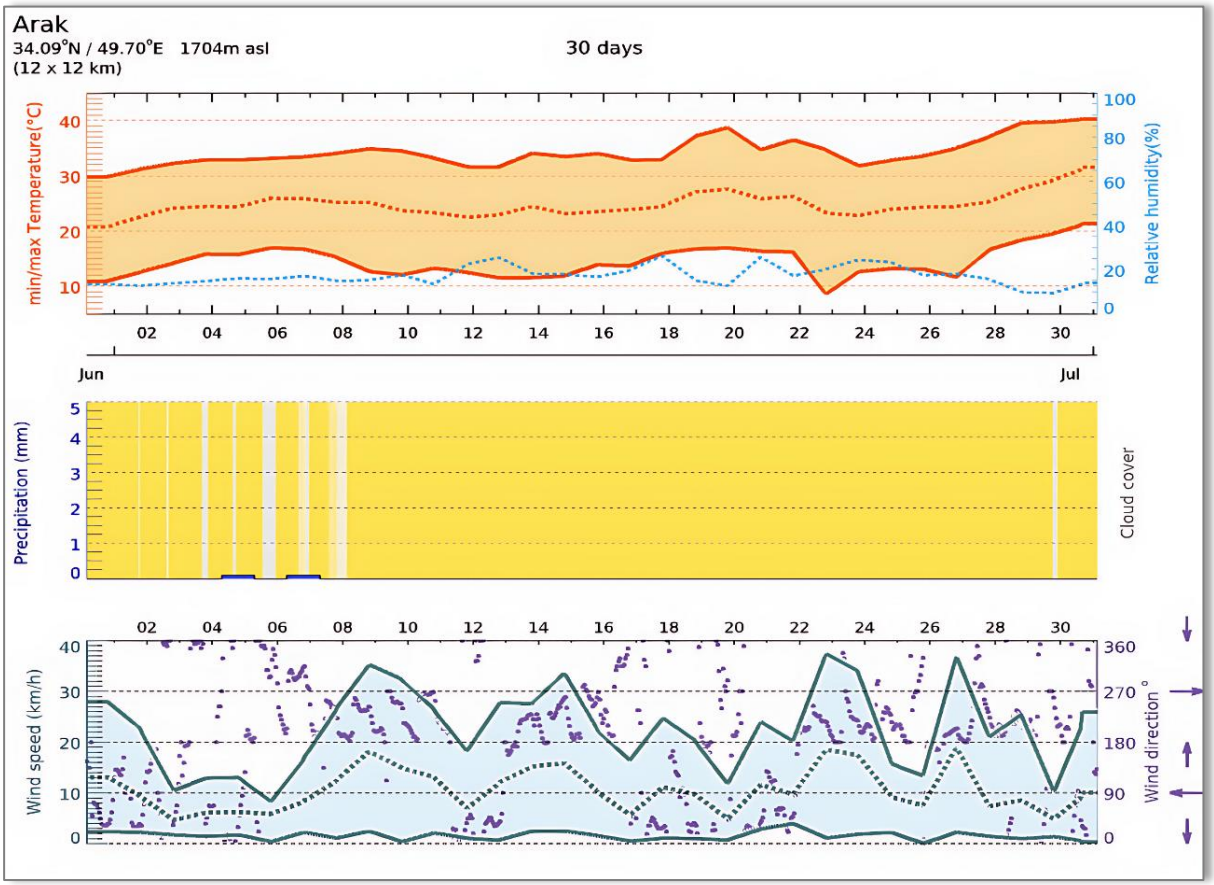


Figure 35: Diagram of air temperature, precipitation & wind speed in June

In the month of June in the city of Arak:

The temperature exhibits a gradual climb throughout the month, commencing at approximately 20°C and gradually rising to nearly 40°C. The minimum temperature exhibits a reasonably stable pattern, remaining close to 20°C during the most of the month.

Precipitation: The occurrence of rainfall is infrequent. There were a few instances of light precipitation occurring at the onset and midpoint of the month.

The wind speed exhibits considerable variability over the course of the month. The velocities predominantly span between 10 km/h to 30 km/h. Multiple spikes are observed, indicating transient intervals of elevated wind velocities.

Humidity: The relative humidity has an initial greater value at the onset of the month, followed by a slow decline, ultimately reaching a relatively low level by the conclusion of June. Cloud Cover: The atmospheric conditions throughout the observed period are characterized by a predominance of clear skies, with minor presence of clouds.

In general, the month of June in Arak is characterized by warm temperatures, clear skies, and limited precipitation. The velocity of wind exhibits variability, although it generally remains below 30 km/h for the majority of instances.

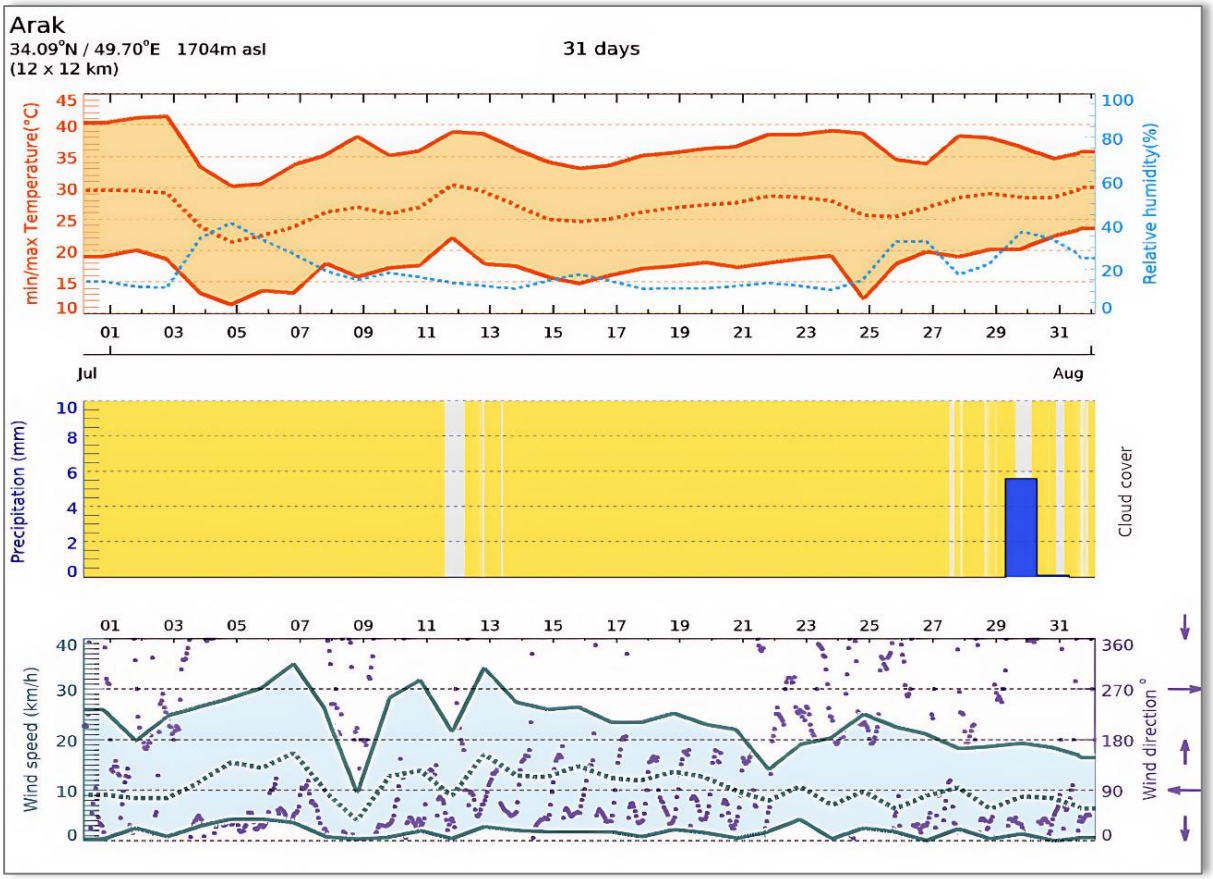


Figure 36: Diagram of air temperature, precipitation & wind speed in July

In the month of July in the city of Arak:

Temperature: The data suggests that there is a consistent level of stability in temperatures over the course of the month. The maximum temperatures exhibit a range of roughly 35°C to 45°C, while the minimum temperatures consistently hover around the 20°C threshold, with a minor decline observed during the midpoint of the month.

Precipitation: The amount of rainfall is relatively low. There are intermittent occurrences of precipitation during the mid-month period.

The phenomenon of wind speed displays a diverse range of patterns. Throughout the majority of the month, the velocity of the subject remains confined within the interval of 10 km/h to 30 km/h. There are multiple spikes suggesting brief periods of increased wind velocity.

Humidity levels demonstrate an initial increase in percentage during the onset of July, followed by a subsequent downward trajectory. The value of the variable decreases to its minimum point as the month approaches its conclusion.

The cloud cover exhibits a pattern of greater values at the commencement and conclusion of the month, with somewhat clearer conditions prevailing during the middle period.

To summarize, the month of July in Arak is distinguished by elevated temperatures, limited precipitation, unpredictable wind velocities, and varying degrees of humidity and cloudiness. Based on the available data, it can be observed that the midpoint of the month exhibits a notable trend of being characterized by lower levels of precipitation and enhanced atmospheric clarity.

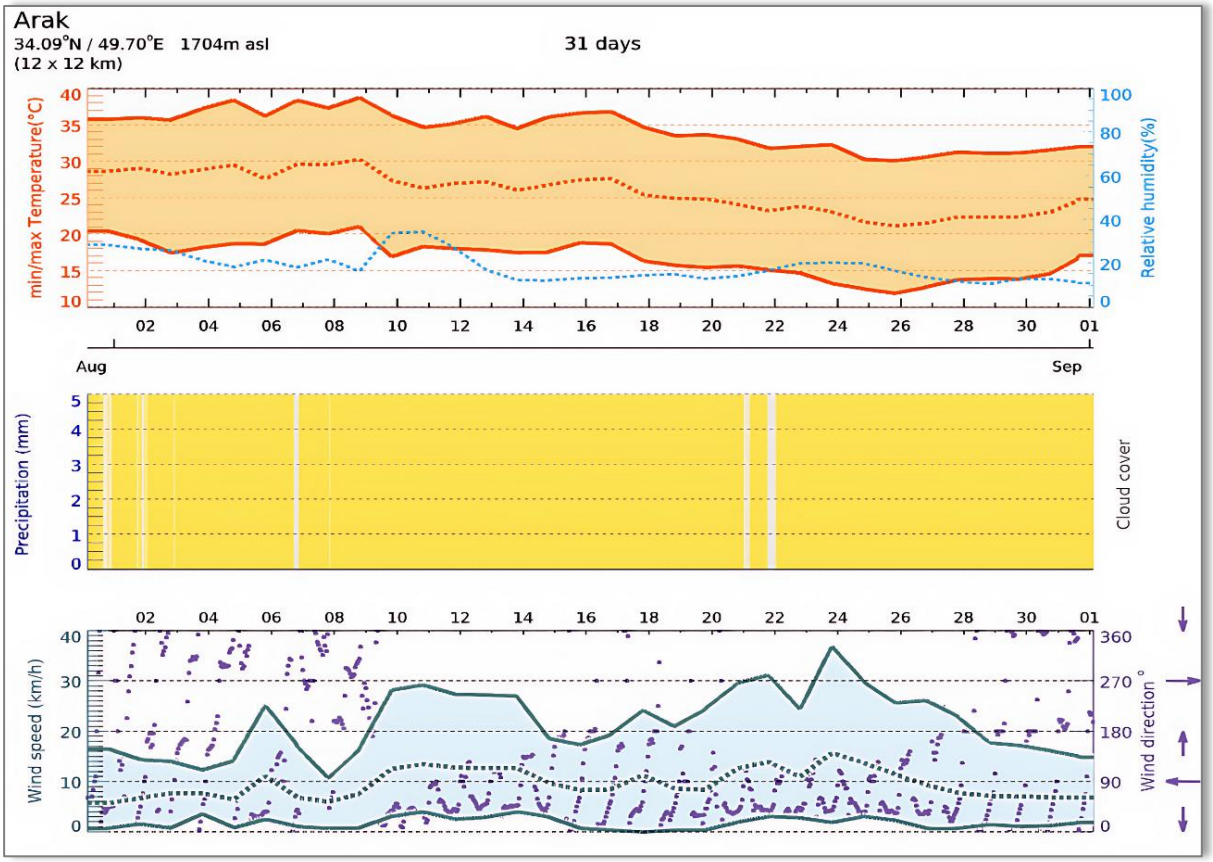


Figure 37: Diagram of air temperature, precipitation & wind speed in August

In the month of August in the city of Arak:

The month commences with relatively lower temperatures, which gradually rise as it progresses. The maximum temperatures exhibit a range spanning from 30°C to slightly

exceeding 35°C. The minimum temperatures consistently hover around the 20°C threshold, occasionally seeing slight decreases below this value.

Precipitation: The month of August exhibits a notable lack of rainfall, with minimal precipitation observed.

The velocity of wind exhibits variability, with the majority of days witnessing wind speeds that span from 10 km/h to 20 km/h. There is a discernible increase observed on the 25th day of each month, during which the velocity attains a maximum value of approximately 35 kilometres per hour.

Humidity: The observed levels of humidity exhibit temporal variability over the course of the month, however consistently fall within the range of 40% to 80%. There is a little upward trend observed in the latter part of the month.

Cloud Cover: The majority of the month enjoys low cloud cover, signifying clear skies. Nevertheless, there exists a temporal interval characterized by heightened cloud cover spanning from the 20th to the 27th.

In summary, the month of August in Arak typically experiences mild temperatures, predominantly clear atmospheric conditions, minimal precipitation, and fluctuating wind velocities. Towards the conclusion of the month, there is a marginal elevation in both humidity levels and cloud coverage.

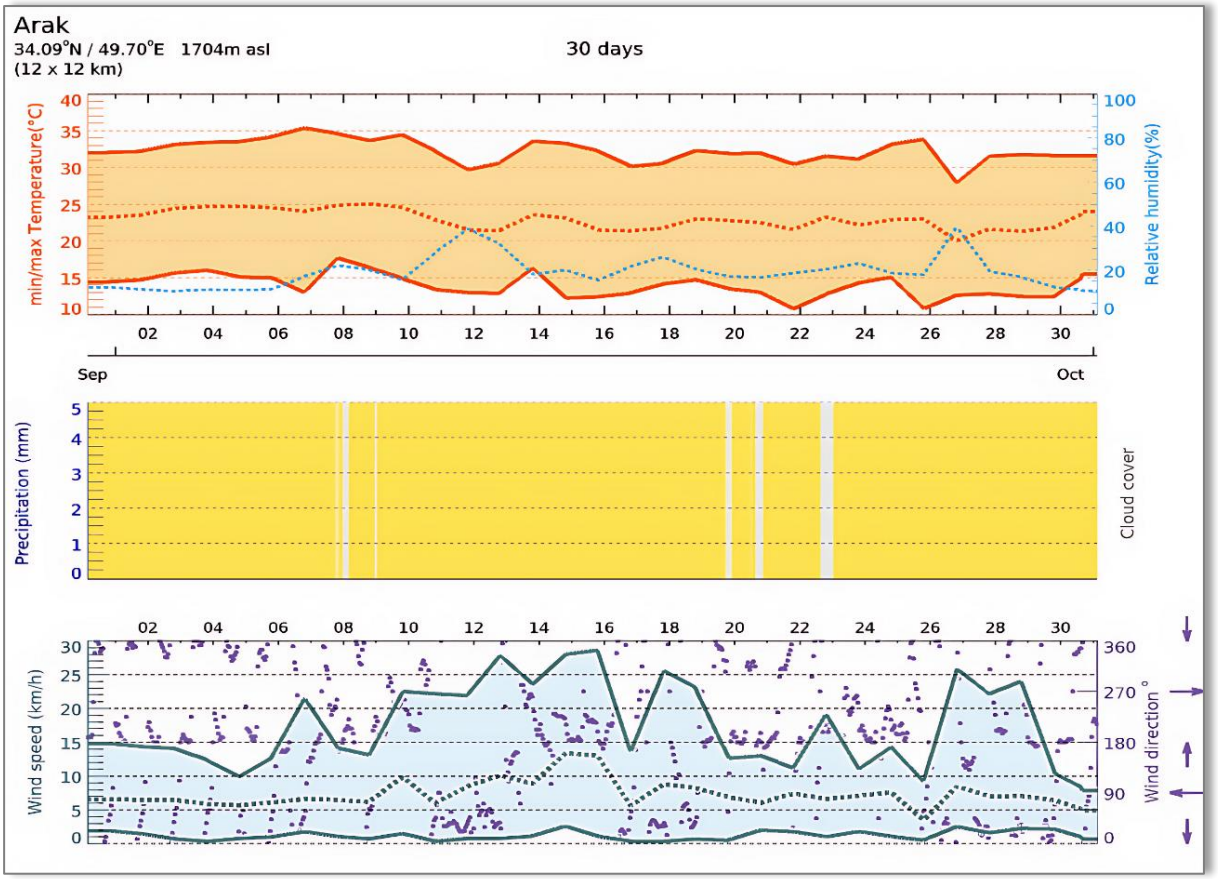


Figure 38: Diagram of air temperature, precipitation & wind speed in September

In the month of September, specifically in the city of Arak:

The temperature exhibits a progressive decline over the course of the month. The maximum temperatures exhibit a gradual decline from just above 35°C to slightly below 30°C during the course of the month. At the onset of September, the minimum temperatures exhibit a range of the mid-20s, gradually declining to approximately 10°C as the month progresses.

The month exhibits a very arid climate, with a subtle indication of precipitation occurring between the 8th and 12th.

The wind speeds in September exhibit variability, although demonstrate a notable apex around the 10th, attaining velocities of up to 30 km/h. Following the culmination, wind velocities often remain under 20 km/h.

Humidity levels exhibit a rather stable range of 40% to 60%. In the latter part of the month, a notable decrease is observed, with figures dropping to approximately 20%.

Cloud Cover: At the beginning of the month, the weather conditions are characterized by clear sky. However, from the 16th to the 24th, there is a noticeable increase in cloud cover, which could potentially be associated with the lower temperatures seen during that time.

In brief, the month of September in Arak is distinguished by a progressive decline in temperatures, limited precipitation, fluctuating wind velocities with a notable peak in the initial days of the month, and heightened cloud cover during the middle period. Towards the conclusion of the month, there is a discernible decrease in levels of atmospheric moisture.

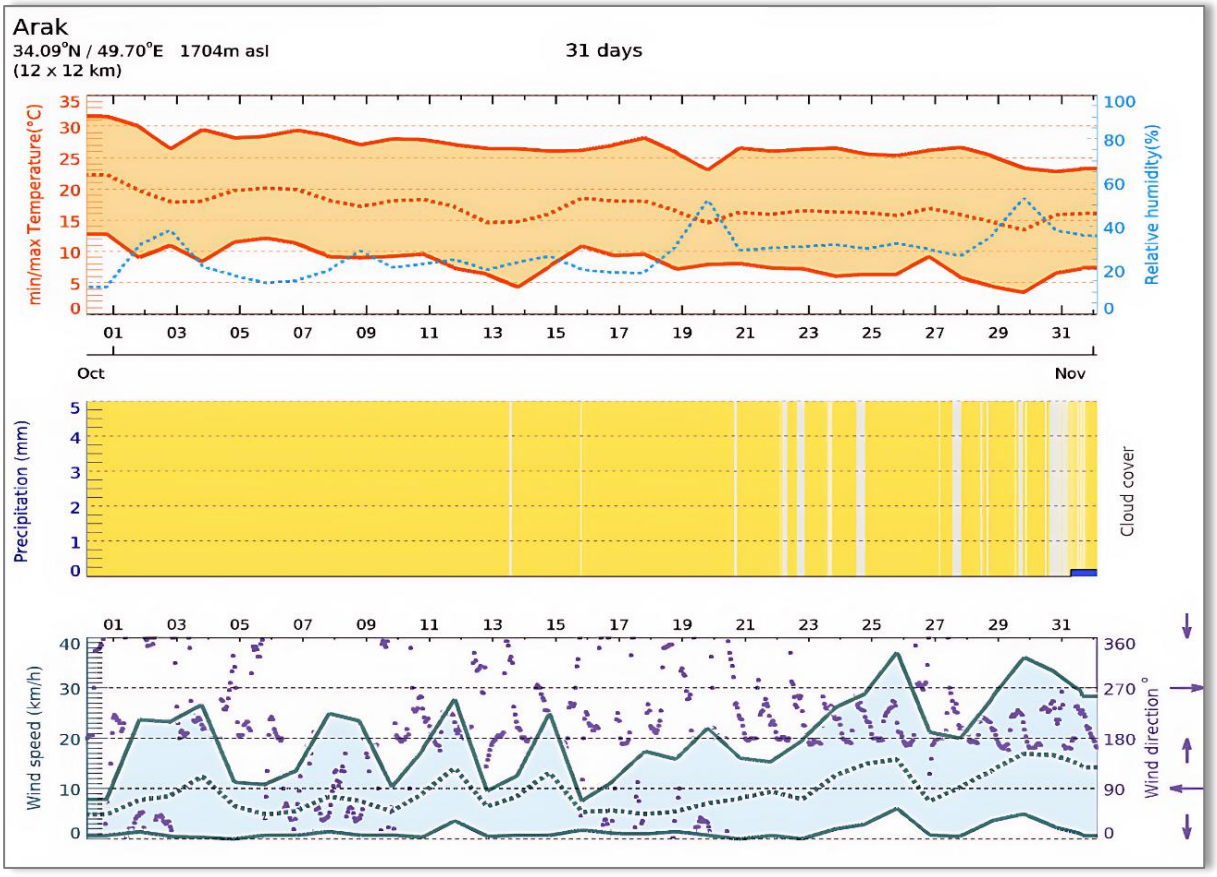


Figure 39: Diagram of air temperature, precipitation & wind speed in October

In the month of October in the city of Arak:

The temperatures exhibit a consistent decline over the course of the month. The maximum temperatures commence slightly below 30°C and progressively decrease to

levels below 25°C. The minimum temperatures commence at a somewhat higher value than 10°C and gradually decline to stabilize at approximately 5°C towards the conclusion of the month.

Precipitation: The month of October exhibits a prevailing pattern of aridity, since there is an absence of noteworthy rainfall measurements.

The velocity of wind exhibits variations over the course of the month, characterized by multiple instances of heightened intensity. It is worth mentioning that wind speeds reach or surpass 30 km/h, particularly on the 9th and 29th. Intermittent intervals of reduced wind velocity can be observed amidst the aforementioned peaks, particularly in the vicinity of the midpoint of the month.

Humidity: The levels of relative humidity often fall between the range of 40% to 60%. Nevertheless, there is a significant decline observed in the latter part of the month, wherein the humidity levels plummet to less than 20%.

Cloud Cover: The majority of the month experiences predominantly clear skies, characterized by minimal to negligible cloud cover, with the exception of the final few days. Commencing around on the 29th, a notable surge in cloud cover becomes evident.

In brief, the month of October in Arak is characterized by a decrease in temperatures, limited precipitation, and variable wind velocities including notable fluctuations. Throughout the bulk of the month, the prevailing weather conditions are characterized by bright sky. However, as the month progresses towards November, there is a discernible rise in cloud cover. Towards the conclusion of the month, there is a notable decrease in the levels of humidity.

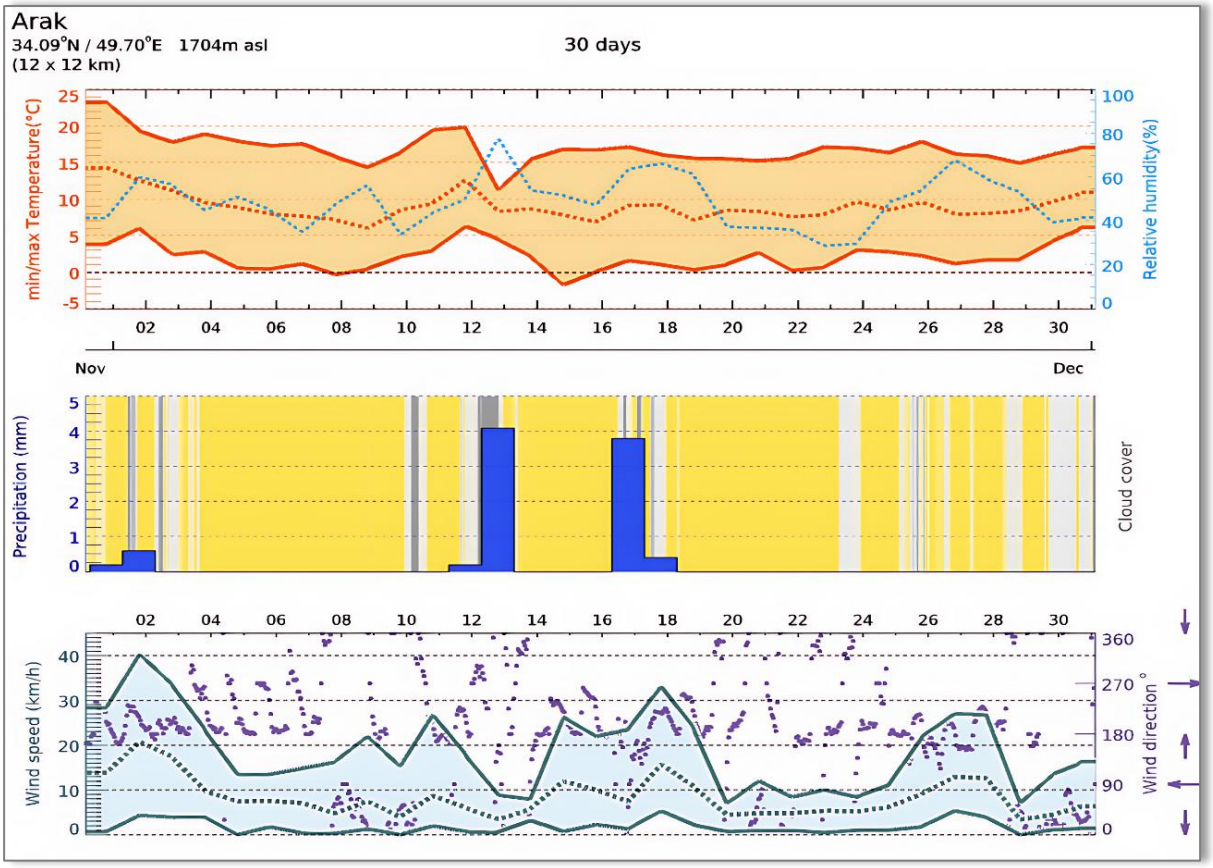


Figure 40: Diagram of air temperature, precipitation & wind speed in November

In the month of November in the city of Arak:

Temperature: In the month of November, there is a continued decrease in temperatures. The maximum temperatures exhibit a fluctuating pattern, hovering around the mid-20s°C at the onset of the month, followed by a gradual decline down below 15°C as the month progresses. Minimum temperatures start slightly over 0°C and continue a falling trend, going below 0°C in the later half of the month.

Precipitation: November experiences multiple instances of rainfall. It is worth mentioning that there is a notable occurrence of substantial precipitation on about the 1st, 15th, and 29th days of the month, with the rainfall on the 29th being the most intense.

The wind speed in November exhibits fluctuations, with a notable maximum occurring around the 6th, where it attains a value of 40 km/h. During the remaining duration of the month, there is a tendency towards moderately paced wind speeds, occasionally exhibiting minor variations.

Humidity levels in November typically exhibit a range of 60% to 80% in terms of relative humidity. Nevertheless, there is a noticeable decline in humidity levels between the 22nd and 24th, with a corresponding decrease to approximately 40%.

Cloud Cover: The initial portion of November is distinguished by intermittent occurrences of both clear and overcast days. During the latter portion of the observed period, specifically starting from the 15th onwards, there is a discernible and continuous upward trend in the extent of cloud cover.

To summarize, the month of November in Arak has a notable decline in temperatures, occasionally dropping below the freezing threshold. The frequency of rainfall increases, particularly in the latter part of the month. The wind speeds exhibit a degree of fluctuation, characterized by a distinct peak during the initial phase of the month. The humidity levels persist at a reasonably elevated state, occasionally experiencing temporary decreases, while the extent of cloud cover intensifies as the month advances.

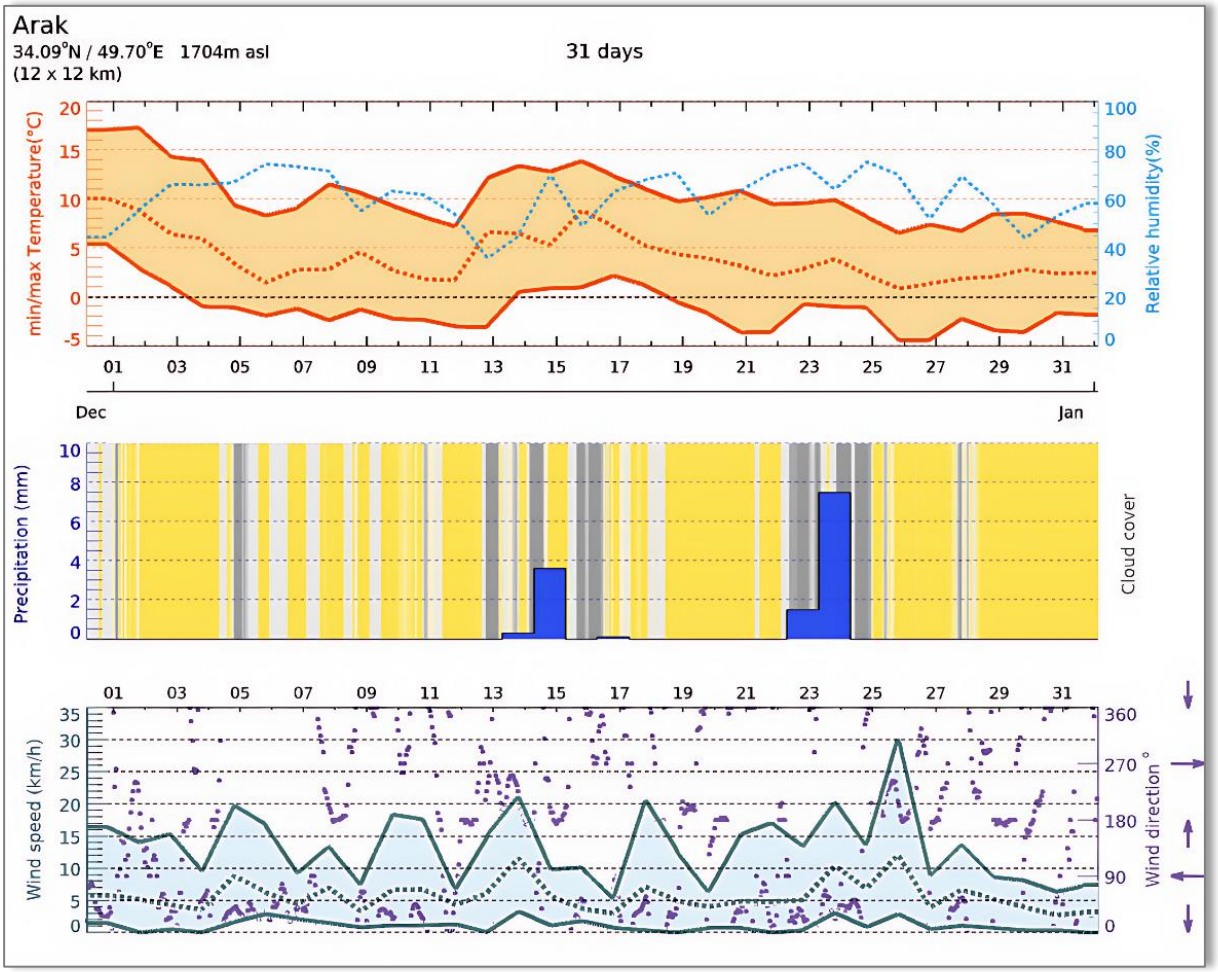


Figure 41: Diagram of air temperature, precipitation & wind speed in December

In the month of December in the city of Arak,

In the month of December, temperatures exhibit a further decrease compared to the preceding month of November. Throughout the majority of the month, the maximum temperatures often range from 10°C to 15°C, while the minimum temperatures frequently go below 0°C. In certain cases, the temperature may decrease to approximately -5°C, particularly during the later portion of the month.

The precipitation patterns in December exhibit noteworthy rainfall, particularly observed between the 18th and 20th of the month. Notably, the biggest deluge of the entire month occurs on the 19th.

The wind speeds in December exhibit temporal variability, characterized by fluctuations over the course of the month, punctuated by a few notable peaks. The peak with the highest magnitude is observed on the 23rd, reaching an approximate velocity of 30 kilometers per hour. During the remaining duration of the month, there will be wind speeds ranging from moderate to high.

Humidity levels in December exhibit a notable degree of stability, primarily fluctuating within the range of 60% to 80%. There are instances of decreased humidity levels, particularly on the 22nd and 23rd, during which the levels fall below 60%.

The cloud cover in December exhibits diverse amounts of cloudiness. At the onset of the month, there is a recurring pattern of alternating periods characterized by clear and cloudy weather conditions. Starting from the 18th of the month, there is a persistent duration of overcast weather conditions that gradually diminishes until the conclusion of the month.

To summarize, the month of December in Arak is distinguished by frigid weather, often seeing multiple days with temperatures below freezing. Rainfall occurrences, particularly around the middle of the month, result in the presence of moisture, while wind velocities exhibit fluctuations and occasional surges. Throughout the majority of the month, the humidity remains at a reasonably high level, while the cloud cover exhibits variability, characterized by a period of extended cloudiness occurring in the middle of the month.

6.2.2. Output of weather simulator software for each hour of every month in Arak city

Monthly Diurnal Averages

Figure 42, displays the average statistics for each hour of each month throughout the year, covering a 24-hour period. The graph displays the mean Dry Bulb Temperature (represented by the upper red curve) and mean Wet Bulb Temperature (represented by the lower red curve) in degrees Celsius. The comfort range, as defined on the Criteria Screen, is represented by the grey bar. The left-hand scale indicates the Average Hourly Radiation for each month in Btu/sq.ft (Wh/sq.m). The Global Horizontal radiation is represented by the color green, the Direct Normal radiation is represented by the color yellow, and the Diffuse Radiation is represented by the color blue. Higher levels of Diffuse Radiation typically indicate a more clouded sky, resulting in a decrease in Direct Normal Beam Radiation and consequently a reduction in Total or Global Horizontal Radiation. The Global Horizontal Radiation is the combined value of the Diffuse Radiation received from the entire sky vault and the Direct Normal Radiation received from the sun, multiplied by the cosine of the angle at which the sun's rays hit the ground.

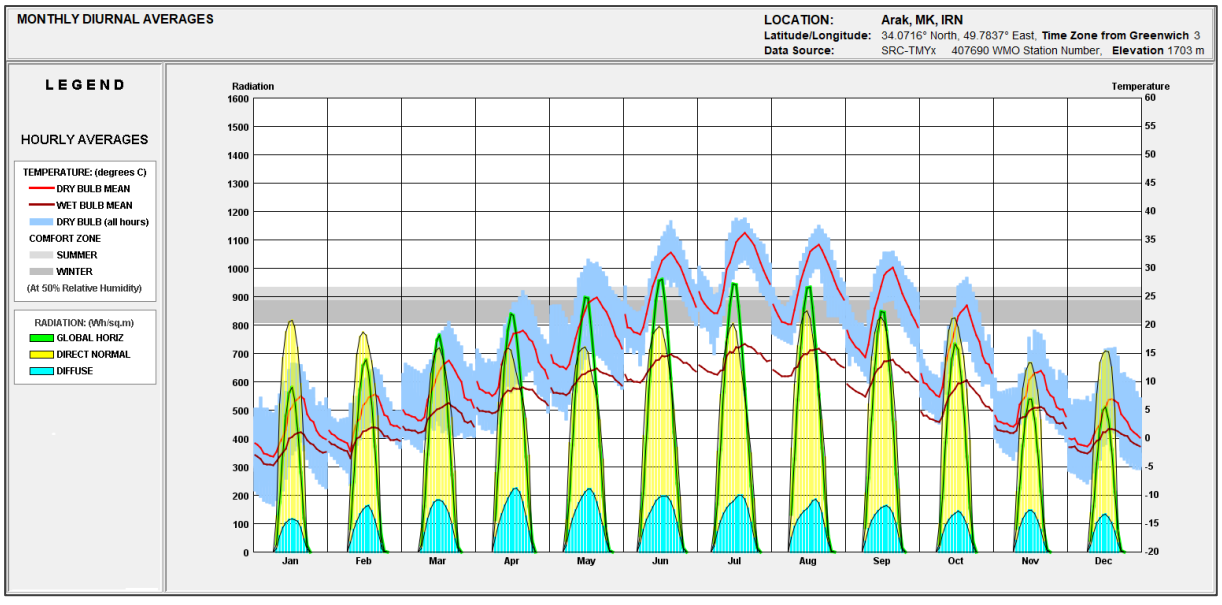


Figure 42: Monthly diurnal average for Arak. (source: Climate Consultant software)

Dry Bulb vs. Relative Humidity

The following 12 charts display (Figure 43) the average Dry Bulb Temperature (represented by yellow dots) and the corresponding Relative Humidity (represented by green dots) for each hour of every month. Additionally, each monthly graphic displays a gray bar representing the Comfort Zone. The dry bulb temperature is essentially the reciprocal of the relative humidity.

The charts (Figure 43) displays the diurnal variation of the dry bulb temperature and relative humidity in Arak over the course of a year.

Data analysis for the month of July:

Dry bulb temperature: The average daytime dry bulb temperature exceeds 30 degrees Celsius, surpassing the range of comfortable temperatures for July. Consequently, the prevailing conditions are too heated for the most of the day.

Relative humidity: The relative humidity during the early morning hours is approximately 50%, although it declines to around 20% as the day progresses. These figures indicate that the air is comparatively arid throughout the summer season.

Data analysis for the month of December:

Dry Bulb Temperature: The average daytime temperatures hover around 10°C, while at night they fall below freezing. This suggests the necessity of continuous heating to provide a comfortable environment during the winter.

Relative humidity: The daily fluctuation of relative humidity ranges from 60% to 80%, indicating a moderately humid climate.

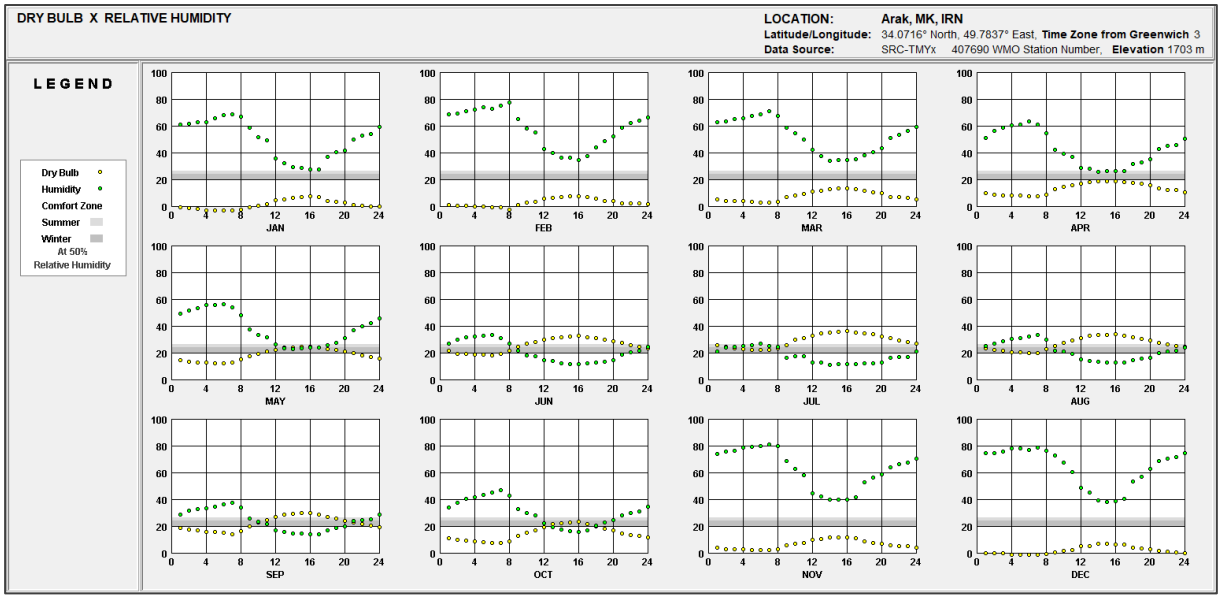


Figure 43: Monthly Hourly Analysis of Dry Bulb Temperature and Relative Humidity with Comfort Zone Representation. (source: Climate Consultant software)

These 12 charts (figure 44) display the average Dry Bulb Temperature (represented by yellow dots) and Dew Point (represented by green dots) for each hour of each month. Additionally, each monthly graphic displays a gray bar representing the Comfort Zone. The Dry Bulb temperature experiences a rapid rise at daybreak and reaches its highest point about 2 or 3 in the afternoon, but the Dew Point temperature remains rather constant throughout the day.

The charts (Figure 43) present the Dry Bulb and Dew Point measurements for Arak city during each month, covering both day and night periods. The dry temperature refers to the ambient temperature of the air, while the dew point is the specific temperature at which the air reaches saturation and any additional moisture condenses into visible water droplets.

<u>July chart analysis:</u>

Dry bulb temperature: The diurnal maximum dry temperature often ranges from 30 to 35 degrees Celsius.

The nocturnal minimum temperature often hovers around 20 degrees Celsius.

The dew point is the temperature at which air becomes saturated with water vapor, causing condensation to occur.

The peak dew point during the day is between 15 and 20 degrees Celsius.

The nocturnal dew point reaches a minimum of approximately 10 degrees Celsius.

Examination: Elevated temperatures and comparably high dew points throughout the month of July are indicative of a sweltering and muggy climate. These conditions necessitate the implementation of active or passive cooling methods to attain thermal comfort.

December diagram analysis:

Temperature measured by a thermometer that is not affected by moisture or humidity.

The average daily maximum temperature in dry conditions ranges from approximately 5 to 10 degrees Celsius.

The nocturnal minimum temperature typically hovers around or below 0°C.

The dew point is the temperature at which air becomes saturated with water vapor, causing condensation to occur.

The peak dew point throughout the day ranges from approximately 0 to 5 degrees Celsius.

The nocturnal dew point frequently falls below freezing.

Evaluation: Cold temperatures and low dew points in December signify the need for heating due to the chilly conditions.

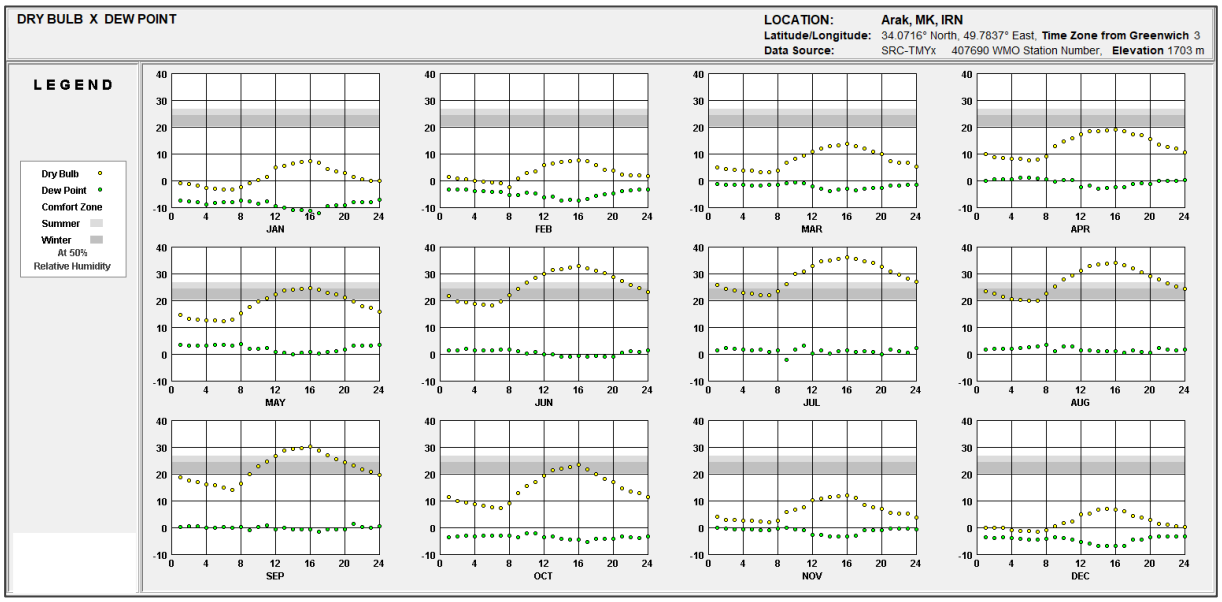


Figure 44: Hourly Variation of Dry Bulb Temperature and Dew Point Across Months with Comfort Zone Indication. (source: Climate Consultant software)

Sun Shading Chart

This diagram (Figure 45) displays the azimuth (horizontal axis) and elevation (vertical axis) of the sun at 15-minute intervals throughout the year, represented by colored dots. The presence of yellow dots signifies that the Dry Bulb temperature is within the defined comfort zone as outlined on the Criteria Screen. The presence of red dots signifies overheating situations when the Dry Bulb temperature exceeds the upper limit of the comfort zone. The presence of blue dots signifies underheat circumstances, which occur when the dry bulb temperatures fall below the lower limit of the comfort zone. For optimal passive heating, it is recommended to leave the windows totally uncovered in areas marked with blue dots. Conversely, to avoid excessive heat, the windows should be completely shaded in areas marked with red or yellow dots.

The solar shading diagram (Figure 45 a) illustrates the trajectory of solar radiation from June 21 (summer solstice) to December 21 (winter solstice) for the specific geographical coordinates of Arak city. The graphic utilizes various colored lines to indicate the specific times of day and seasons during which shade is necessary to avoid excessive heat, as well as the periods when the sun's heat can be beneficial for heating the spaces.

Analysis of the chart:

Red lines (WARM/HOT > 27°C) represent periods during the year when the outside temperature exceeds 27°C. In such instances, it is necessary to provide shading for a total of 262 hours in order to avoid excessive heat buildup.

The yellow lines represent the periods when the temperature falls within the comfortable range of 20-27°C. These lines account for a total of 1388 hours every year. Shading in this temperature can provide assistance but is not essential.

Blue lines (COOL/NEEDED < 20°C): These lines indicate the periods when the outdoor temperature falls below 20°C, and the building is exposed to this temperature for a total of 747 hours every year. During these periods, solar radiation is necessary to heat the area.

The solar shading diagram (Figure 45 b) depicts the path that solar radiation takes from the winter solstice on December 21 to the summer solstice on June 21. This path is especially depicted for the geographic coordinates of Arak. The evaluation of shade requirements throughout the year and for different building orientations is made easier by the use of this image.

Examining the chart in detail:

Periods of the year in which the average temperature is higher than 27 degrees Celsius are represented by the red lines. These lines, which date back to the summer solstice and continue until the beginning of October, emphasize the importance of shading in order to reduce the temperatures inside and prevent excessive heat.

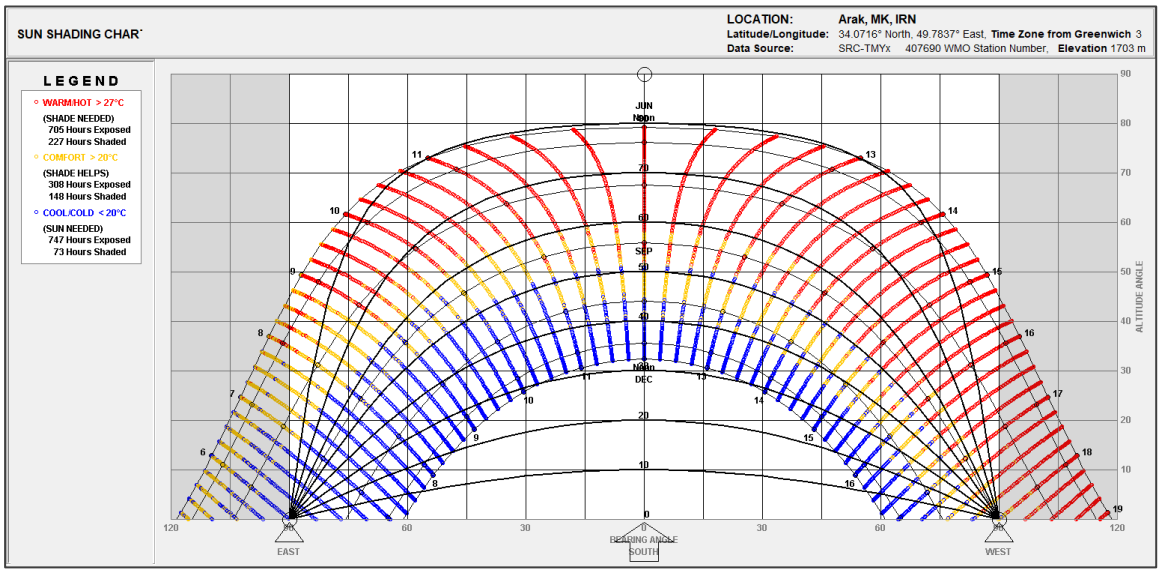
While the temperature is within the range of thermal comfort, the yellow lines (COMFORT 20-27°C) depict the time periods during which the temperature is comfortable. The yellow phases on this figure, which occur from late fall to winter solstice and then from spring to summer solstice next, show periods of reduced shade requirements. These phases occur from late fall to winter solstice.

Blue lines, denoted as COOL/COLD < 20°C, signify the intervals during which the temperature of the surrounding environment is lower than 20°C. When these lines appear during colder seasons such as late autumn, winter, and early spring, they serve as markers that it is necessary to make use of solar heat for the purpose of heating the interior of a building.

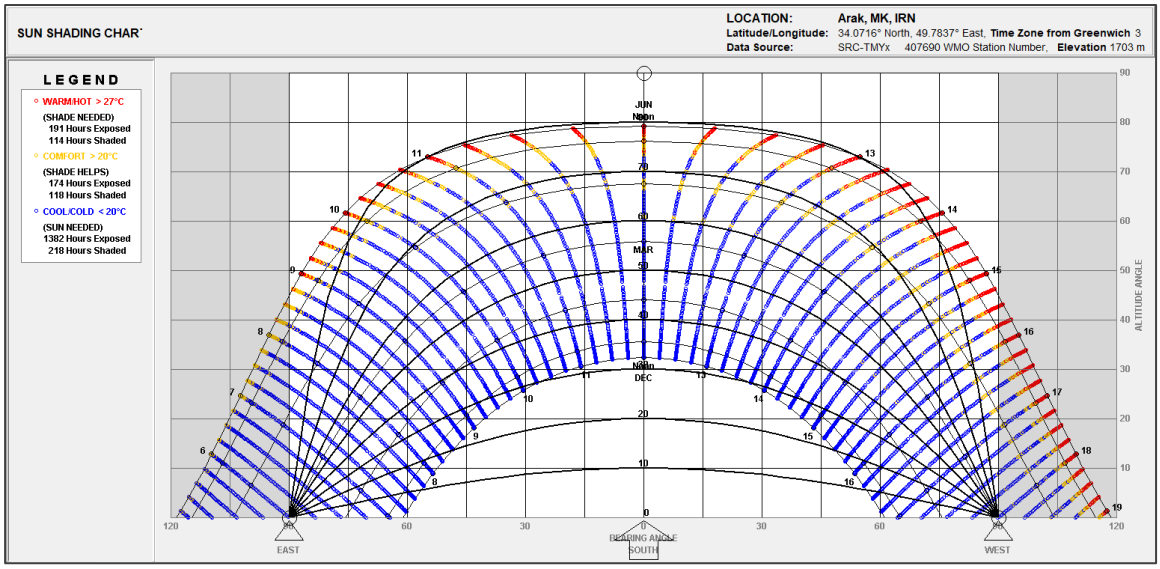
For the purpose of preventing excessive heat, the requirement for shade is 1914 hours per year.

There are 1748 hours in a year that fall into the comfort temperature range (COMFORT), which is the total amount of hours.

Requirements for Heating Hours: In order to get temperatures up to an appropriate level, a total of 1532 hours of heating time must be spent each year.



(a)



(b)

Figure 45: Solar Position and Thermal Comfort Analysis: Azimuth-Elevation Mapping with Temperature Zone Indicators. (a)Summer; (b)winter (source: Climate Consultant software)

Timetable Plot

This plot (Figure 46) shows along the bottom the months of the year and along the side the hours of the day. The time when Sunrise and Sunset occurs for this latitude is indicated by the curved yellow lines.

The Dry Bulb Temperature plot was initially named by Olgyay as the Timetable of Bioclimatic Needs and was used in his text to display graphically the differences between different types of climates. It also shows in the darkest blues when sun-facing windows should be exposed for passive heating and in light blue and red when windows should be shaded.

The "TimeTable Plot" graph (Figure 46) displays the annual variation in Dry Bulb Temperature for the specific site of Arak, along with the corresponding sunrise and sunset timings. This graphic is valuable for climate analysis and building design planning, specifically for determining thermal and light needs.

Analysis of the chart:

Dry Bulb Temperature: Various hues indicate the atmospheric temperature over the course of the year:

Dark blue represents temperatures below 0°C, signifying extremely cold circumstances.

The color light blue represents a temperature range of 0 to 21°C, signifying cool conditions.

The color green represents a temperature range of 21 to 27 °C, which signifies circumstances of thermal comfort.

Red: temperature exceeding 27°C, signifying high temperatures.

Times of daybreak and nightfall:

The yellow lines represent the precise moments when the sun rises and sets. During the summer season, the sun ascends earlier and descends later, signifying an extension in the duration of daylight.

During the months of January to March and October to December, temperatures predominantly fall within the light blue spectrum, suggesting a requirement for heating.

During the months of June to August, the majority of temperatures fall inside the red area, which signifies the necessity for cooling.

The temperatures that provide thermal comfort (green) are predominantly observed throughout the months of April, May, and September.

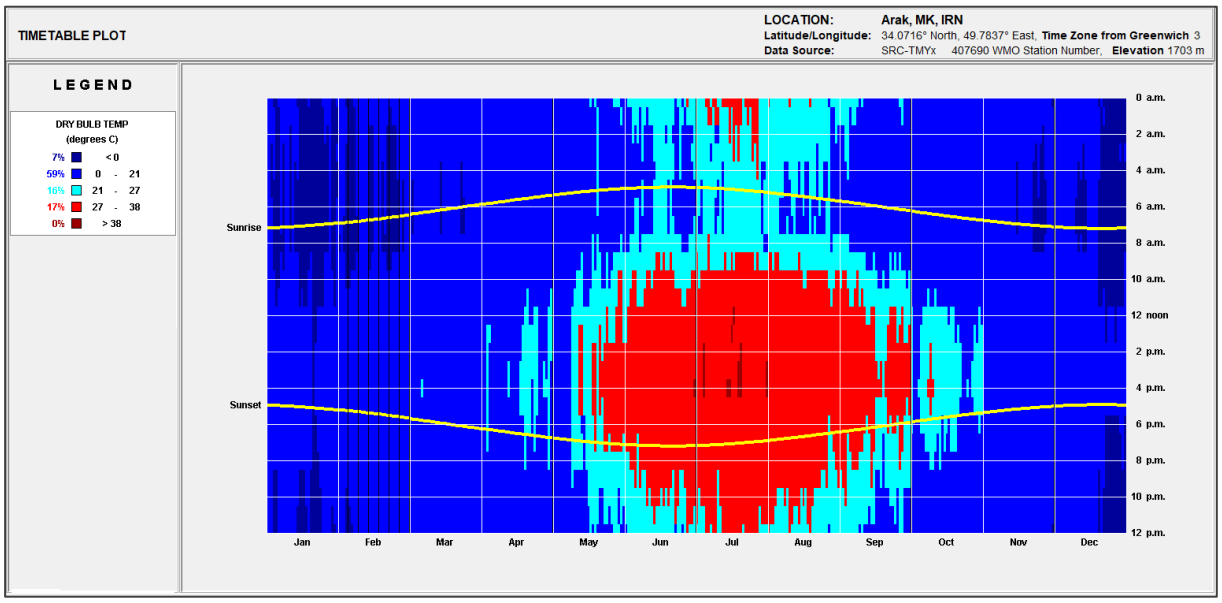


Figure 46: Bioclimatic Timetable: Dry Bulb Temperature, Sunrise and Sunset Patterns Across Months and Hours. (source: Climate Consultant software)

Wind Wheel

Figure 47 display shows the Wind Velocity and Frequency of Occurrence for each wind direction, together with the present average Dry Bulb Temperature and Relative Humidity. The outer ring displays the proportion of hours during which the wind originates from each direction. The subsequent ring displays the average wind temperature from each direction, with the height and color of the bars indicating the temperature range (light blue represents the comfort zone, blue indicates chilly or cold temperatures, and red signifies warm or hot temperatures). The subsequent, more diminutive band displays the mean level of moisture in the atmosphere (light green represents a pleasant level, yellow indicates a lack of moisture, and green signifies a high level of humidity). The innermost circle displays the wind velocities originating from various directions. The tallest brown triangle represents the maximum velocity during that period, the medium brown triangle represents the average velocity, and the smallest light brown triangle represents the minimum velocity. The figure does not include any hours with a wind speed of zero. The essential visual representation of all this data is encapsulated in the icon located at the bottom right corner, clearly labeled with the parameters of Wind Speed, Relative Humidity, Temperature, and Hours.

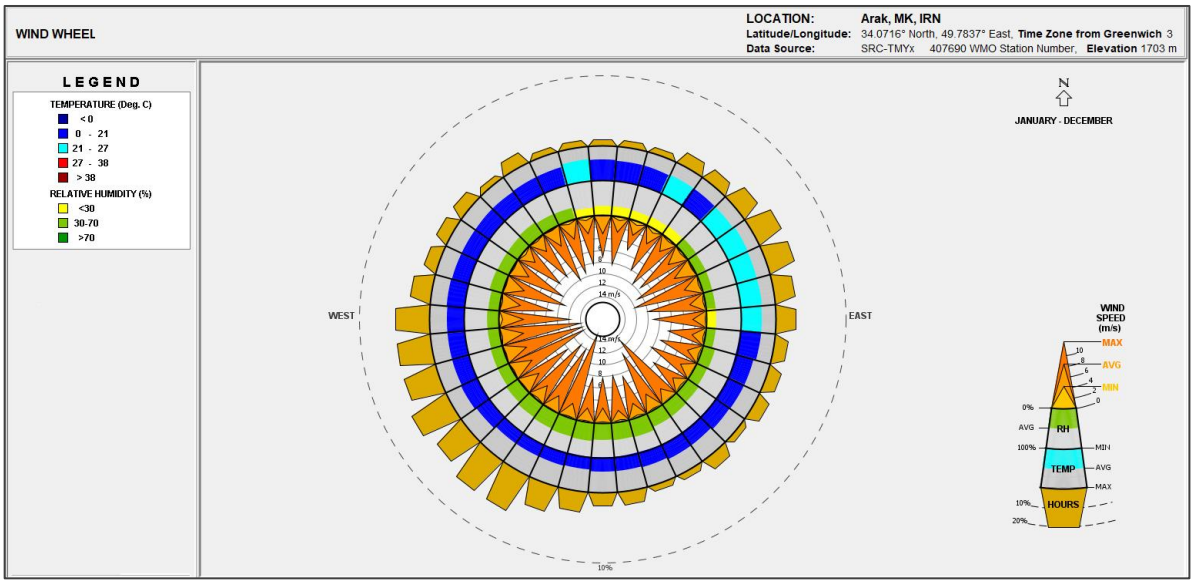


Figure 47: Wind Wheel for Arak during the year. (Source: Climate Consultant software)

6.2.3. Temperature Parameters of Simulation with Design Builder

Figure 48 illustrates the results of a simulation that was performed using EnergyPlus. It is EnergyPlus that is responsible for providing Design Builder with its weather data. There are several different types of energy flows that are modeled, including lighting, ventilation, heating, and cooling. The result demonstrates a variety of measures that correspond to temperature and heat gains for a building that has a dome roof design. The information is exhaustive, and it is presented in a detailed analysis with sub-hourly intervals on the 15th of July this year.

The oscillations in temperature both within and outside of the structure are depicted by the temperature lines (air, radiant, operative, and exterior dry-bulb) in the analysis of the graphs.

Over the course of the day, the "Air Temperature (°C)" line illustrates the changes that occur in the temperature of the air inside the building.

The operating temperature, expressed in degrees Celsius, is a composite measurement that takes into consideration both the air temperature and the radiant temperature. It offers a subjective depiction of how members of the occupant population would experience the temperature.

The term "Outside Dry-Bulb Temperature (°C)" refers to the temperature of the temperature of the air outside, which naturally varies more than the temperatures inside the building.

The bar chart illustrates the changes in relative humidity (in percentage terms) that occur throughout the course of the day.

The energy gains and losses, measured in kilowatts, are depicted by the bars. These bars indicate several components that contribute to the energy profile of the structure, such as the glazing, the walls, and the ceilings.

Cooling that is both sensible and total (kW): Both the dark blue and the light blue bars are meant to illustrate the cooling capacity that is required to keep the temperatures within the building at an optimal level.

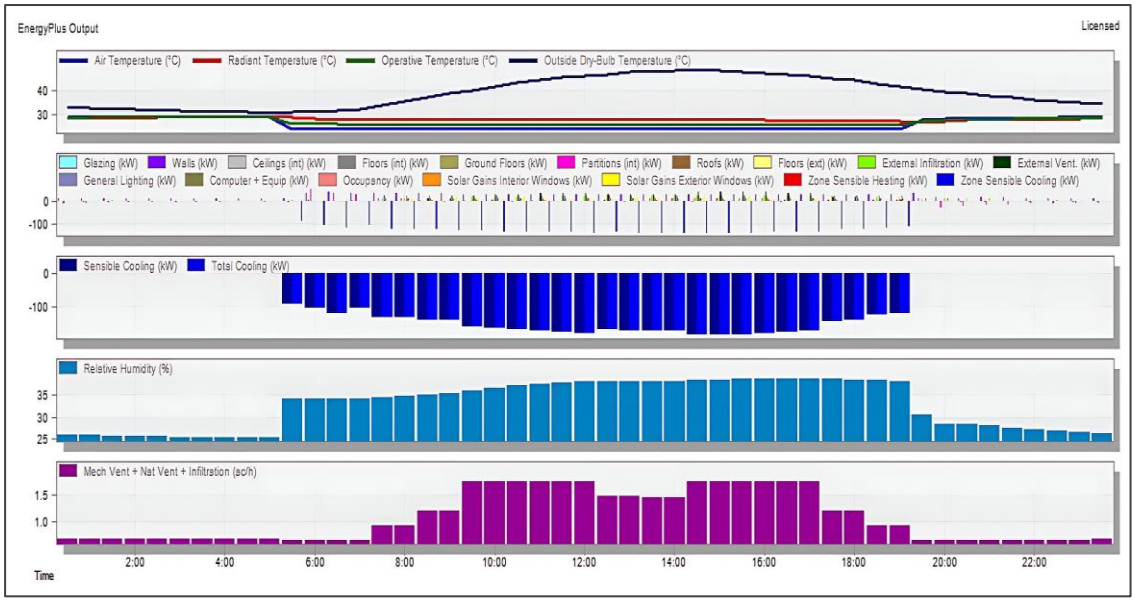


Figure 48: Output of Temperature Parameters of Simulation Nowzari Caravanserai (source: Design Builder software)

In accordance with the recommendations that have been presented by comparable scholarly articles (Zomorodian, & Tahsildoost, 2016; Fathalian, & Kargarsharifabad, 2018), it is essential to exercise control over a variety of factors and parameters in order to improve the dependability of the predictions that are generated by simulation software. The precise characteristics of the surrounding area will determine the nature of the link that exists between the wind speed that is present in the vicinity of the market building and the amount of radiation that is actually received. As a result, the coefficients that belong to wind and its reflection were regulated based on the positioning of the market building in relation to its surrounding environment. This was done in order to guarantee that the outputs of the program closely reflected the actual values.

The statistics presented in Figure 49 correspond to the outdoor temperature and the internal temperature on the warmest day of the warmest month in Nowzari Caravanserai, Arak Bazaar, with a dome roof. The objective of this comparison is to better understand the variations in temperature.

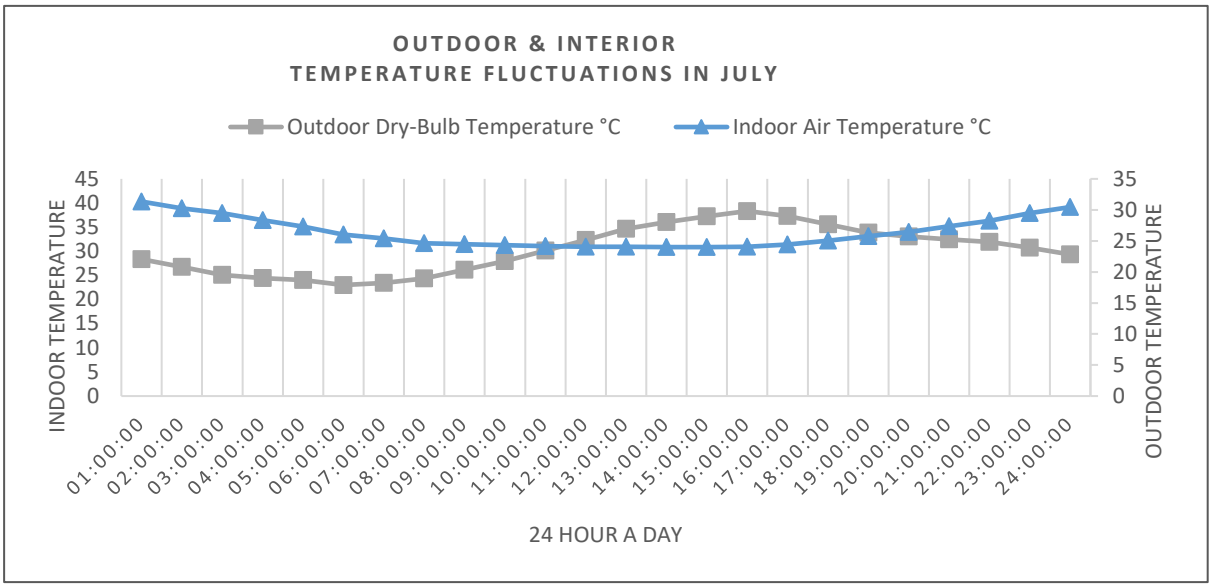


Figure 49: Diagram of outdoor and interior temperature fluctuations of Nowzari Caravanserai on the hottest day of July.

The outdoor dry-bulb temperature, measured in degrees Celsius, exhibits a diurnal pattern consistent with typical daily variations. The minimum temperature of 23.00 °C is recorded at 6 a.m., whereas the maximum temperature of 38.33 °C is recorded at 4 PM. In this pattern, temperatures are at their lowest in the early hours of the morning prior to sunrise and at their highest during the afternoon.

The data suggest that there is a delay in the indoor air temperature in relation to the outdoor temperature. The indoor temperature reaches its minimum value of 24.00 °C at 3 PM, which coincides with the outdoor temperature nearing its maximum value. Conversely, the indoor temperature reaches its maximum value of 31.34 °C at 1 a.m.

The mean absolute temperature difference between 6:00 a.m. and 6:00 p.m., as calculated from available data, is −6.44 °C.

The average absolute temperature difference during the nocturnal period, from 18:00 to 6:00, was found to be −1.54 °C. It should be noted that negative values indicate that the indoor temperature was lower than the outdoor temperature.

On average, the indoor temperature exhibits a decrease of 6.44 °C compared to the outdoor temperature during the day, and a decrease of 1.54 °C during the night.

Upon computation of the correlation coefficient, it was determined that the correlation between outdoor temperature and indoor temperature was −0.39534, which falls below

the threshold of 0.5 and thus suggests a correlation that is weak to moderate in nature. This implies that the correlation between the ambient outdoor temperature and the indoor temperature is relatively weak.

Figure 50 displays information regarding the outdoor temperature, and indoor temperature of the most frigid day of the chilliest month at Nowzari Caravanserai, Arak Bazaar, with dome roof, with the intention of facilitating a comparative analysis.

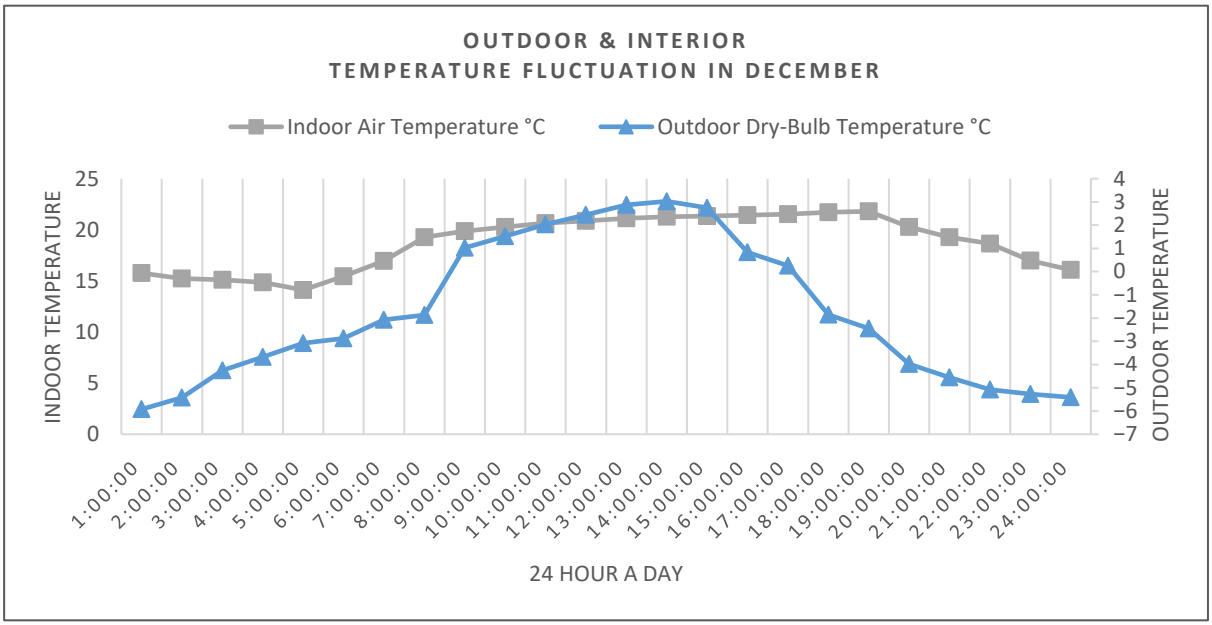


Figure 50: Diagram of outdoor and interior temperature fluctuations of Nowzari Caravanserai on the coldest day of December.

The minimum temperature of −5.925 °C is recorded at 1 a.m., whereas the maximum temperature of 3.025 °C is recorded at 2 p.m. The ambient temperature outdoors is sub-zero, whereas the indoor temperature is significantly elevated, maintaining a range of approximately 14 to 21 °C.

The diurnal temperature range exhibits an average absolute difference of approximately 19.32 °C, while the nocturnal temperature range displays an average absolute difference of around 21.94 °C. The aforementioned statement implies that the indoor temperature of the building maintains an average of being 19.32 °C higher during the daytime and 21.94 °C higher during the night-time in comparison to the outdoor temperature.

The correlation coefficient calculation reveals that there exists a positive correlation of +0.704731 between the outdoor temperature and indoor temperature. This suggests that

there is a positive correlation between outdoor temperature and indoor temperature, whereby an increase in one variable is accompanied by a corresponding increase in the other variable.

6.2.4. Assessing thermal comfort using ASHRAE Standard 55-2020

To construct the psychometric diagram representing ASHRAE's comfort conditions, it is essential to consider six primary factors that influence thermal comfort. The parameters to be considered in this study are as follows: air temperature (°C), mean radiant temperature (MRT—°C), air speed (m/s), relative humidity (%), metabolic rate (met), and clothing level (col).

The aforementioned parameters are evaluated based on the climatic conditions prevailing in the region during the peak heat of the warmest month and the extreme cold of the coldest month, as indicated in Table 10.

Table 10. Psychometric factors that affect thermal comfort of Nowzari Caravanserai.

Month	Mean Air Temperature (°C)	Mean Radiant Temperature (°C)	Air Speed (m/s)	Relative Humidity (%)	Metabolic Rate (met)	Clothing Level (col)
July	26.37	26	0.15	35.23	1.7	0.5
December	18.74	18	0.2	21.17	1.7	1

Air Temperature [°C]: This is the temperature of the air surrounding the person, usually measured at about chest height. It's one of the most straightforward indicators of comfort but isn't the only factor.

Mean Radiant Temperature (MRT) [°C]: This refers to the average temperature of the surrounding surfaces from which a person either absorbs or loses radiant heat. For instance, if you're next to a cold window in winter, even if the air temperature is warm, you might still feel cold because of the cold radiation from the window.

Air Speed [m/s]: This is the speed at which air is moving around a person. A gentle draft can improve comfort in warm conditions by increasing evaporation from the skin, but in cooler conditions, it might cause discomfort.

Relative Humidity [%]: It's the ratio of the amount of moisture in the air to the maximum amount of moisture the air could hold at that temperature. High humidity can make it harder for sweat to evaporate and can make conditions feel warmer than the actual air temperature, while low humidity can dry out the skin and respiratory system.

Metabolic Rate [met]: This measures the amount of energy a person is producing. One 'met' is defined as the metabolic rate of a person at rest, roughly equivalent to 58 watts/m^2. Activities like running or working hard increase the metabolic rate. A person doing these activities will produce more heat and might feel warmer than someone at rest, even if environmental conditions are the same.

Clothing Level [clo]: A measure of the insulation provided by a person's clothing. One 'clo' is roughly the amount of insulation required to keep a resting person warm in an indoor environment at 21°C (70°F). Different clothing items have different 'clo' values, and the total insulation is the sum of the 'clo' values for each item worn.

As can be seen from the information presented in Table 10, the air temperature parameter takes into account the calculation of the average temperature on both the hottest and coldest days of the year. There is an average air humidity of 35.23% and an air speed of 0.15 meters per second during the peak of July. These are the characteristics that characterize the prevailing atmospheric conditions. The inquiry into the temperature that is considered to be comfortable within the grounds of the market primarily focused on the activities that are typically carried out by the people who use the market, such as strolling, moving through the market, and engaging in activities related to shopping. As a consequence of this, a metabolic rate of 1.7 (met), which is the standard for walking, was taken into consideration. In the context of ordinary summer clothing, the value of 0.5 (col) is frequently utilized as a representation of the clothing level parameter.

In addition, the average humidity on the day of December that is the coldest is noted as being approximately 21.17%. It has been determined that the air speed during this period

of time is 0.2 meters per second, while the metabolic rate is calculated to be 1.7 percent (met). In addition, the clothing level component is given a value of 1 (col), which is representative of the clothes that is often worn during the winter.

Additional climate consultant software-defined parameters, in addition to those that are given in Table 10, are depicted in Figure 51. There is a separate explanation offered for each parameter, along with its corresponding influence on the efficiency of the thermal comfort approach, which may be found at the bottom of Figure 52.

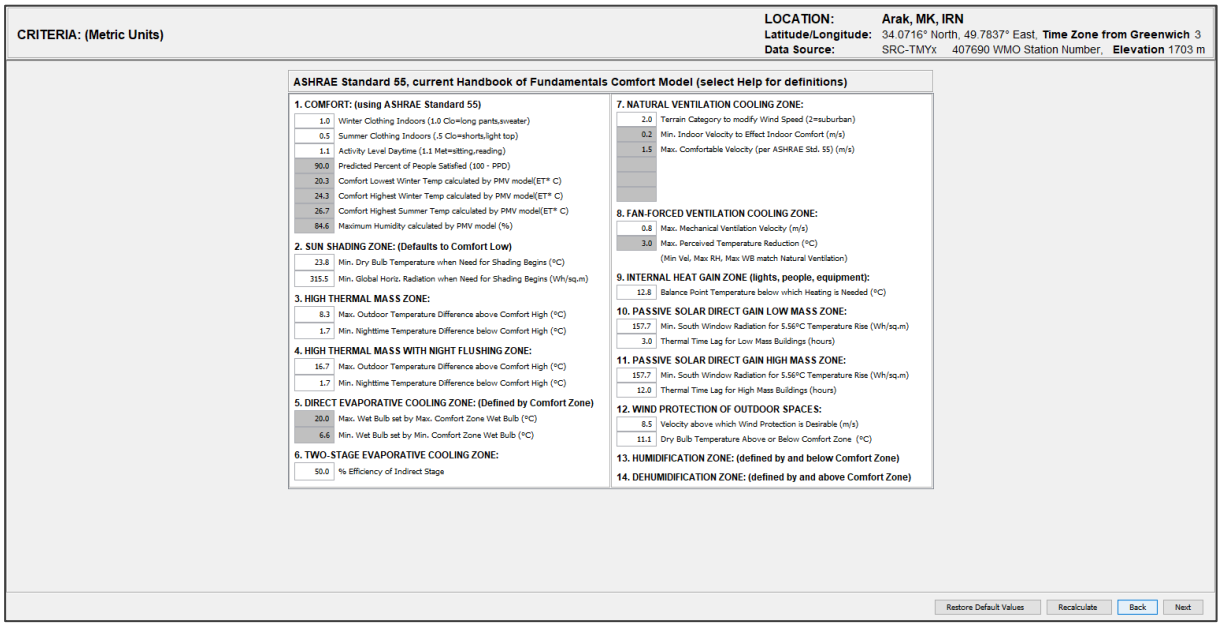


Figure 51: Building comfort and energy performance criteria based on ASHRAE standards. (Source: Climate Consultant software tool)

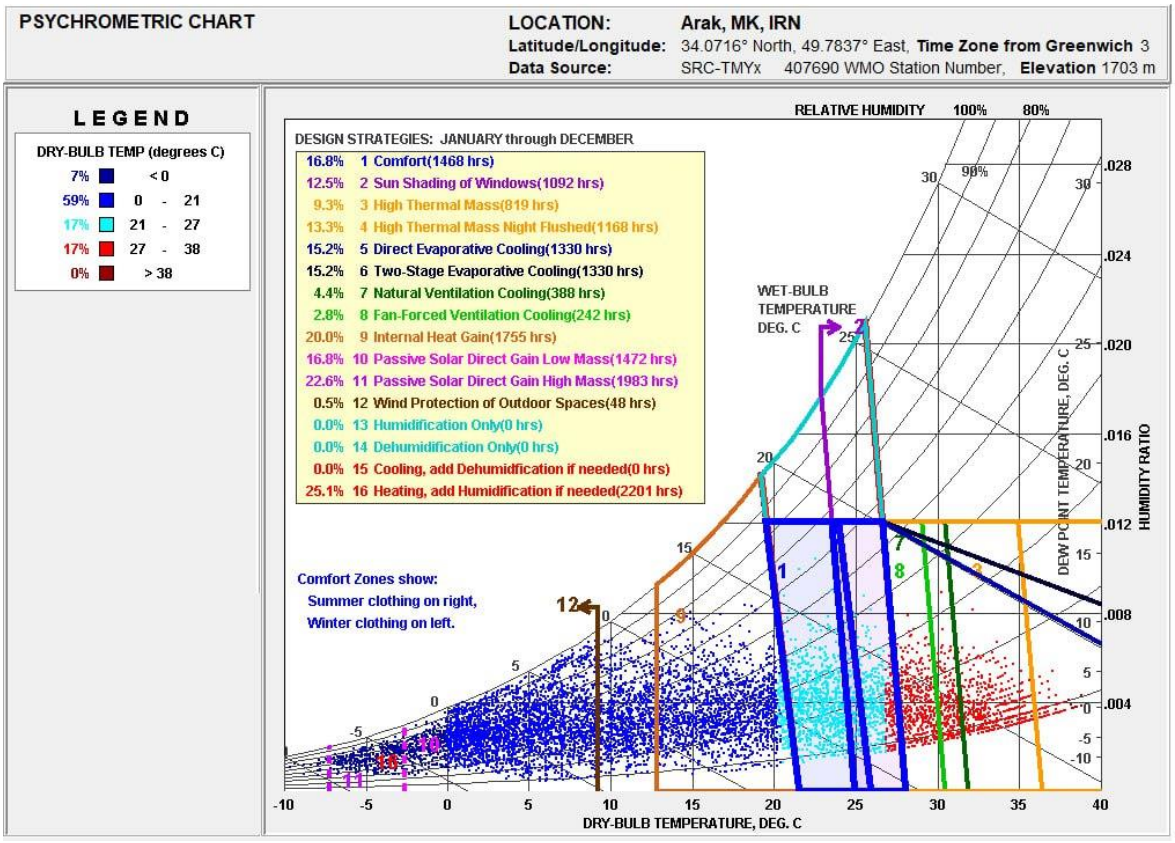


Figure 52: Psychometric chart and design strategies for Arak. (Source: Climate Consultant software tool)

Criteria:

1. Comfort zone

The Comfort Zone is determined on the criterion screen and is prominently displayed on the Psychrometric Chart. It is primarily defined by the Dry Bulb Temperature, and in certain models, it is also influenced by Humidity and Clo (seasonal clothes).

The choice of the Comfort Model will significantly impact the duration of time spent within the comfort zone.

The Comfort zone is determined based on the criteria screen and is visually represented on the Psychrometric Chart, typically starting at or below the Comfort Low temperature.

2. Sun Shading Zone

The shading of windows should occur when the external Dry Bulb Temperature exceeds a specified Minimum Total Horizontal Radiation. An effective guideline is to utilize the minimum temperature that defines the comfort zone. This is because any solar radiation that enters the building over this temperature will not enhance

comfort and is likely to induce overheating in the space. To mitigate the impact of high internal loads in buildings, such as heat generated by lights and equipment, it is recommended to lower the Minimum Dry Bulb Temperature by 5° or 10º F below the Comfort Zone when shading is required. The threshold for sun shading to be recommended in hot regions is approximately 50 Btu/sq.ft (157.7 Wh/sq.m), but it can reach 200 Btu/sq.ft (630.9 Wh/sq.m) or more in cooler cloudy areas. Sun shading is highly efficient in outdoor areas for regulating radiant temperatures, and on windows for preventing indoor dry bulb temperatures from exceeding the ambient temperature. The Psychrometric Chart displays the duration of hours during which Sun Shading is presumed to be present. However, these hours are not included in the overall count of comfortable hours since shading alone does not ensure comfort.

3. And 4. High Thermal Mass Zone

During summer, in regions with hot and arid climates, employing large thermal mass on the interior is an effective technique for cooling. This relies on the thermal storage capacity, time delay, and dampening effects of the mass. Consequently, the significant fluctuations in exterior temperature on a daily basis will result in little fluctuations in internal temperature. As a result, the building will be sealed and maintain stable temperatures during high daytime temperatures. High mass architecture is an effective natural cooling approach in hot desert areas, particularly on days when outdoor temperatures were lower than the Comfort High temperature the previous evening. During winter, large mass buildings can have a good warming impact as long as the external temperatures during the day reach a comfortable level. It should be noted that this effect is more noticeable when there is Passive Solar Direct Gain (winter sun) entering the interior, as described in Strategies 10 and 11. The zone is determined on the Criteria screen by a Maximum Dry Bulb temperature difference that can be up to 15 °F higher than the Comfort High, and by a corresponding Minimum Dry Bulb temperature difference below the Comfort Low. The Minimum area is omitted from the Psychrometric Chart to maintain clarity and avoid overcrowding. It is positioned horizontally and to the right of the Comfort Zone. The upper and lower boundaries of the High Thermal Mass zone are determined by the Dew Point temperature limits at the upper and lower boundaries of the Comfort zone. This is done to prevent the occurrence of precipitation on surfaces with high mass in humid circumstances.

5. Direct Evaporative Cooling Zone

The zone in question is established inside the Criteria screen and is visually represented on the Psychrometric Chart, situated below and to the right of the Comfort Zone. Evaporative cooling occurs when water undergoes a phase shift from liquid to gas, absorbing the latent heat of fusion. As a result, the air gets cooler but also more humid. Evaporation occurs along the Wet Bulb Temperature curve on the Psychrometric Chart. Therefore, an evaporative cooler is an effective cooling method for arid regions with high temperatures. The boundaries of this zone are determined automatically based on the upper and lower limits of Wet Bulb Temperatures that are considered within the range of comfort. The Climate Consultant software does automatic calculations of these two numbers and displays them, but it does not provide the option to modify them on the Criteria page.

6. Two-Stage Evaporative Cooling Zone

The zone in question is established within the Criteria screen and appears on the Psychrometric Chart as an alteration of the Direct Evaporative Cooling Zone. The Indirect Evaporative Cooler is similar to the Direct Evaporative Cooler, with the exception that the angle of the top border is increased in proportion to the effectiveness of the Indirect Phase. In the initial phase, evaporation is employed to lower the temperature of the external surface of a heat exchanger. This exchanger facilitates the entry of incoming air into the subsequent phase, where it is cooled through direct evaporation.

7. Natural Ventilation Cooling Zone

The zone in question is established inside the Criteria screen and is visually represented on the Psychrometric Chart, positioned above and to the right of the Comfort Zone. In hot and humid settings, air circulation is one of the limited methods to provide a cooling sensation on the human body. This is achieved by enhancing the rate of perspiration evaporation and creating a psychological perception of coolness (it is important to note that ventilation does not physically lower the dry bulb temperature). Wind velocities are influenced by the presence of surrounding objects. Climate data is typically collected in flat, exposed regions known as Terrain Category 3. Climate Consultant software considers the presence of urban and suburban areas, as well as wooded areas, which are referred to as Terrain Category 2. Urban areas are referred to as Terrain Category 1. The software assumes that the building's height is approximately 33 feet (10 meters), which matches the assumed height of the wind

measurement instrument. Indoor air velocities are decreased according to the calculation provided in the ASHRAE Handbook of Fundamentals 2005. Climate Consultant software assumes that the building's windows will be adjusted to take full advantage of lower wind speeds or to decrease higher wind speeds to achieve comfortable indoor velocities. Additionally, it assumes that the building is designed to have sufficient cross ventilation or stack ventilation in order to maintain comfortable air velocities throughout the building. Natural Ventilation Cooling is a multifaceted process that can be defined in various manners. The zone of efficacy in software is determined by the Minimum Air Velocity required to achieve comfort, typically set at a minimum of 40 fpm (.2 m/sec). If the speed of outdoor air drops below this minimum threshold, it is presumed that Natural Ventilation Cooling is ineffective. The Maximum Indoor Comfortable Air Velocity is the threshold above which individuals experience discomfort. When engaged in sedentary activities, the maximum comfortable velocity is typically around 160 fpm (.82 m/sec), which is barely perceptible. However, in indoor settings where individuals can move around freely, such as in a home, the maximum comfortable velocity may reach 300 fpm (1.60 m/sec) or higher. At this level, a gentle breeze can be felt on the face and papers may rustle. The air speeds mentioned will result in a perceived temperature reduction of 4.6F (2.5C) in the first case and 6.6F (3.7C) in the second case, according to ASHRAE Standard 55-2004. It should be noted that individuals who have the ability to manipulate the speed of air movement will be able to endure a broader range of comfortable conditions. The upper boundary of this area is determined by a Maximum Relative Humidity and a Maximum Wet Bulb Temperature (Givoni 1994). In this area, the humidity is so high that Air Conditioning is necessary, often both to decrease the humidity and to lower the air temperature.

8. Fan Forced Ventilation Cooling Zone

This zone is established inside the Criteria screen and is visually represented on the Psychrometric Chart, positioned above and to the right of the Comfort Zone. When ventilation cooling is required, it is commonly considered that centralized mechanical fans, ceiling fans, or tiny local fans placed on a desk or table can generate fan forced air motion. In hot and humid settings, air circulation is one of the limited methods to provide a cooling sensation on the human body. This is achieved by enhancing the rate of sweat evaporation and creating a psychological perception of

coolness (that ventilation does not physically lower the dry bulb temperature). The process is intricate and can be defined in various ways. The Fan Forced Ventilation Zone in Climate Consultant is characterized by the same boundaries as the Natural Ventilation Zone, with the exception that the Maximum Mechanical Ventilation Velocity can be specified independently as the threshold air velocity at which individuals begin to experience discomfort. In formal sedentary situations, the maximum tolerable speed is often around 160 feet per minute (0.082 meters per second), which is scarcely perceptible. However, in indoor environments where people can move around, the maximum speed may reach 300 feet per minute (1.60 meters per second), resulting in a moderate breeze that can be felt on the face and may cause papers to rustle. According to ASHRAE Standard 55-2004, these air speeds will create a sensation of comfort equivalent to a decrease in temperature of 4.6F (2.5C) in the first scenario and 6.6F (3.8C) in the second scenario. The minimal air velocity required for achieving comfort is considered to be 40 fpm (.2 m/sec). If the air velocity falls below this threshold, it is assumed that Ventilation Cooling is ineffective. The upper boundary of this zone on the Psychrometric chart is determined arbitrarily using the same restrictions as the Natural Ventilation Zone. In this particular area, the level of humidity is sufficiently high that Air Conditioning is required, often not just to lower the air temperature but also to decrease the humidity.

9. Internal Heat Gain Zone

This zone is established inside the Criteria screen and appears on the Psychrometric Chart, positioned to the left of the comfort Zone. It is an approximate measure of the thermal energy contributed to a structure by inside sources, including lighting, occupants, and machinery. The level of dependence varies significantly based on the specific building type and design. The Balance Point Temperature refers to the ambient temperature at which the building's internal heat sources are sufficient to maintain a comfortable inside environment. Buildings that are well constructed and well insulated have significantly lower balance point temperatures, resulting in a substantial reduction in heating energy use. Certain building categories, such as residential dwellings and storage facilities, exhibit relatively minimal internal heat generation and thus require additional heating. Consequently, the Balance Point for these structures may be set at 60ºF. Buildings that have significant internal loads, such as industries, require minimal supplementary heating and so may have a Balance Point close to 20°F.

10. Passive Solar Direct Gain Low Mass Zone

The zone in question is established inside the Criteria screen and is visually represented on the Psychrometric Chart, positioned to the left of the Comfort Zone. This line is represented by dashes as it can only serve as an approximate estimation due to its strong dependence on the architecture of the building. Passive solar heating can increase inside temperatures if the building is equipped with an appropriate amount of sun-facing glass. Software operates under the assumption that shade effectively stops all instances of Direct Solar Gain when it is unnecessary. There is a risk that if this building has a low mass, the un-shaded solar gain could rapidly cause the space to become too hot. In Climate Consultant software, this zone is determined by the requirement for a minimum beam radiation (or direct normal radiation) in the previous hour that will result in a temperature increase of 10º F, typically at least 50 Btu/sq.ft (in metric units, the temperature increase would be 5.6º C for 157.5 Wh/sq.m). This zone exhibits a comparatively short Thermal Time Lag for Low Mass Buildings, approximately 3 hours. This implies that the radiation is detected 3 hours prior to the present hour. An hour is considered to be within this zone if the temperature increase caused by radiation surpasses the minimal Comfort temperature. The lower limit of this zone on the Psychrometric Chart is determined by the lowest outdoor air temperature at which the available solar radiation will result in the minimal Comfort temperatures.

11. Passive Solar Direct Gain High Mass Zone

The zone in question is established inside the Criteria screen and is visually represented on the Psychrometric Chart, positioned to the left of the Comfort Zone. This line is represented by dashes as it can only provide an approximate value due to its strong dependence on the architecture of the building. Passive solar heating can increase inside temperatures if the building has an appropriate amount of glass facing the sun. If the structure has a high mass, it can accommodate a larger amount of glass without the risk of excessive solar gain causing overheating in the room. In order to accumulate solar heat gain and subsequently release it when necessary, it is essential for the internal mass to be in direct contact with the internal air. In Climate Consultant software, this zone is characterized by the requirement for a Minimum Beam Radiation (or Direct Normal Radiation) that results in a 10° F temperature increase within the previous hour, often equivalent to at least 100 Btu/sq.ft (in Metric units, the temperature rise would be 5.6° C for 315.0 Wh/sq.m). This zone also assumes a significant Thermal Time Lag for High Mass Buildings, typically around 12 hours or more. This means that the radiation being detected is from 12 hours ago, not

the current hour. An hour is considered to be within this zone if the increase in interior temperature caused by radiation surpasses the minimum Comfort temperature. The lower limit of this zone on the Psychrometric Chart is determined by the lowest outdoor air temperature at which the available solar radiation will result in the minimal Comfort temperatures.

12. Wind Protection of Outdoor Spaces

The two zones are delineated on the Criteria screen and can be shown on the Psychrometric Chart as a vertical line positioned either above or below the comfort zone, or both. During extremely cold weather, it denotes the time when frigid winds make outside areas uncomfortable, whereas in extremely hot weather, it signifies the hours when scorching winds render outdoor spaces uncomfortable. These zones are displayed exclusively when there are hours that satisfy the specified conditions. The limits of these two zones are determined on the Criteria screen when the Wind Velocity exceeds a specific threshold (e.g. 20 mph) and when the Dry Bulb Temperature deviates by a predetermined amount from the upper or lower limit of the Comfort Range (e.g. at least 20° F). In extremely low temperatures, it is necessary to have a barrier (such as plants, a wall, a sheltered area, or a roof) to shield outdoor spaces or entrances from the effects of cold wind, snow accumulation, wind chill, and frostbite. During extremely hot and arid weather, it is necessary to have some form of wind barrier (such as a courtyard, screen wall, porch, or awning) in order to shield outdoor areas or entrances from the scorching dry wind, blowing sand, windburn, and even heatstroke. It should be noted that the Design Strategies list on the Psychrometric Chart indicates the duration of time when Wind Protection of Outdoor Spaces is necessary. However, as this factor does not directly impact the comfort level indoors, these hours are not included in the overall count of indoor comfort hours. According to the Beaufort Number scale, which measures the impact of wind, a wind speed of 19 mph is described as follows: "The wind's strength can be felt on the body, small leafy trees will sway, and this is the maximum level of wind that is considered pleasant."

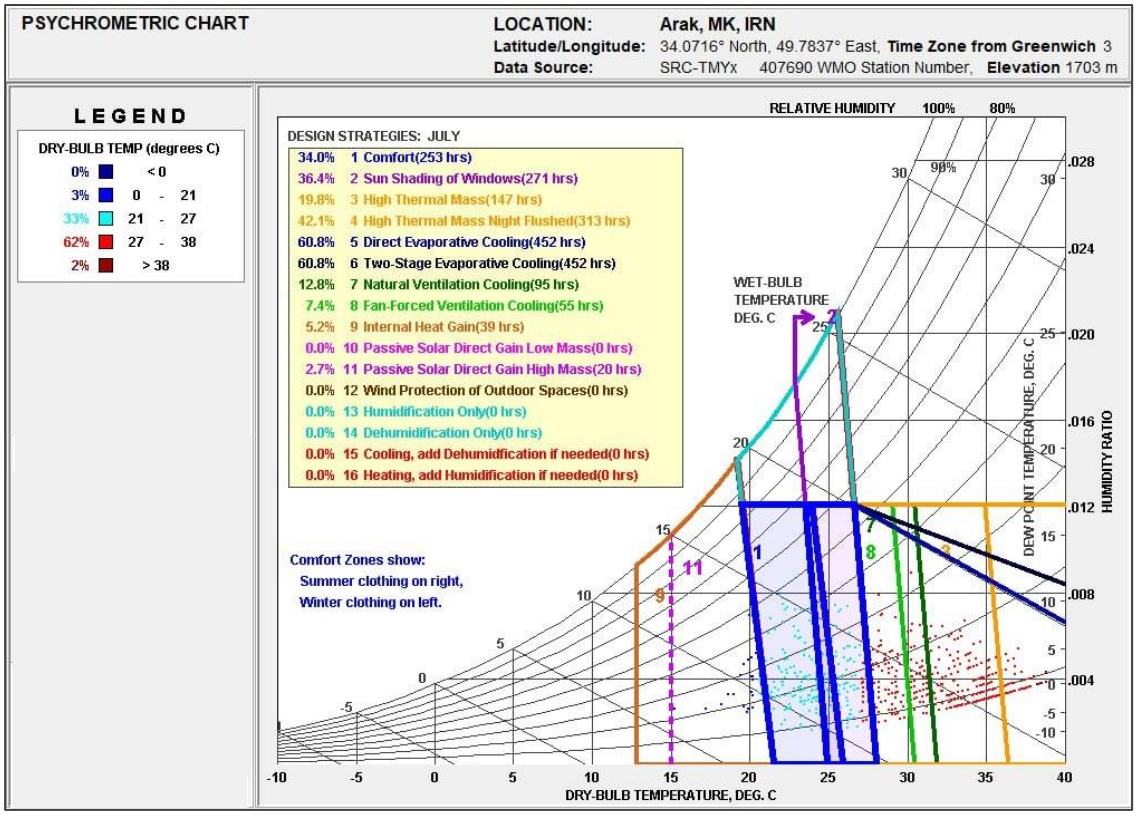


Figure 53: Thermal comfort chart (Tartarini et al, 2020) of Arak in July (Source: Climate Consultant software).

The psychrometric chart (Figure 53) presented here provides information regarding the level of thermal comfort experienced in the city of Arak during the month of July. In addition to incorporating temperature and humidity, the psychrometric chart also incorporates a number of design concepts that aim to improve thermal comfort.

An analysis of the chart reveals that the chart illustrates the temperature of the dry bulb.

Across a number of different ranges, the frequency distribution of dry temperature include:

No time is spent at temperatures lower than 0 degrees Celsius.

There is a three percent chance that the temperature will be between 0 and 21 degrees Celsius.

thirty percent of the time, when the temperature is between twenty-one and twenty-seven degrees Celsius

When temperatures are between 27 and 38 degrees Celsius, 62% of the time they are inside that range.

2% of the time when the temperature is higher than 38 degrees Celsius

In relation to the greatest amount of moisture that the air is capable of holding at a specific temperature, the humidity level is stated as a percentage.

There are a number of lines on the graph that represent the relative humidity levels, and the lines that ascend diagonally from the bottom left to the top right indicate the proportion of absolute humidity.

Methods for the Design Process:

According to the paper from July, there are a number of different design ideas that are recommended to achieve thermal comfort.

The window darkening lasted for a total of 271 hours.

A total of 452 hours were spent using direct evaporative cooling, while 95 hours were spent using natural ventilation. Both methods were applied for the duration of the experiment.

The duration of time required for the sensory cooling procedure is a total of 39 hours.

Cooling of the entire system is required for 0.2% of the total monthly time.

Those Comfort Zones:

A graphic representation of the zones that define the ideal conditions for thermal comfort during the summer and winter seasons is presented here.

During the month of July in Arak city, the dry temperature frequently exceeds the range of temperatures that are regarded to be comfortable during the summer. This is the conclusion that can be drawn from the examination of the graph. It would appear from this that there is a necessity for the implementation of methods that lower the temperature of the surroundings. The utilization of window shading, evaporative cooling, and natural ventilation are all included in these strategies. Additionally, this can be accomplished by taking into account the thermal mass of the structure and using systems for night cooling, which can substantially reduce the amount of artificial cooling that is required. When it comes to planning buildings and choosing HVAC systems, it is essential to take these factors into consideration in order to achieve the maximum level of thermal comfort and the most effective use of energy.

Table 11. Simulation temperature results of Nowzari Caravanserai with dome roof on 15 July 2022.

Date/Time (July)	Relative Humidity %	Outdoor Dry-Bulb Temperature °C	Indoor Air Temperature °C
	Simulation	Simulation	Simulation
06:00:00	36.04	23.00	26.03
07:00:00	36.76	23.41	25.40
08:00:00	37.36	24.35	24.62
09:00:00	38.40	26.15	24.48
10:00:00	39.73	27.95	24.30
11:00:00	40.81	30.13	24.16
12:00:00	41.36	32.35	24.04
13:00:00	41.71	34.63	24.03
14:00:00	41.94	36.03	24.03
15:00:00	42.49	37.20	24.00
16:00:00	43.18	38.33	24.05
17:00:00	43.69	37.33	24.40
18:00:00	43.73	35.55	25.02
19:00:00	43.52	33.83	25.77
20:00:00	34.52	33.03	26.42
21:00:00	34.03	32.45	27.35

Analysis of table data (table 11):

Temperature measured in the open air without any moisture present:

The ambient temperature progressively rises from 23°C at 6:00 AM to a peak of 38.33°C at 4:00 PM. These numbers denote elevated temperatures in outer space.

Indoor Air Temperature: The temperature within the building remains consistently within the range of 24 to 27 degrees Celsius. The temperature stability of the caravanserai can be attributed to its structural characteristics, such as the thermal mass located above the walls and the domed roof.

Relative humidity: The relative humidity rises during the day, starting at 36.04% at 6:00 a.m. and reaching approximately 43.69% at 5:00 p.m., demonstrating an elevation in humidity as the temperature climbs.

Contrast with psychrometric chart (Figure 53):

When compared to the psychrometric chart (Figure 53), the graph reveals that the majority of the time during the month of July, the ambient temperature was higher than the range that is deemed to be comfortable for summer conditions. According to the design strategies that are presented in the chart, it is recommended to take into consideration measures such as window shading and direct evaporative cooling in order to reduce the temperatures that are found inside.

Based on the data presented in the table, it is possible to make the observation that the temperature within the building is rather stable and falls within the range of thermal comfort, despite the fact that the temperature outside has increased. This could be ascribed to the use of effective design strategies, such as the utilization of materials that have a high thermal mass and the utilization of suitable shading mechanisms, which successfully prevent the increase in temperatures that occur inside the building.

In addition, the findings suggest that Nowzari Caravanserai demonstrates an effective tolerance to high temperatures as well as considerable fluctuations in the temperature of the surrounding environment.

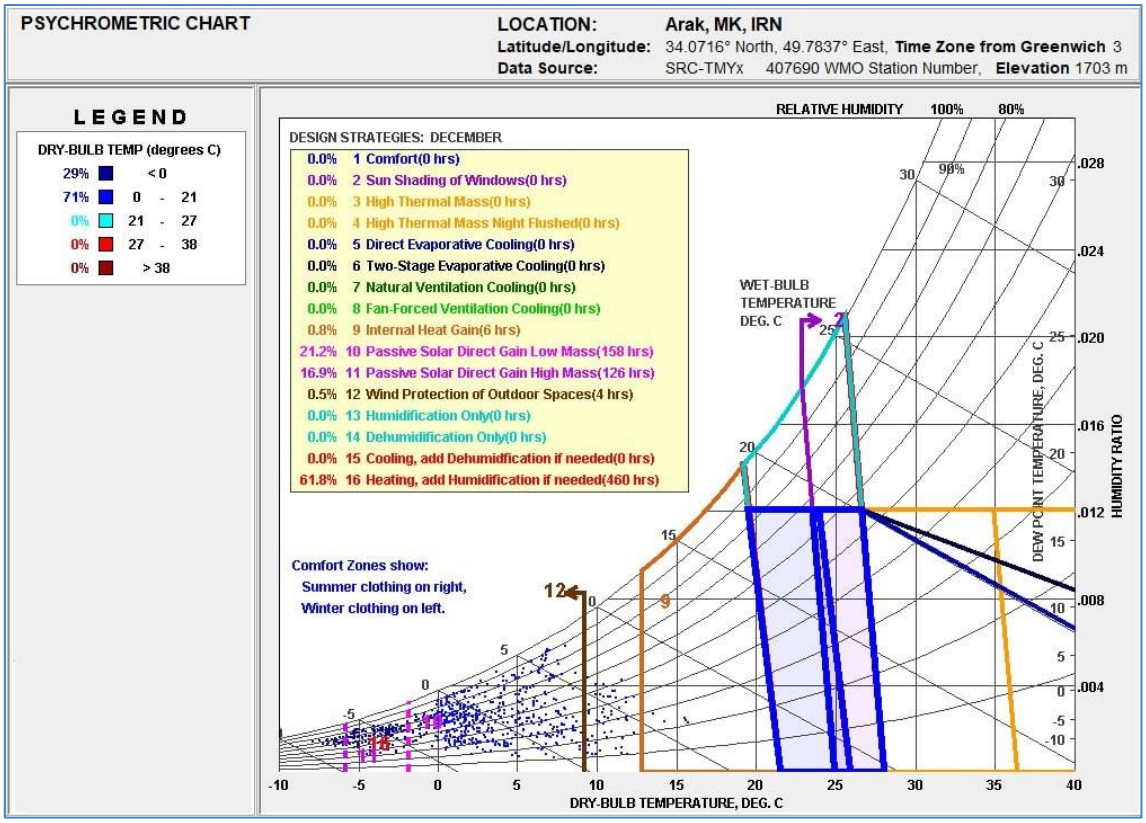


Figure 54: Thermal comfort chart of Arak in December (Source: Climate Consultant software).

The psychrometric diagram (Figure 54) that is given for the month of December in the city of Arak provides information regarding the dry-bulb temperature and relative humidity for this time period. Additionally, it highlights many design strategies that can be implemented to improve thermal comfort.

According to the psychrometric diagram, the dry-bulb temperature is as follows:

The majority of temperatures, which account for 71% of the total, fall within the range of 0 to 21 degrees Celsius, which indicates that the weather is cool to mild.

In situations where the temperature is below 0 degrees Celsius, cold conditions are indicated 29% of the time.

At a specific temperature, the humidity level is measured in relation to the maximum quantity of moisture that the air is capable of holding.

The relative humidity levels for this month are quite high, which is an indication that humid weather is now present.

Methods for the Design Process:

As a recommendation for design choices for the month of December, the figure suggests using passive solar direct gain low mass heating for 158 hours and passive solar direct gain high mass heating for 126 hours.

Sixty-one point eight percent of the time, there is a necessity for both heating and humidification, which indicates that heating measures are required the majority of the time.

Those Comfort Zones:

The graph demonstrates that temperatures remain outside of the range of comfort that is often associated with winter during the bulk of the month of December. This demonstrates that it is necessary to execute strategies that give warmth.

Table 12. Simulation temperature results of Nowzari Caravanserai with dome roof on 15 December 2022.

Date/Time (December)	Relative Humidity %	Outdoor Dry-Bulb Temperature °C	Indoor Air Temperature °C
	Simulation	Simulation	Simulation
6:00:00	20.27	−2.87	15.46
7:00:00	19.35	−2.06	16.96
8:00:00	17.94	−1.88	19.26
9:00:00	17.76	1.03	19.85
10:00:00	18.34	1.53	20.27
11:00:00	18.97	2.03	20.65
12:00:00	19.43	2.45	20.87
13:00:00	19.62	2.88	21.11
14:00:00	19.79	3.03	21.27
15:00:00	20.13	2.75	21.33
16:00:00	20.30	0.83	21.44
17:00:00	20.27	0.25	21.51
18:00:00	19.53	−1.85	21.72
19:00:00	18.80	−2.45	21.80
20:00:00	21.59	−3.98	20.27
21:00:00	22.26	−4.55	19.26

At Nowzari Caravanserai, the table, which is explicitly marked as table 12, provides accurate information regarding the temperatures both inside and outside as well as the relative humidity throughout the entire month of December. It is possible to link the data with the information that is presented in the psychrometric chart (Figure 54) in order to provide a comprehensive analysis of the thermal performance of the building during the winter temperatures.

The analysis of the data table (table 12):

Temperature of the Air:

by six o'clock in the morning, the temperature is -2.87 degrees Celsius, and it gradually rises to 3.03 degrees Celsius by two o'clock in the afternoon before continuing to fall.

The air temperature inside of a building is as follows:

The inside temperature is consistently warm and ranges between 15.46 and 21.80 degrees Celsius, despite the fact that the temperature outside is rather low overall.

At a specific temperature, the humidity level is measured in relation to the maximum quantity of moisture that the air is capable of holding.

The initial relative humidity at the beginning of the day is 20.27%, and it gradually decreases until it reaches 18.80% by 19:00. After that, at 21:00, it had advanced to a level of 22.26%.

Psychrometric chart analysis reveals that the majority of the time, the temperature outside is within the cool to cold range, which is between 0 and 21 degrees Celsius. This is indicated by the psychrometric chart for the month of December.

In order to further the concept of thermal comfort, various design solutions have been presented, including the utilization of direct sunlight and the implementation of active heating systems.

Comprehensive analysis: By combining this table with the psychrometric chart (Figure 54), we are able to see that the caravanserai's internal temperature reveals that it is able to maintain a pretty high temperature over the winter months, despite the fact that the

temperatures outside are exceedingly low. There are a few possible explanations for this, including the exploitation of thermal mass to absorb and hold heat, or the effectiveness of insulation.

It is demonstrated by the psychrometric chart (Figure 54) and design techniques that making use of solar radiation during the month of December is beneficial for increasing the temperature within the building. Additionally, the data table substantiates the fact that the temperature inside the building is efficiently maintained.

Upon careful inspection, it has been determined that Nowzari Caravanserai offers enough protection from the weather conditions that prevail in Arak during the month of December and has the capacity to maintain a temperature that is both constantly warm and comfortable inside. It is possible that this is due to particular architectural qualities, such as the thickness of the walls, the materials that were used in construction, and the use of passive solar approaches into the design of the structure.

6.3. Site Orientation

The northeast-southwest orientation of the Arak bazaar, which spans 14 hectares, is the direction in which it is located. Due to the presence of the color red, Figure 55 provides a clear illustration of the position of the Nowzari Caravanserai within the Arak Bazaar complex. This structure was built in a direction that runs from northeast to southwest.

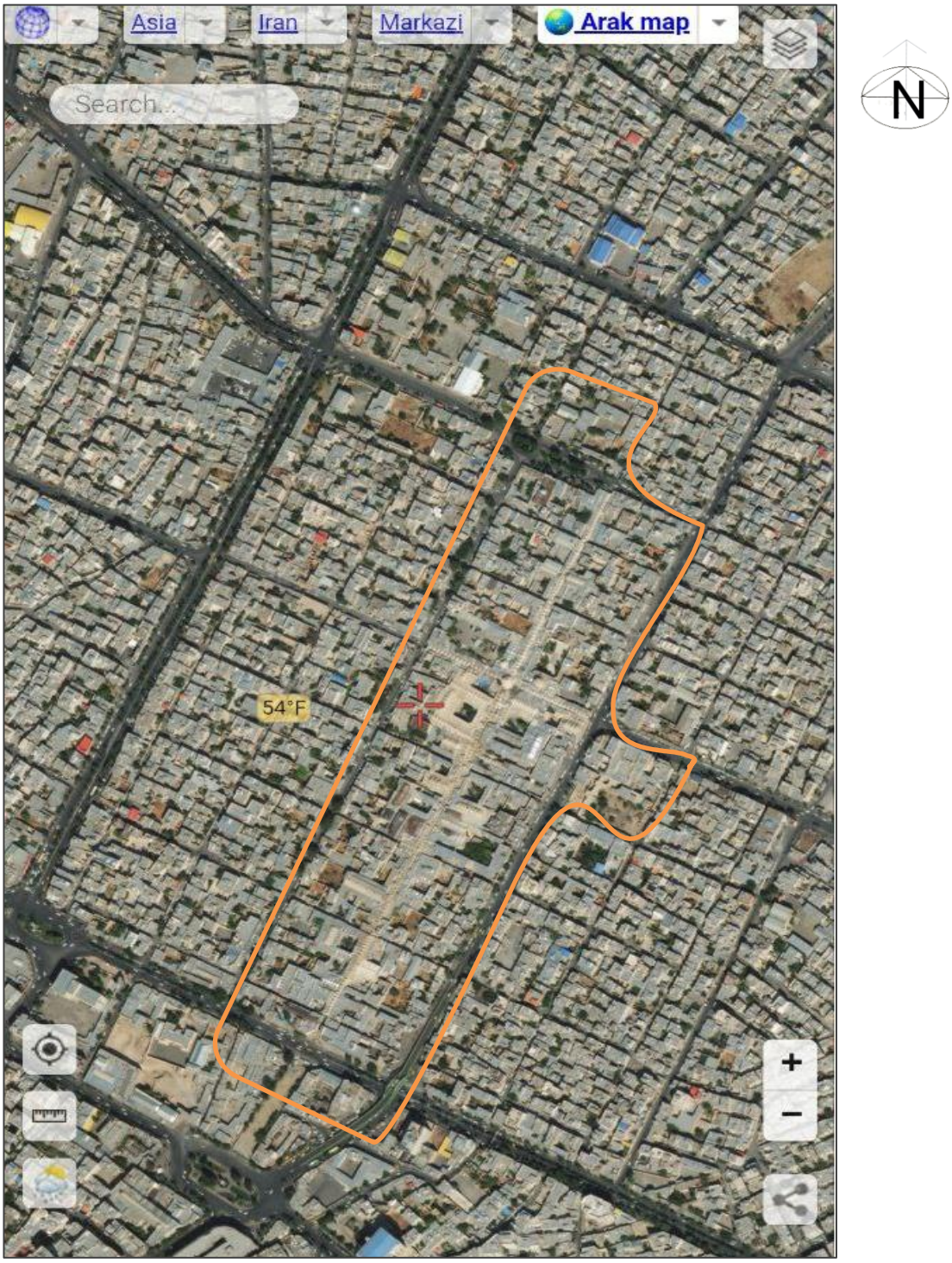


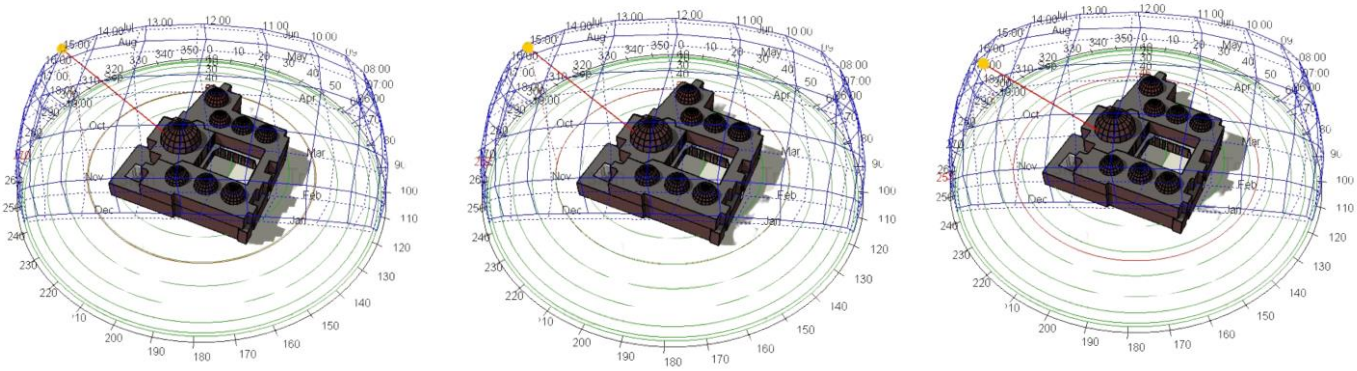
Figure 55: Satellite view of Arak Bazaar (source: satellites.pro//Iran, Markazi)

6.4. Site Shadow Analysis

According to the simulation, Figure 56 demonstrates that the eastern edge of the site is shaded during the summer season at midday, which is the time of day when temperatures are at their peak.

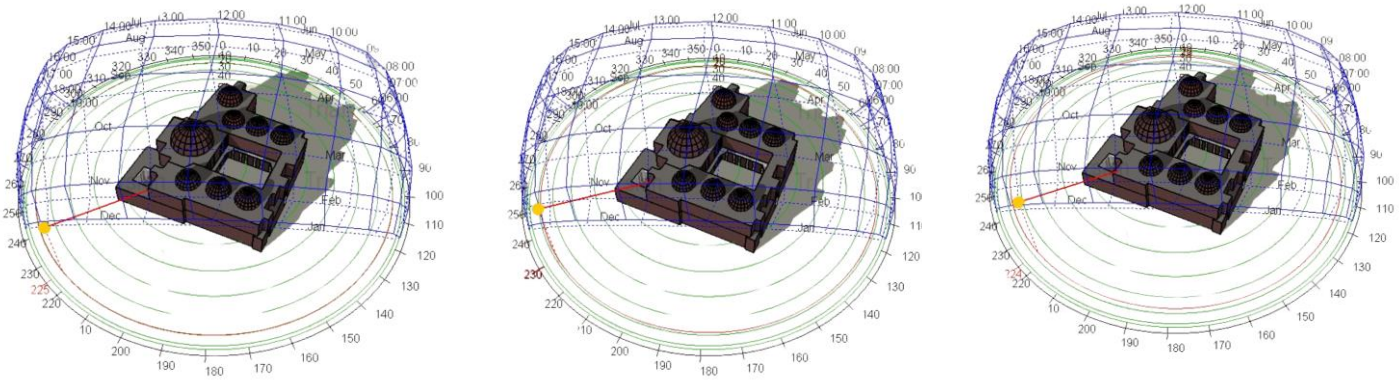
According to the simulation, the north-eastern border of the site encounters shade during the middle of the day during the winter season. This is illustrated in Figure 57. In addition, the simulation indicates that this occurs.

The orientation of the structure has an effect on the direction in which shade is experienced during the summer and winter seasons.



(a) (b) (c)

Figure 56: Shadow analysis for Nowzari Caravanserai in summer (a)June; (b)July; (c)August. (source: Design Builder software)



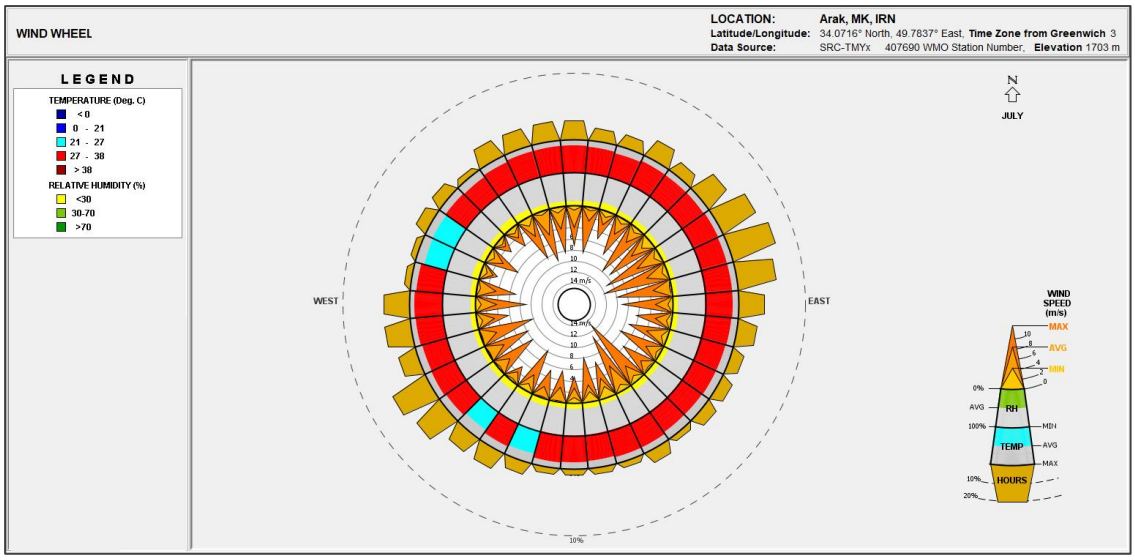
(a) (b) (c)

Figure 57: Shadow analysis for Nowzari Caravanserai in winter (a)November; (b)December; (c)January. (source: Design Builder software)

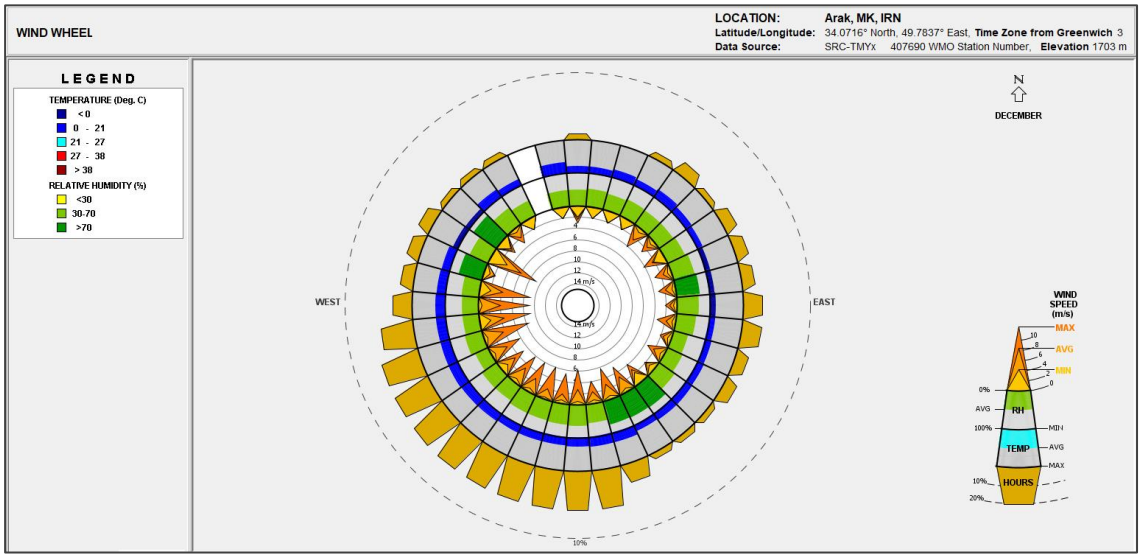
6.5. Site Wind Analysis

According to Figure 58a, the most intense and forceful winds occur in the northeast and southwest directions throughout the month of July, which is the time of year when temperatures are at their highest.

As seen in Figure 58b, the primary winds blow primarily from the south and southwest throughout the month of December, which is commonly considered to be the coldest month of the winter.



(a)



(b)

Figure 58: Wind Wheel for Arak. (a) in July; (b) in December. (Source: Climate Consultant software tool)

6.6. Passive Strategies used in the Design of Nowzari Caravanserai

Traditional architecture makes use of efficient methods to improve energy efficiency in Nowzari Caravanserai. The goal of these approaches is to lessen the amount of energy that is required to heat and cool the structure, which in turn will reduce the amount of energy that is consumed by the structure. The explanations for some of the effective methods and strategies that are utilized in Iranian vernacular architecture to deal with a hot and dry climate have already been presented in the parts that came before this one. After that, the material that follows provides an overview of the traditional and passive methods that were utilized during the design process of the Nowzari Caravanserai.

6.6.1. Courtyards and Ponds

Courtyards are a prominent and widely embraced element of traditional Iranian architecture. The courtyard offered both security and seclusion for the residents, while still providing ample natural light for the adjacent rooms (Figure 59).

A delightful outdoor area has been built for the residents to enjoy during the summer months, featuring a centrally located pool and the addition of deciduous trees in the yard.

Indeed, this system functions as a microclimate, characterized by a slightly lower air temperature and a greater relative humidity as compared to indoor areas. The aspect ratio of courtyards to enclosed spaces is crucial for achieving optimal performance.

The ideal proportion of the courtyard's area to the overall area of the building can differ based on unique site characteristics, building orientation, and the intended equilibrium between cooling and ventilation effects. Nevertheless, it is commonly advised to maintain a typical range of 20-40% for courtyards in arid and warm areas in order to optimize their capacity for cooling (Zamani, Heidari, & Hanachi, 2018). This means that the courtyard should occupy between one-fifth and one-third of the total floor area of the building (Soflaei et al. 2017).

Expanding the size of the courtyard can enhance shading and minimize the amount of direct solar heat absorbed by the building's walls, resulting in a cooler internal atmosphere. Nevertheless, an excessively spacious courtyard can also impede the flow of

fresh air, which is crucial for eliminating heat and humidity from the indoor areas. Hence, it is imperative to maintain an equilibrium between these two components (Zamani, Heidari, & Hanachi, 2018).



Figure 59: Central courtyard in Nowzari Caravanserai

The inclusion of a central courtyard within the core of the Nowzari Caravanserai structure (Figure 60) has effectively optimized the utilization of air conditioning during the summer season. The yard serves the purpose of facilitating natural ventilation and also provides shading on the walls. Cross ventilation is achieved in each space by opening the windows that face the yard on one side and the windows that face the street on the other side, resulting in a decrease in the level of heat and humidity.

The central courtyard functions as a natural cooling mechanism for the inner spaces by acting as an air cooler and facilitating the escape of hot air. The center courtyard serves as an artificial ventilation system, in addition to its role in arranging and connecting other locations inside the neighborhood.

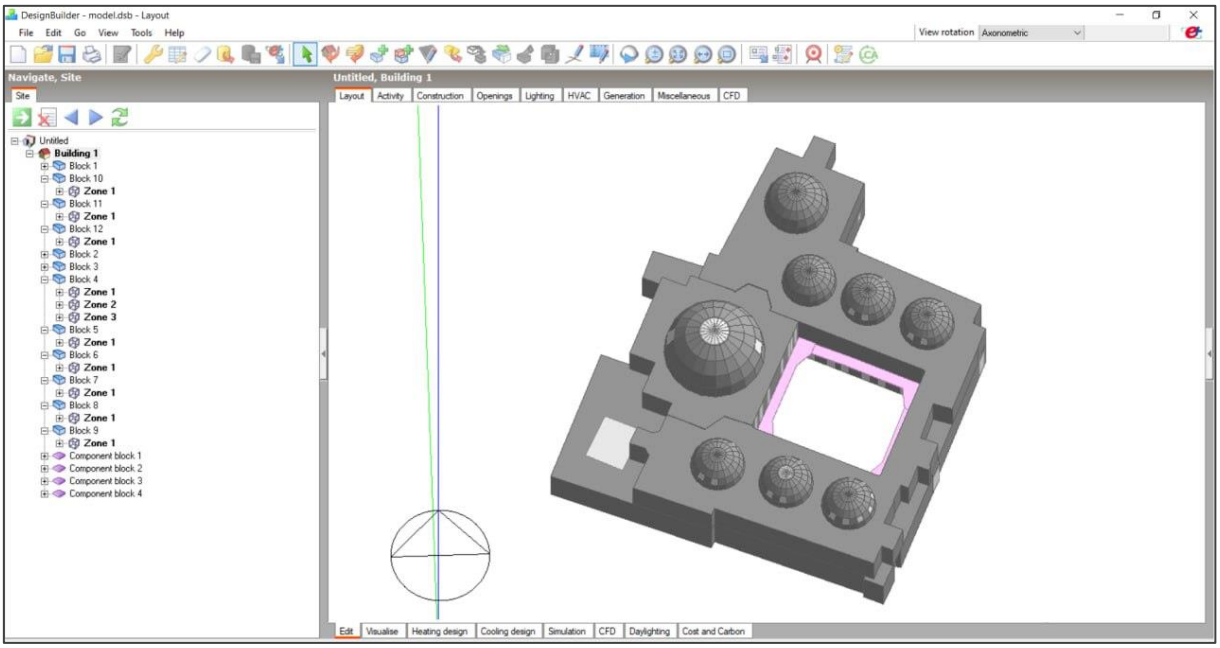


Figure 60: Central Courtyard within the core of the Nowzari Caravanserai (source: Design Builder software)

6.6.2. Natural Ventilation

The opening plays a significant role in the architectural composition of the Arak region. The distribution of shop openings is directly correlated with the direction of wind flow, which significantly impacts the establishment's ability to maintain optimal thermal comfort conditions within the building. The orientation of the structure's apertures is crucial, as it directly affects the ingress of light and the circulation of air within the building. The wind in summer blows predominantly from the west, south-west, and north-east directions (Figure 58 a). Because the Arak caravanserai is linked to the adjacent caravansaries on its southern side, it lacks windows or openings in that direction. However, the wind originating from the west and southwest has the potential to infiltrate the center courtyard (Figure 60). The windows are situated on the northern side of the construction, which is positioned in the geographical northeast direction (Figure 61).

The image (Figure 61) depicts the complete simulated structure, which has been turned 90 degrees in a clockwise direction to ensure the visibility of the windows.

The windows on this side facilitate the expulsion of wind that reaches the central courtyard from the southwest and west, allowing it to flow into the adjacent businesses and enabling natural air circulation.

Furthermore, during certain hours of the day, the wind blows from the northeast (Figure 58 a), allowing it to pass through these windows.

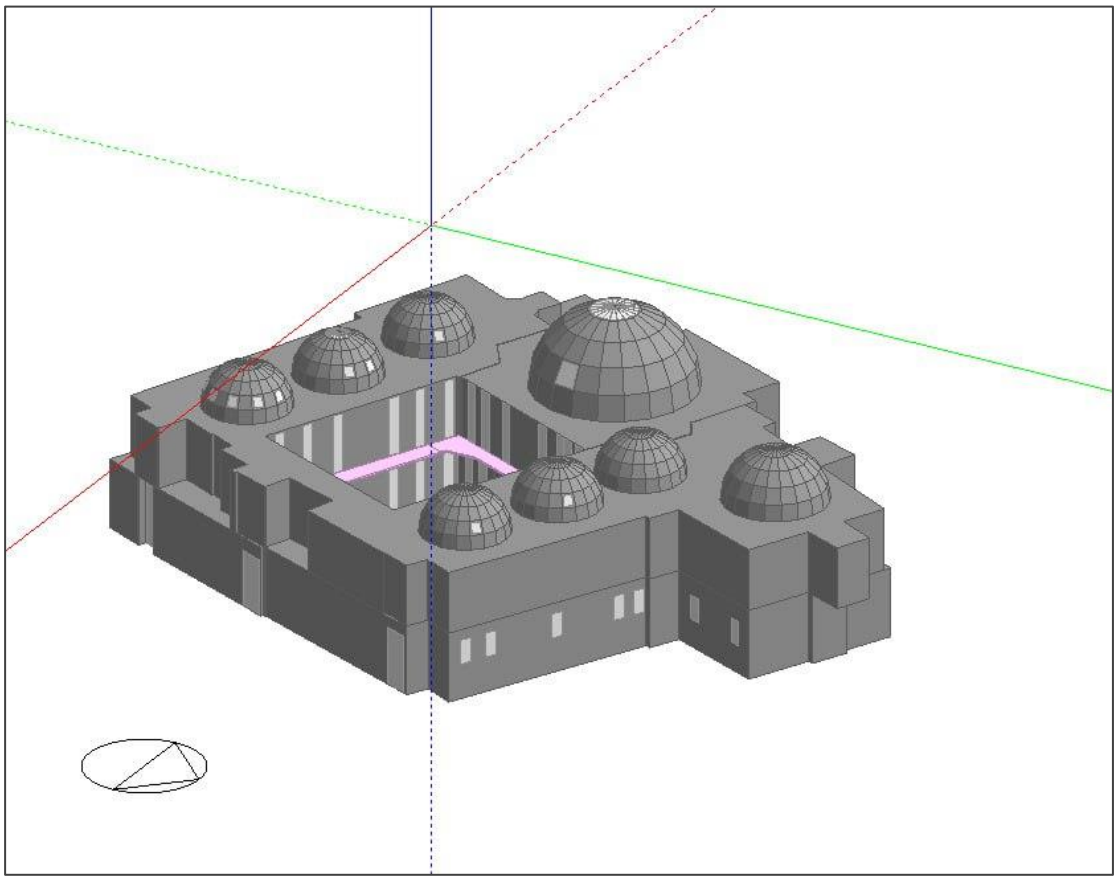


Figure 61: The placement of windows. By 90 degrees, the simulated structure is rotated clockwise. (source: Design Builder software)

To obtain additional details and view the software's simulation configurations, please consult the annexes located on page 45.

Furthermore, the domes of Nowzari Caravanserai are equipped with ventilation apertures (Figure 62), in addition to the accurate positioning of the windows. The quantity of apertures fluctuates based on the positioning of the dome on the edifice.

The size of the ventilation hole varies depending on the dimensions of the dome.

To examine the impact of ventilation holes on energy usage, please consult Chapter 6, specifically page 110 & 111.

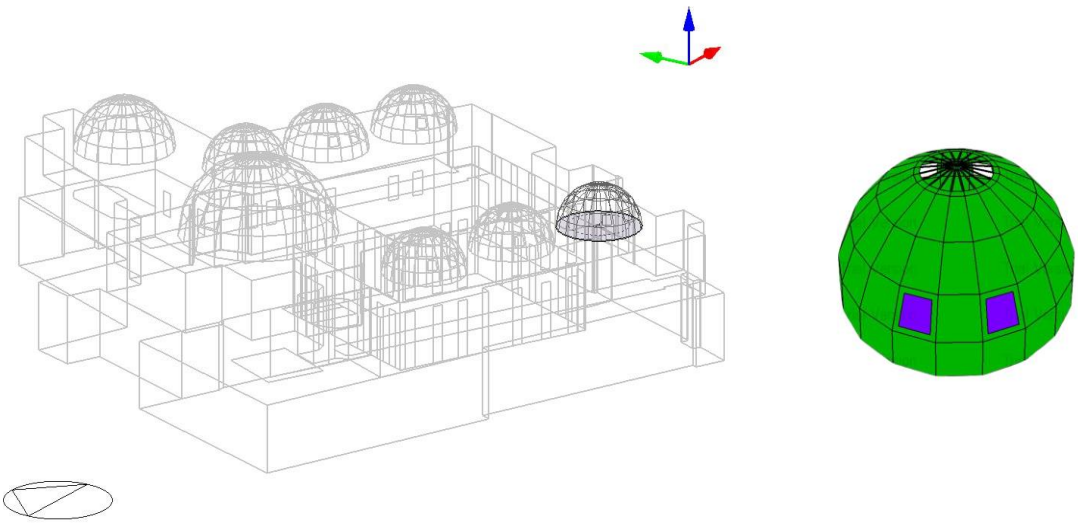


Figure 62: Dome ventilation openings on the Nowzari Caravanserai. (source: Design Builder software)

To obtain additional details and view the software's simulation configurations, please consult the attachment located on page 46 & 47.

6.6.3. Material Color

One of the distinctive features chosen by the architect for a building is the exterior colors of the building's envelope. The selection of external colors can significantly influence the overall aesthetic and visual attractiveness of the structure. Additionally, it can contribute to energy efficiency by virtue of lighter colors reflecting sunlight and minimizing heat absorption, whereas darker colors may intensify heat absorption. Hence, it is crucial to meticulously choose colors that harmonize with the architectural design and correspond to the intended environmental performance of the structure. (Sadineni, Madala, & Boehm, 2011).

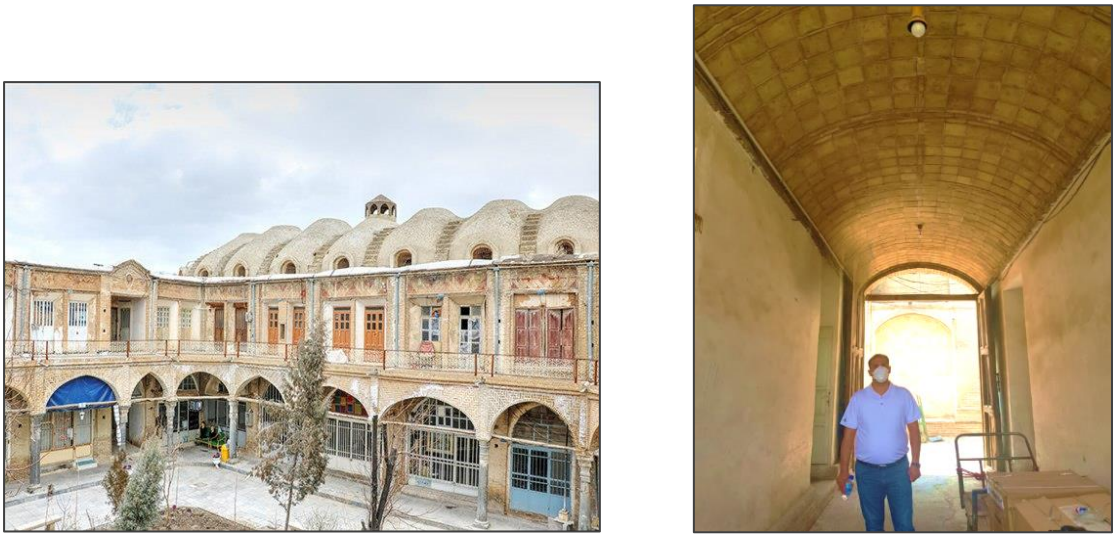


Figure 63: The color of the material used in the walls and structure of Nowzari Caravanserai.

The walls and ceilings in Nowzari Caravanserai appear to be light in hue, as depicted in Figure 63.

6.6.4. Constructional Materials

The envelope of an energy efficient structure is a crucial design issue. It has been demonstrated that effectively insulating a structure to retain or block heat is one of the most economically efficient methods of conserving energy. Utilizing materials with low thermal conductivity and high thermal mass can decrease heat transfer through the building in hot-dry conditions, hence reducing energy expenses within the buildings. The thermal flywheel effect is achieved by using thick and heavy walls constructed of construction materials with low thermal conduction. This effect creates a cold climate in summer and a warm environment in winter (Sadineni, Madala, & Boehm, 2011).

The construction of Nowzari Caravanserai utilized materials such as brick, Gypsum plastering, and concrete (Figure 64).

The specifications of the parameters incorporated in the simulation software pertaining to the materials employed in the Nowzari Caravanserai structure are provided on the pages 20 – 35 in annexes. The attachment contains the Convective heat transfer coefficient and radiative heat transfer coefficient of all materials utilized in the structure of the caravanserai.

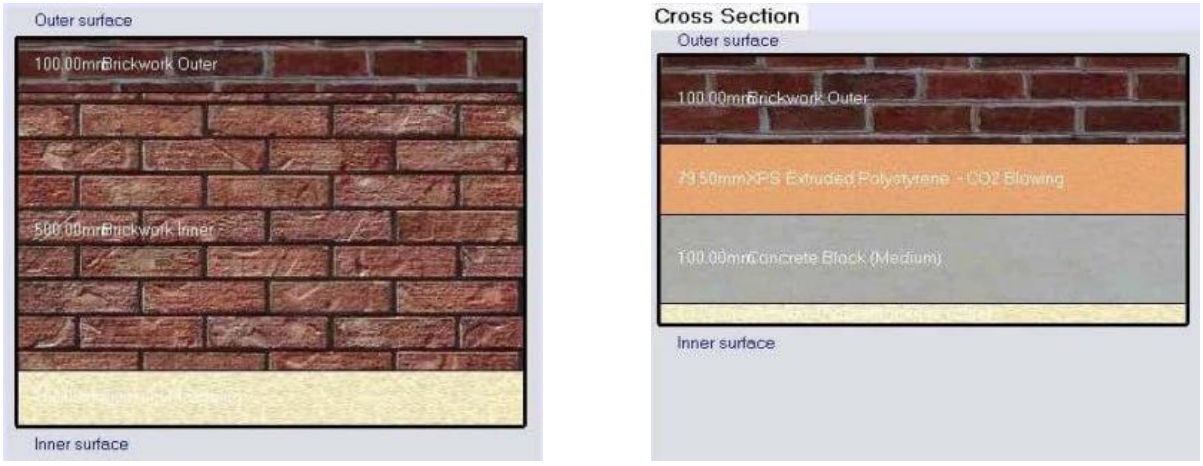


Figure 64: Materials utilized to build the Nowzari Caravanserai's walls and structure. (source: Design Builder software)

6.7. Discussion

Latitude 34.07 degrees north and longitude 49.78 degrees east are the coordinates of the city of Arak, which can be found in the central province of Iran. The elevation of the city of Arak is 1703 meters above the level of the sea.

When summer arrives, this city's climate is hot, and when winter arrives, it is chilly.

As can be seen in Figure 19, the yearly mean temperature for Arak is roughly 14 degrees Celsius, whereas the comfort zone, as defined by the Adaptive Comfort Model in ASHRAE Standard 55- 2020, varies from month to month and has a range that takes it from 21 degrees Celsius to 27 degrees Celsius. In Arak, the highest temperature ever recorded for a typical year was 41 degrees Celsius in July, and the lowest temperature ever recorded was -7 degrees Celsius in December.

Figure 19 indicates that the weather is chilly during the months of January, February, March, November, and December. In order to achieve a temperature that is pleasant, it is required to make use of the heating system during these period of time. The weather is hot during the months of June, July, and August, and it is necessary to have a cooling system in order to achieve a temperature that is pleasant between the hours of twelve o'clock midday and twelve o'clock night.

The monthly diurnal average for Arak is depicted in Figure 42. During the months of June through August, the Global Horizontal radiation reaches its highest point of approximately 950 Wh/sq.m. This is also the time when the dry and wet bulb temperatures are at their highest levels. In addition, the maximum levels that were received for Worldwide Horizontal radiation were 960 Wh/sq.m in the month of June, 830 Wh/sq.m for Direct Normal radiation in the month of August, and 210 Wh/sq.m for Diffuse radiation in the month of April.

Figure 45 is a diagram of the sun and shadows that are cast over the city of Arak. For the period beginning on June 21 and ending on December 21, this chart (figure 45 a) indicates that on days with temperatures greater than 27 degrees Celsius, 932 hours of shade are required in order to achieve the desired level of thermal comfort inside the indoor environment. Additionally, pleasant circumstances are established at temperatures ranging from 20 to 27 degrees Celsius per year, for a total of 456 hours, with the assistance of appropriate shading. In order to maintain a suitable interior atmosphere on days that have an annual temperature of less than 20 degrees Celsius, 820 hours of sunlight are required.

It takes 305 hours of shade to attain thermal comfort in an interior environment on days with temperatures higher than 27 degrees Celsius from December 21 to June 21 (figure 45 b). This is the amount of shading that is required to fulfill this need. Through the utilization of shading, comfortable circumstances may be maintained for a total of 292 hours at a temperature that ranges from 20 to 27 degrees Celsius throughout the year. In order to maintain a suitable interior atmosphere on days that have an annual temperature of less than 20 degrees Celsius, there must be a total of 1600 hours of sunlight.

The Wind Wheel depicted in Figure 47 displays the Wind Velocity and the frequency of occurrence for each wind direction, in addition to the present average Dry Bulb Temperature and Relative Humidity. On average throughout the year (figure 47), the wind blows from the west and southwest. In July, the wind blows from the southwest and northeast (figure 58 a), and in December, the wind blows from the south and southwest (figure 58 b).

Figure 52 depicts a psychometric chart that provides an overview of the primary design concept for Arak. According to the results of the internal temperature obtained from the simulation of Nowzari Caravanserai with a dome roof by Design Builder software (reported in Tables 11 and 12), and in accordance with the comfort range shown in Figure 53 and 54 (where the range of thermal comfort in July is reported to be between 25 and 27 degrees Celsius, and in December it is reported to be between 19 and 24 degrees Celsius), The percentage of indoor air that does not fall inside the thermal comfort level is only 18.75% in July of 2022. In addition, the temperature of the air within the building is only outside the thermal comfort zone 12.5% of the time during the month of December, which is the coldest month of the current year.

Taking into consideration the predominant wind patterns, the orientation of the Nowzari Caravanserai is perfectly adapted to the surroundings of the city of Arak. It is more common for the wind to blow from the northeast and west during the summer months (Figure 58 a), whereas during the winter months, it is more likely to blow from the south and southwest (Figure 58 b).

Choosing the most advantageous building orientation is a crucial decision in designing for energy efficiency, as it directly affects the energy performance of the building envelope. Al-Tamimi et al. (2011) highlighted this matter and conducted a study to examine the impact of building orientation on energy usage (Al-Tamimi et al. 2011).

During the warmer months, the caravanserai's orientation along the northeast-southwest direction allows for the most efficient movement of air (Figure 55, 56, 57). It is possible for the breeze to easily enter the caravanserai through the courtyard when it is blowing from the northeast or west. This provides a sensation that is both refreshing and

invigorating. In addition to this, the dome creates a cross-ventilation phenomenon and makes air circulation easier to achieve.

Due to the location of the caravanserai, it is possible to make use of passive solar heating throughout the winter months (Figure 57). When the sun is at a low angle in the sky, it casts direct rays into the courtyard, which causes the structure to become heated. This occurs during the time when the sun is in this position. This heat is contained and maintained by the dome, which ensures that the caravanserai is kept at a comfortable temperature.

In addition to its other important functions, the central courtyard of the caravanserai is responsible for maintaining the temperature. The courtyard works as a thermal reservoir, collecting thermal energy from the atmosphere during daylight hours and subsequently expelling it during nighttime. Due to this characteristic, the caravanserai is able to maintain a cool temperature during the summer and a warm temperature during the winter. Confirming this matter, we can cite the recent study conducted by Zamani, Heidari and Hanachi in 2018, wherein they asserted that courtyards, when designed with appropriate geometry and other settings, have the ability to effectively filter solar radiation, facilitate natural ventilation, decrease energy usage, and enhance the microclimate of the building (Zamani, Heidari & Hanachi, 2018).

Additional research has demonstrated that deep and narrow courtyards offer increased amounts of shade, resulting in ideal thermal comfort (Al-Hafith et al, 2017; Guedouh & Zemmouri, 2017) . Nevertheless, enhancing the flow of air via open areas might result in excessive heat buildup in arid regions with high temperatures. Higher openings can cause greater discomfort than their lower counterparts. Thus, in arid and warm climates, it is more advantageous to have enclosed yards (Chatzidimitriou & Yannas, 2016; Berkovic et al, 2012).

Both the orientation and construction of the Nowzari Caravanserai provide a number of additional benefits, including the following:

Because of its location, the caravanserai is protected from the harsh winter winds (Figure 58 b). As a result of the caravanserai's ability to capture natural sunshine, the amount of artificial illumination that is required is significantly reduced.

The central courtyard of the caravanserai functions as a community space where folks can assemble and engage in social interactions with one another.

In addition to contributing to the creation of a unique ambiance, the dome of the caravanserai gives the structure a more appealing appearance from an aesthetic standpoint.

In general, the orientation and architecture of the Nowzari Caravanserai are quite suitable for the weather conditions that prevail in the city of Arak. The structure is able to successfully harness the natural elements in order to create an environment that is both pleasurable and environmentally friendly for the people who live there.

The results obtained from this investigation validate and broaden the scope of prior research activities that have investigated energy usage in various architectural configurations. The energy consumption of the flat-, dome-, and sloping-roof structures exhibited notable dissimilarities, particularly in the months with high temperature peaks.

During the month of December, it was observed that flat structures exhibited the highest energy consumption. This observation is consistent with the research conducted by Jimin et al. (2020), which indicated that the dome roofs exhibit a greater amount of radiant reflection compared to their matching flat roofs. Thus, domed roofs are mostly employed in arid and warm regions, as they absorb an equivalent quantity of radiation as flat roofs but experience greater heat loss through convective heat transfer (Runsheng, 2003; Faghih & Bahadori, 2011; Jimin et al. 2020).

This observation is consistent with the findings of Abraham et al. (2016), who suggested that the energy-efficient characteristics of dome structures could be attributed to their geometric shape (Abraham, & Chandran, 2016). The airflow passing over the dome enhances the convectional heat transfer to the surrounding air. In addition, the roof experiences an increase in heat loss due to thermal radiation sent towards the sky. The remaining heat received by the dome is carried through the dome material and ultimately distributed to the interior air by convection, as well as to the interior walls through radiation. The specific geometry of these roofs leads to an augmentation in wind velocity above them, thus leading to an elevation in the convection heat transfer coefficient (Faghih & Bahadori, 2011). (More information about the absorption coefficient in the domed ceiling in annexes, pages 48 & 49).

Moreover, the heat transfer from these roofs is enhanced due to their larger surface areas compared to flat roofs.

In the month of July, which is typically characterized by high temperatures, there was a decrease in the energy-consumption discrepancy among various architectural designs. However, it is noteworthy that flat structures continued to exhibit the highest energy-consumption levels. The dome structures exhibited commendable energy efficiency by

consuming relatively low energy, as confirmed by the findings of (Mahdavinejad et al. 2013; Faghih, & Bahadori, 2011; Doke, 2022), particularly during temperature extremes.

Regarding the temporal discrepancy between outdoor and indoor temperatures, the warm season of the year also plays a role in enhancing energy efficiency. Improved insulation can result in decreased energy consumption, as evidenced by a delayed indoor response to outdoor temperatures. The correlation coefficient of −0.39534 observed between outdoor and indoor temperature suggests a moderate association between these variables. This finding implies that changes in outdoor temperature do not necessarily result in corresponding changes in indoor temperature. These results are consistent with the research carried out by (Varzaneh, 2014; Gounni et al. 2022; Piselli, 2019).

The supplementary discoveries serve to underscore the variations in thermal regulation and energy expenditure among diverse architectural arrangements, with particular emphasis on the dome-shaped edifices situated in Arak Bazaar.

During the month with the lowest temperatures, the minimum temperature of −5.925 °C was documented at 1 AM, while the maximum temperature of 3.025 °C was recorded at 2 PM. The aforementioned fluctuations were found to be uniform, as the indoor temperature levels displayed a mean absolute deviation of roughly 19.32 °C during daytime hours and 21.94 °C during nighttime hours, relative to the corresponding outdoor temperature levels. The significant contrast highlights the insulating capabilities of dome-shaped structures, which aligns with the research conducted by Sedighi (2017) & Vega (2023), demonstrating that dome structures demonstrate better thermal efficiency in comparison to alternative designs.

Furthermore, a statistically significant positive correlation coefficient of +0.704731 was observed between the outdoor and indoor temperatures. This represents a deviation from previous discoveries that indicated a feeble adverse association. The alteration in temperature regulation within the dome structures at Arak Bazaar can potentially be ascribed to their distinct characteristics, including the presence of ventilation apertures. These features may have contributed to a heightened sensitivity to fluctuations in external temperature.

The Design Builder software was utilized to conduct a comprehensive assessment of the ventilation apertures present in the dome roofs. The study aimed to compare the energy

consumption of two scenarios—one with ventilation holes and the other without—in order to determine their respective impacts. The findings indicate that structures featuring apertures for ventilation exhibit reduced energy consumption, corroborating prior scholarship that underscores the significance of passive ventilation in augmenting energy efficacy. The studies conducted by Soleimani et al. (2016), Vega et al. (2023), & Ayoariyo & Atolagbe, (2021) are of academic interest.

The observed trends were in line with prevailing assumptions and align with the outcomes of prior research activities (Mirzazadeh Akbarpoor et al. 2021; & Ahn et al. 2022).

7. Chapter 7

Conclusions

This research embarked on a detailed examination of the bioclimatic strategies implemented in the traditional bazaar of Arak city. The primary aim was to explore how these strategies influence thermal comfort within this significant historical and commercial landmark. This exploration was particularly pivotal for understanding the broader implications of bioclimatic principles in architecture. In this context, the traditional bazaar of Arak city was not just a case study but a critical model that encapsulates the confluence of traditional Iranian architectural wisdom with contemporary bioclimatic approaches.

The thesis was structured around three primary goals: conducting a comprehensive literature review to understand the application of bioclimatic techniques in commercial buildings at the global level and within traditional Iranian architecture, executing a simulation a part of the Arak bazaar to investigate the bioclimatic factors in its environment, and verifying the simulation data through experimental field observations. This multi-faceted approach allowed for a thorough analysis of the bazaar's bioclimatic attributes and their impact on energy efficiency and indoor comfort conditions.

Central to this investigation was the research hypothesis that the type of roofing in the Arak bazaar significantly contributes to its bioclimatic behavior, notably reducing energy demand and enhancing indoor comfort. This hypothesis aimed to underscore the pivotal role of architectural elements in bioclimatic design, positing that traditional design features can be instrumental in achieving modern sustainability goals.

The research documented the climate parameters of Arak city through simulation with Climate Consultant software and using the local climate data file taken from the Energy Plus climate data engine.

To validate the simulation results, field measurements were compared with simulated data. The research involved comprehensive documentation of various architectural elements and an extensive energy survey. The comparison of temperature readings from field measurements and simulations revealed a discrepancy of 1 to 3 percent, which falls within the acceptable range according to validation studies of the Design Builder simulation software. This indicates a high degree of accuracy in the simulation results.

In the hottest month of the year, the mean absolute temperature difference between indoor and outdoor environments was found to be -6.44°C during the day and -1.54°C at night, indicating the indoor temperature was consistently lower than the outdoor temperature. During the coldest month, the difference between the highest and lowest

temperatures during the day is, on average, about 19.32 °C. At night, the difference between the highest and lowest temperatures is, on average, around 21.94 °C. The statement suggests that the indoor temperature of the building maintains during the daytime and higher during the night-time in comparison to the outdoor temperature.

The ASHRAE Standard 55-2020 was utilized to assess thermal comfort, indicating the effectiveness of the building's design in maintaining comfort despite external temperature variations.

The implementation of materials possessing high thermal mass and light hues, coupled with the appropriate geographical alignment of the caravanserai to harness local winds and the shading mechanisms of the domes, proved efficacious in averting the rise in internal temperature despite the escalation in external temperature.

The study emphasized significant variations in energy usage between flat, dome, and sloping roofs, especially during months with extreme temperature spikes. Dome-shaped roof exhibit superior thermal efficiency.

A comparative analysis of structures with and without ventilation apertures in dome roofs showed that with ventilation holes exhibited reduced energy consumption, highlighting the importance of passive ventilation for energy efficiency.

The findings underscore the importance of sustainable architectural practices, particularly in regions with extreme climatic conditions. By demonstrating the effectiveness of traditional roofing styles in energy conservation and thermal comfort, this research advocates for a re-examination and potential revival of such methods in contemporary designs. This could lead to more environmentally conscious building practices that leverage local materials, traditional techniques, and natural ventilation strategies to achieve energy efficiency.

The study provides practical insights for architects and builders, particularly in the context of energy-efficient and cost-effective construction. The detailed analysis of thermal performance across different roofing types offers valuable guidelines for choosing appropriate designs based on climatic conditions and building functions.

This thesis opens up new avenues for future research in several key areas. Firstly, it invites further exploration into the integration of traditional architectural elements with modern building technologies. Secondly, the study's methodology, combining field measurements with simulation tools, provides a robust framework for future architectural research, encouraging a more empirical approach to architectural design and assessment. Finally, given the specific focus on the bazaar of Arak city, the study highlights the potential for regional-specific architectural research, underscoring the importance of contextual and cultural factors in design decisions.

Despite the interesting findings, this research, like all studies, is subject to constraints that impact the validity of the conclusions. To ensure the results may be applied to a wider context, it is important to take into account these restrictions as well.

One of the primary limitations of this research is its geographical and architectural scope. While the traditional bazaar of Arak city provides a rich and illustrative example of bioclimatic architecture, the findings may not be universally applicable to other regions with different climatic conditions and cultural architectural practices. This geographical limitation suggests the need for caution in generalizing the results.

Although the combination of field measurements and simulation tools offered robust data, there were inherent limitations in this approach. The simulation models, despite their accuracy, might not capture the full complexity of real-world environmental interactions. Additionally, the field measurements were constrained by the specific time frames and conditions under which they were conducted, which may not comprehensively represent the full range of environmental and operational variables.

Conducting a study of this magnitude inevitably encounters resource and time limitations. More extensive field studies, encompassing a broader range of buildings and longer observation periods, might have yielded more comprehensive data. However, due to practical constraints, the research had to be limited in scope and duration.

Future research should aim to explore the application of bioclimatic principles in a variety of geographical locations, particularly in different climatic zones. This would provide a broader understanding of how these principles can be adapted to diverse environmental and cultural contexts.

Further research could involve a comparative analysis of bioclimatic strategies in different architectural styles, including contemporary and traditional designs. This would enrich the understanding of how different architectural choices impact energy efficiency and thermal comfort.

Future studies could employ more advanced simulation tools or develop new models that better capture the complexities of traditional architecture. Also, incorporating user experiences and feedback into the research could provide valuable insights into the practical implications of bioclimatic designs. Studies focusing on occupant comfort and behavior in relation to bioclimatic architecture would add an important dimension to the field.

As I conclude this significant phase of my academic journey, I find myself reflecting on the profound impact this research has had on my professional and academic development. This thesis, focusing on the bioclimatic strategies employed in the traditional bazaar of Arak city, was not just an academic endeavor but a journey of discovery and learning.

Delving into the intricate world of bioclimatic architecture has significantly deepened my understanding of how traditional design principles can be effectively merged with modern sustainability needs. I learned the importance of considering environmental factors and cultural heritage in architectural design, which has reshaped my perspective on sustainable architecture.

This research journey has heightened my appreciation for interdisciplinary approaches. The blend of architecture, environmental science, and cultural studies in this thesis has taught me the value of looking beyond the confines of a single discipline to find comprehensive solutions to complex problems.

The process of conducting this research honed my skills in data analysis, critical thinking, and academic writing. Navigating through the challenges of fieldwork, simulations, and literature review was a rigorous exercise in problem-solving and perseverance.

Engaging with the practical aspects of architectural design, particularly through field measurements and simulations, provided me with invaluable insights into the real-world implications of architectural decisions. This experience has bridged the gap between theoretical knowledge and practical application, which is essential in my professional growth as an architect.

In summary, this research has been a transformative experience, equipping me with the knowledge, skills, and insights necessary to contribute meaningfully to the field of architecture. The journey has been challenging but incredibly rewarding, and I look forward to applying these learnings in my future endeavors.

As this thesis draws to a close, it stands as a testament not only to the rich architectural heritage of Arak city but also to the enduring relevance of bioclimatic principles in our quest for sustainable living. This research journey has been more than an academic pursuit; it has been a deep exploration into the harmonious blend of tradition and innovation, reminding us that the answers to contemporary challenges often lie in the wisdom of the past.

The traditional bazaar of Arak city, with its intricate design and sustainable practices, emerges not just as a historical monument but as a blueprint for future architectural endeavors. It underscores the profound impact that thoughtful, context-aware design can have on environment and society. This thesis reaffirms that sustainable architecture is not a modern concept but a timeless principle, deeply rooted in our history and culture.

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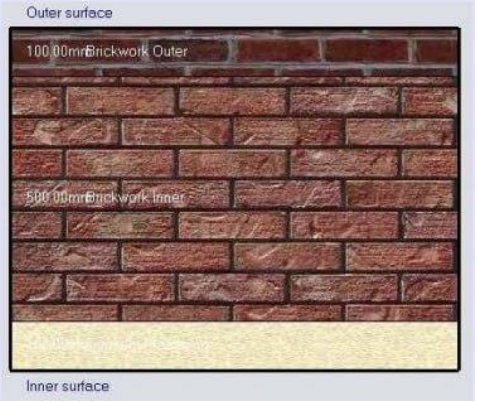
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Annexes

Setting Panel of Design Builder software

External walls

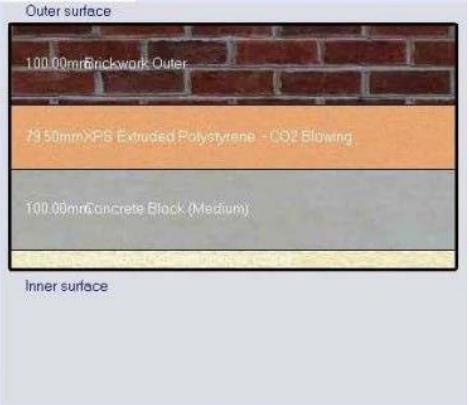
General	
Project wall	
Source	
Category	Walls
Region	IRAN (ISLAMIC REPUBLIC OF)
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	3
Outermost layer	
Brickwork Outer	
Thickness (m)	0.1000
Bridged?	No
Layer 2	
Brickwork Inner	
Thickness (m)	0.5000
Bridged?	No
Innermost layer	
Gypsum Plastering	
Thickness (m)	0.1000
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.851
R-Value (m2-K/W)	1.345
U-Value (W/m2-K)	0.743
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.7000
Upper resistance limit (m2-K/W)	1.345
Lower resistance limit (m2-K/W)	1.345
U-Value surface to surface (W/m2-K)	0.851
R-Value (m2-K/W)	1.345
U-Value (W/m2-K)	**0.743**
Cost	
Cost type	1-Auto-calculate



Below grade walls

General	
Project below grade wall	
Source	
Category	Below grade walls
Region	IRAN (ISLAMIC REPUBLIC OF)
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	4
Outermost layer	
Brickwork Outer	
Thickness (m)	0.1000
Bridged?	No
Layer 2	
XPS Extruded Polystyrene - CO2 Blowing	
Thickness (m)	0.0795
Bridged?	No
Layer 3	
Concrete Block (Medium)	
Thickness (m)	0.1000
Bridged?	No
Innermost layer	
Gypsum Plastering	
Thickness (m)	0.0130
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.372
R-Value (m2-K/W)	2.856
U-Value (W/m2-K)	0.350
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.2925
Upper resistance limit (m2-K/W)	2.847
Lower resistance limit (m2-K/W)	2.847
U-Value surface to surface (W/m2-K)	0.372
R-Value (m2-K/W)	2.857
U-Value (W/m2-K)	**0.350**
Cost	
Cost type	1-Auto-calculate

Cross Section



Internal partitions

General	
Project partition	
Source	
Category	Partitions
Region	IRAN (ISLAMIC I
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	3
Outermost layer	
Gypsum Plasterboard	
Thickness (m)	0.0250
Bridged?	No
Layer 2	
Air gap 10mm	
Thickness (m)	0.1000
Bridged?	No
Innermost layer	
Gypsum Plasterboard	
Thickness (m)	0.0250
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
No Bridging	
U-Value surface to surface (W/m2-K)	2.857
R-Value (m2-K/W)	0.610
U-Value (W/m2-K)	1.639
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1500
Upper resistance limit (m2-K/W)	0.520
Lower resistance limit (m2-K/W)	0.520
U-Value surface to surface (W/m2-K)	2.857
R-Value (m2-K/W)	0.520
U-Value (W/m2-K)	**1.639**
Cost	
Cost type	1-Auto-calculate

Cross Section



Semi exposed walls

General	
Project semi-exposed wall	
Source	
Category	Walls
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	4
Outermost layer	
Brickwork Outer	
Thickness (m)	0.1000
Bridged?	No
Layer 2	
XPS Extruded Polystyrene - CO2 Blowing	
Thickness (not used in thermal calcs) (m)	0.0795
Bridged?	No
Layer 3	
Concrete Block (Medium)	
Thickness (m)	0.1000
Bridged?	No
Innermost layer	
Gypsum Plastering	
Thickness (m)	0.0130
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040

No Bridging	
U-Value surface to surface (W/m2-K)	0.372
R-Value (m2-K/W)	2.856
U-Value (W/m2-K)	0.350
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.2925
Upper resistance limit (m2-K/W)	2.856
Lower resistance limit (m2-K/W)	2.856
U-Value surface to surface (W/m2-K)	0.372
R-Value (m2-K/W)	2.856
U-Value (W/m2-K)	**0.350**
Cost	
Cost type	1-Auto-calc

Cross Section

Outer surface



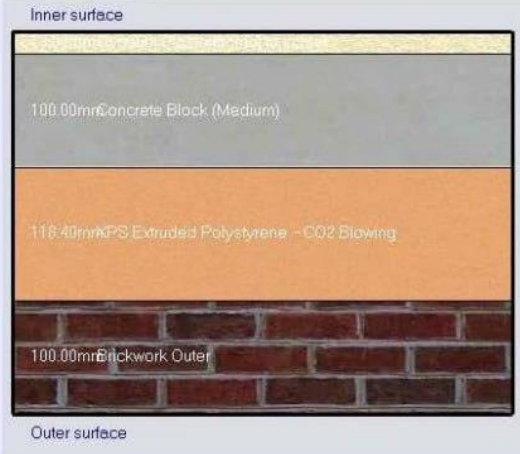
Inner surface

Semi exposed floor

General	
Project semi-exposed floor	
Source	
Category	Floors (semi-exposed)
Region	IRAN (ISLAMIC REPUB
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	4
Outermost layer	
Brickwork Outer	
Thickness (m)	0.1000
Bridged?	No
Layer 2	
XPS Extruded Polystyrene - CO2 Blowing	
Thickness (m)	0.1184
Bridged?	No
Layer 3	
Concrete Block (Medium)	
Thickness (m)	0.1000
Bridged?	No
Innermost layer	
Gypsum Plastering	
Thickness (m)	0.0130
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.261
R-Value (m2-K/W)	4.000
U-Value (W/m2-K)	0.250
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.3314
Upper resistance limit (m2-K/W)	4.000
Lower resistance limit (m2-K/W)	4.000
U-Value surface to surface (W/m2-K)	0.261
R-Value (m2-K/W)	4.000
U-Value (W/m2-K)	**0.250**
Cost	
Cost type	1-Auto-calculate

Cross Section



Ground floor

General	
Project ground floor	
Source	
Category	Floors (ground)
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	4
Outermost layer	
Urea Formaldehyde Foam	
Thickness (m)	0.1327
Bridged?	No
Layer 2	
Cast Concrete	
Thickness (m)	0.1000
Bridged?	No
Layer 3	
Floor/Roof Screed	
Thickness (m)	0.0700
Bridged?	No
Innermost layer	
Timber Flooring	
Thickness (m)	0.0300
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No

Inner surface	
Convective heat transfer coefficient (W/m2-K)	0.342
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.170
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.264
R-Value (m2-K/W)	4.001
U-Value (W/m2-K)	0.250
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.3327
Upper resistance limit (m2-K/W)	4.001
Lower resistance limit (m2-K/W)	4.001
U-Value surface to surface (W/m2-K)	0.264
R-Value (m2-K/W)	4.001
U-Value (W/m2-K)	**0.250**
Cost	
Cost type	1-Auto-calculate

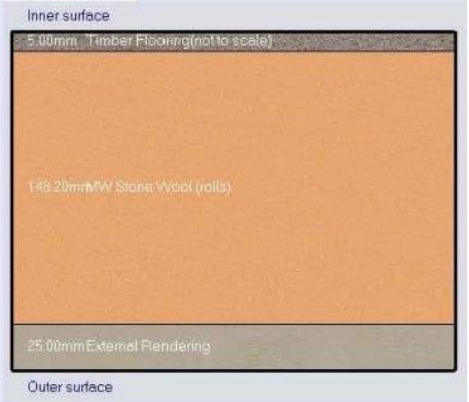
Cross Section



External floor

General	
Project external floor	
Source	
Category	Floors (external)
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	3
Outermost layer	
External Rendering	
Thickness (m)	0.0250
Bridged?	No
Layer 2	
MW Stone Wool (rolls)	
Thickness (m)	0.1482
Bridged?	No
Innermost layer	
Timber Flooring	
Thickness (m)	0.0050
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	0.342
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.170
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.264
R-Value (m2-K/W)	4.001
U-Value (W/m2-K)	0.250
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1782
Upper resistance limit (m2-K/W)	4.001
Lower resistance limit (m2-K/W)	4.001
U-Value surface to surface (W/m2-K)	0.264
R-Value (m2-K/W)	4.001
U-Value (W/m2-K)	**0.250**
Cost	
Cost type	1-Auto-calculate

Cross Section



Internal floor

General	
Project internal floor	
Source	
Category	Floors (internal)
Region	IRAN (ISLAMIC REPUBLIC OF)
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	1
Single layer	
Cast Concrete (Dense)	
Thickness (m)	0.1000
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	0.342
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.170
Outer surface	
Convective heat transfer coefficient (W/m2-K)	4.460
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.100
No Bridging	
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.341
U-Value (W/m2-K)	2.929
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1000
Upper resistance limit (m2-K/W)	0.341
Lower resistance limit (m2-K/W)	0.341
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.341
U-Value (W/m2-K)	**2.929**
Cost	
Cost type	1-Auto-calculate

Cross Section



Walls sub surface

General	
Project wall sub-surface construction	
Source	
Category	Walls
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	1
Single layer	
Cast Concrete (Dense)	
Thickness (m)	0.1000
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.241
U-Value (W/m2-K)	4.142
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1000
Upper resistance limit (m2-K/W)	0.241
Lower resistance limit (m2-K/W)	0.241
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.241
U-Value (W/m2-K)	**4.142**
Cost	
Cost type	1-Auto-ca

Cross Section



Internal wall sub surface

General	
Project internal wall sub-surface construction	
Source	
Category	Walls
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	1
Single layer	
Cast Concrete (Dense)	
Thickness (m)	0.1000
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.241
U-Value (W/m2-K)	4.142
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1000
Upper resistance limit (m2-K/W)	0.241
Lower resistance limit (m2-K/W)	0.241
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.241
U-Value (W/m2-K)	**4.142**
Cost	
Cost type	1-Auto-calculate

Cross Section



External door

General	
Project external door	
Source	
Category	Doors
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	1
Single layer	
Painted Oak	
Thickness (m)	0.0350
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.460
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	5.429
R-Value (m2-K/W)	0.354
U-Value (W/m2-K)	2.823
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.0350
Upper resistance limit (m2-K/W)	0.354
Lower resistance limit (m2-K/W)	0.354
U-Value surface to surface (W/m2-K)	5.429
R-Value (m2-K/W)	0.354
U-Value (W/m2-K)	**2.823**
Cost	
Cost type	1-Auto-calculate

Cross Section



Internal door

General	
Project internal door	
Source	
Category	Doors
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	1
Single layer	
Painted Oak	
Thickness (m)	0.0350
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.460
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	5.429
R-Value (m2-K/W)	0.354
U-Value (W/m2-K)	2.823
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.0350
Upper resistance limit (m2-K/W)	0.354
Lower resistance limit (m2-K/W)	0.354
U-Value surface to surface (W/m2-K)	5.429
R-Value (m2-K/W)	0.354
U-Value (W/m2-K)	**2.823**
Cost	
Cost type	1-Auto-calculate

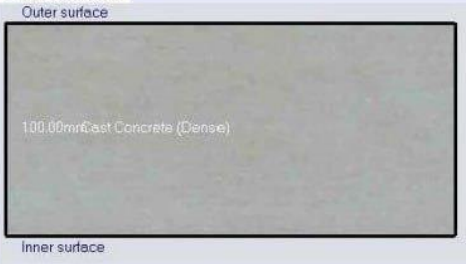
Cross Section



Internal mass

General	
Project internal mass	
Source	
Category	Partitions
Region	IRAN (ISLAMIC
Colour	
Definition	
Definition method	1-Layers
Calculation Settings	
Simulation solution algorithm	1-Default
Involves metal cladding	No
Layers	
Number of layers	1
Single layer	
Cast Concrete (Dense)	
Thickness (m)	0.1000
Bridged?	No
Outside Surface	
Fix convective heat transfer coefficient	No
Inside Surface	
Fix convective heat transfer coefficient	No
Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
No Bridging	
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.331
U-Value (W/m2-K)	3.017
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1000
Upper resistance limit (m2-K/W)	0.331
Lower resistance limit (m2-K/W)	0.331
U-Value surface to surface (W/m2-K)	14.000
R-Value (m2-K/W)	0.331
U-Value (W/m2-K)	**3.017**
Cost	
Cost type	1-Auto-calculate

Cross Section



Models of Thermal Comfort

This study employed two weather simulation instruments of superior quality. The "Meteoblue" online simulators and "Climate Consultant" software. This application utilizes meteorological information obtained from Energy Plus meteorological via the extension Epw.

Due to the integration of the Design Builder simulation software with the Energy Plus climate data engine, the identical data file is utilized by both the "Climate Consultant" and "Design Builder" applications. (The climate data file encompassing Arak city with extension epw is accessible to researchers and will be sent to them via email should further investigation be required.)

Prior to utilizing Energy Plus weather data, an accuracy check was conducted, and a comparison was made with the weather report file obtained from the Arak City Meteorological Center.

Finally, the Energy Plus file was used for the implementation of the analysis and simulation software due to the more comprehensive factor report.

Human thermal comfort is primarily determined by the dry bulb temperature and humidity. However, there may be subtle variations in the definitions provided by different sources.

Two distinct categories of models exist for evaluating thermal comfort: static models and adaptive models.

The California Energy Code Comfort Model, which is the default in Climate Consultant, is a fixed model. It presupposes that the desired indoor temperature for achieving thermal comfort remains constant throughout the different seasons. The high and low temperatures that establish the comfort range remain constant.

The Adaptive Comfort Model, as specified in ASHRAE Standard 55, represents the opposite end of the spectrum. It presupposes that the areas rely on natural airflow for ventilation and that the inhabitants have the ability to manually open and close windows. Consequently, the thermal response of these systems will be influenced by the exterior environment, resulting in a broader range of comfort compared to buildings equipped with centralized HVAC systems.

Within the spectrum of possibilities in Climate Consultant, there are two additional models available: the ASHRAE Handbook of Fundamentals Comfort Model and the ASHRAE Standard 55 Comfort Model utilizing PMV (Predicted Mean Vote). Both of these models presuppose that individuals will adjust to climate change by modifying their

attire, resulting in the establishment of two distinct comfort zones (one for winter and one for summer) that are determined by a shift in the range of temperatures considered comfortable.

The alternate Comfort Models comprise the following:

- The default model for the California Energy Code Comfort is the 2013 version.
- The user is referring to the ASHRAE Standard 55, which is the current edition of the Handbook of Fundamentals Comfort Model.
- The ASHRAE Handbook of Fundamentals Comfort Model is applicable up until 2005.
- The Adaptive Comfort Model is a component of the ASHRAE Standard 55-2010.

1) **The default model for the California Energy Code Comfort Model is the 2013 version**

The initial or standard comfort model is determined by the existing California Energy Code. The Psychrometric chart displays parallel sides that are determined by the Comfort Low and Comfort High Dry Bulb Temperatures. According to the 2013 California Residential Energy Code, the indoor design temperatures for sizing space conditioning equipment should be set at 68°F (20°C) for heating and 75°F (23.9°C) for cooling. The Code does not provide any recommendations regarding optimal humidity levels for comfort. The sloped top of the Comfort Zone in Climate Consultant is determined by the maximum Relative Humidity at the Comfort Low Temperature, and aligns with the Wet Bulb Temperature line. When the relative humidity is set at 80% and the temperature is at the Comfort Low Temperature of 68°F (20°C), the corresponding wet bulb temperature is 66°F (18.9°C), which is considered reasonable. The minimum acceptable humidity level is indicated by the lower boundary of this zone, as determined by the Minimum Dew Point Temperature, which is established at 27°F (-2.8°C). All of these values can be modified on the criterion screen (California Energy Code, 2008).

2) **The ASHRAE Standard 55 and the Current Handbook of Fundamentals Comfort Model are two references used to determine comfort levels**

The second comfort model is specified in ASHRAE Standard 55. The model is alternatively referred to as the PMV (Predicted Mean Vote) model. The algorithm is derived from experimental data and takes into account factors such as dry bulb temperature, humidity, air velocity, and metabolic activity. The system features two distinct comfort zones for summer and winter attire, with the temperature limitations slightly adjusted to accommodate the fact that individuals tend to feel more comfortable at somewhat higher temperatures in drier air. In this model, Climate Consultant considers that the mean radiant temperature (MRT) is about equivalent to the dry bulb temperature.

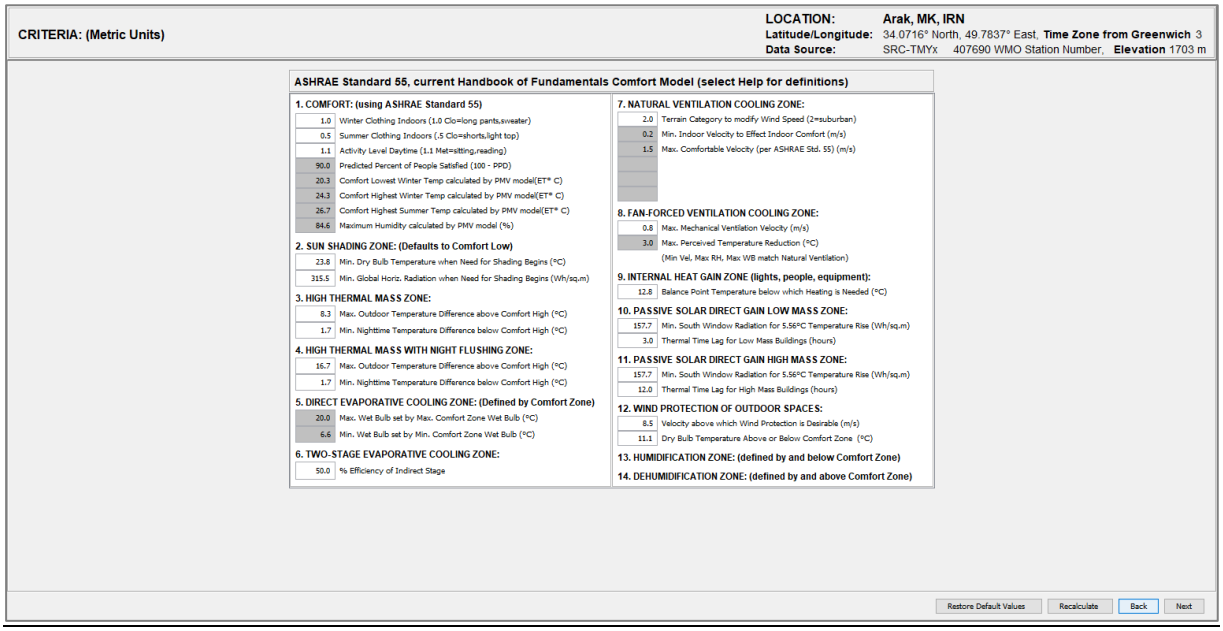
3) **The ASHRAE Handbook of Fundamentals Comfort Model is valid till 2005**

The third comfort model is specified in the 2005 ASHRAE Handbook of Fundamentals. The data illustrates the relationship between the comfort zone and clothing (CLO), indicating that individuals wearing lighter summer clothes tend to have a warmer comfort zone. The temperatures are represented as gently inclined curves that take into consideration the impact of humidity on comfort (as the air becomes drier, individuals will feel comfortable at somewhat higher temperatures). (ASHRAE, 2005).

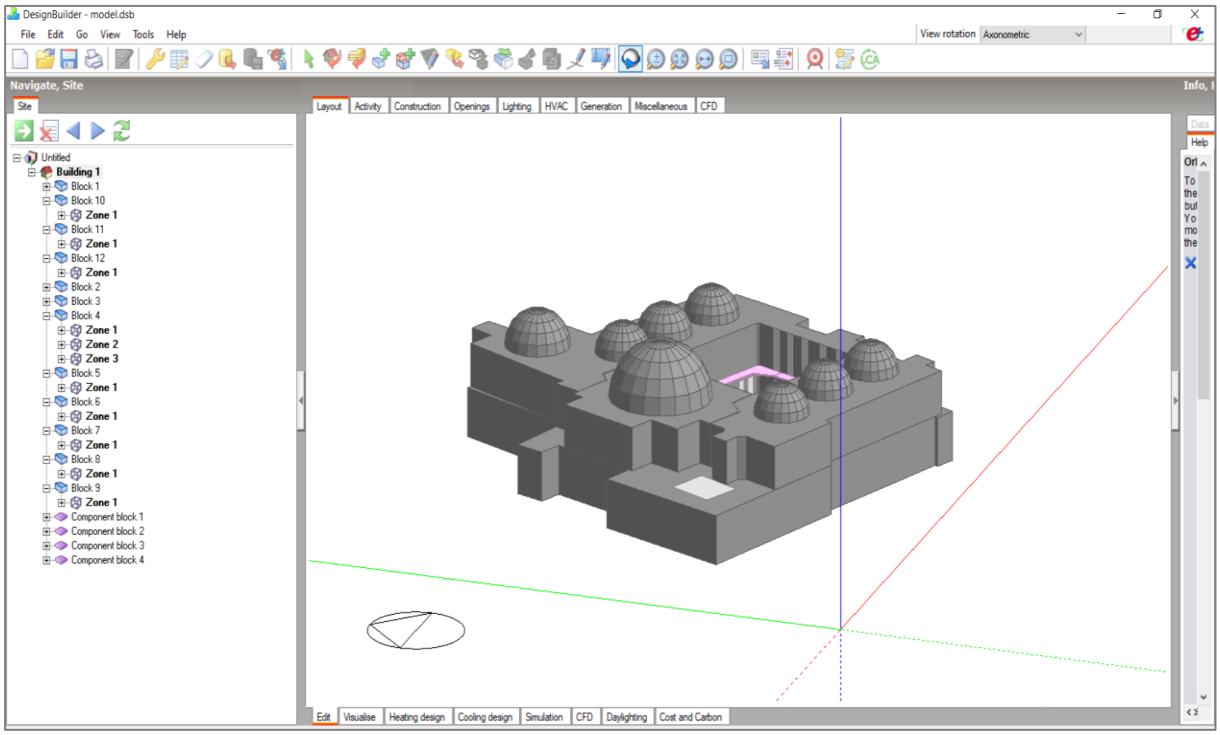
4) **The ASHRAE Standard 55-2010 incorporates the Adaptive Comfort Model**

The fourth type, known as the Adaptive Comfort model, is likewise specified in ASHRAE Standard 55. This is applicable in spaces that are naturally ventilated, allowing individuals to freely open and close windows. Indoor circumstances are considered satisfactory when the typical outdoor air temperatures range from 50° F to 92° F. Additionally, the indoor temperatures must be maintained within a specific range of 10 degrees of the ASHRAE Standard 55. Thermal comfort is influenced by external circumstances, and buildings with centralized HVAC systems have a narrower range of comfort for inhabitants compared to other buildings. This model is not applicable during the operation of a building's heating system, nor is it applicable in the presence of an air conditioning system. It presupposes that individuals will adjust their attire according to the weather conditions, ranging from 1.0 to 0.5 Clo. Additionally, it considers that they are involved in stationary tasks like reading, with a metabolic rate of 1.0 to 1.1 Met. The Standard does not address the impact of other building Design Strategies on adaptive comfort (de Dear-Brager, 2001).

The second model was employed in this study to assess thermal comfort. The table below contains a listing of all the registered parameters used to simulate the climate of Arak and assess thermal comfort.

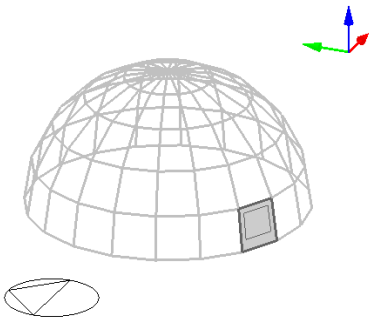


Dome Roof Simulation:

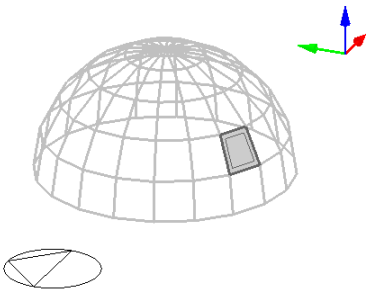


Block 5:

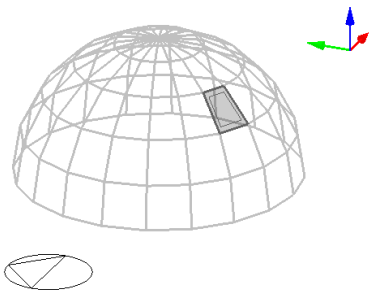
Sections	**Total Area (ft^2)**	**Total Area (m^2)**	**Angel (^{0})** **(for each square)**
Floor	788.87	73.29	___
Wall 1 (20 squares)	24.37	2.26	81^0
Wall 2 (20 squares)	21.94	2.04	63^0
Wall 3 (20 squares)	17.35	1.61	45^0
Wall 4 (20 squares)	11.10	1.03	27^0
Wall 5 (20 squares)	3.81	0.35	9^0



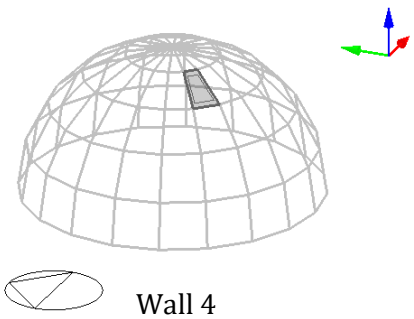
Wall 1



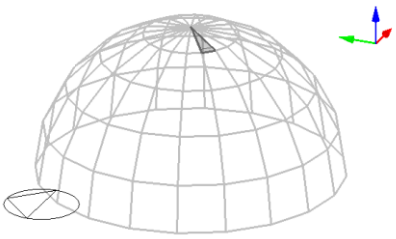
Wall 2



Wall 3



Wall 4



Wall 5

$A = \pi r^2$ π (r²)=73.29 r=4.83 m

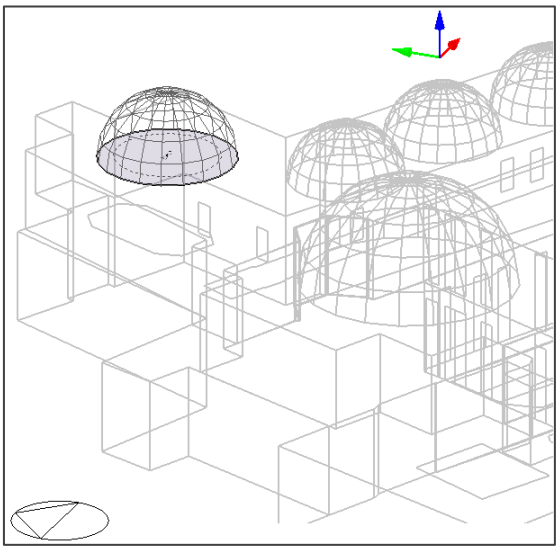
Block 6:

Sections	**Total Area (ft²)**	**Total Area (m²)**	**Angel (⁰) (for each square)**
Floor	319.81	29.71	___
Wall 1 (20 squares)	9.88	0.92	81⁰
Wall 2 (20 squares)	8.89	0.82	63⁰
Wall 3 (20 squares)	7.03	0.65	45⁰
Wall 4 (20 squares)	4.50	0.42	27⁰
Wall 5 (20 squares)	1.55	0.14	9⁰

$A = \pi r^2$ π (r²)=29.71 r=3.08 m

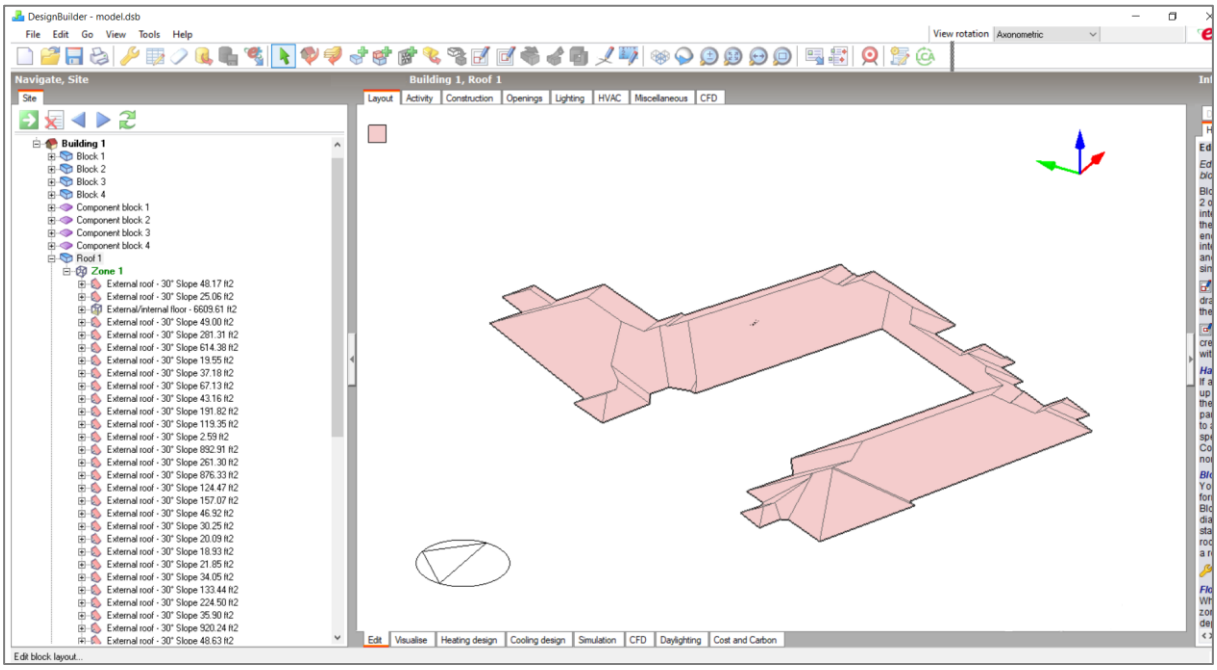
Block 7-12:

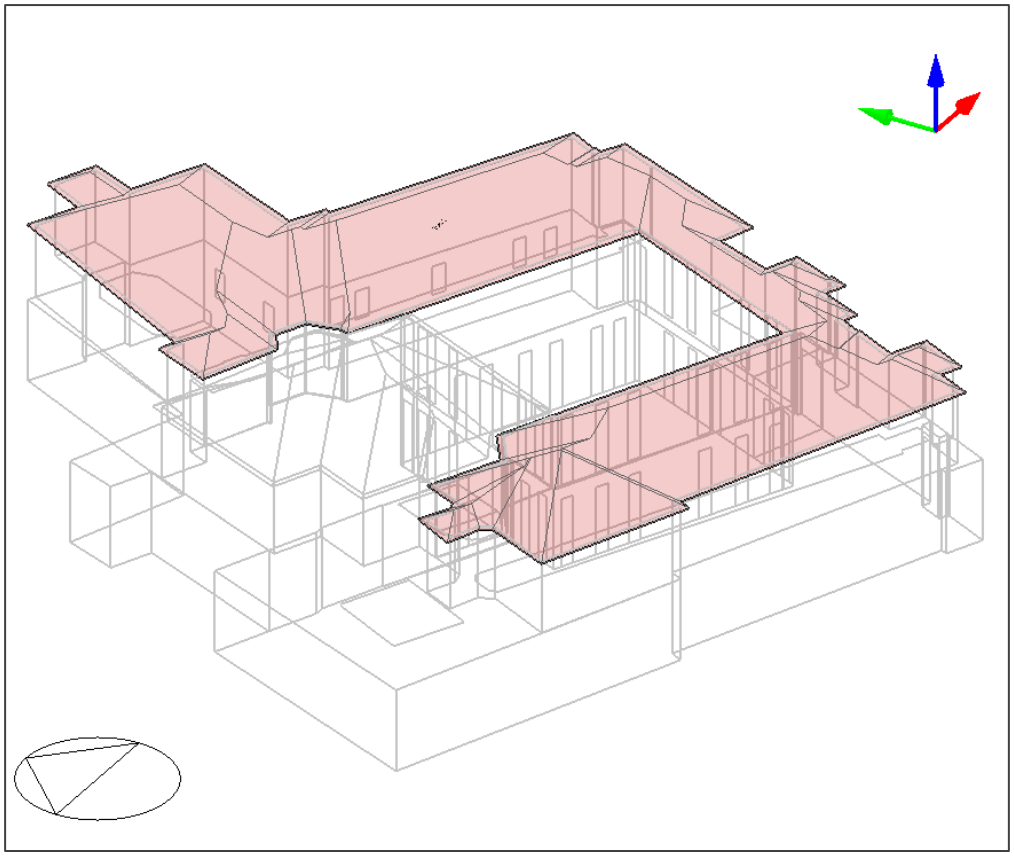
Sections	**Total Area (ft²)**	**Total Area (m²)**	**Angel (⁰) (for each square)**
Floor	229.45	27.82	___
Wall 1 (20 squares)	7.09	0.66	81⁰
Wall 2 (20 squares)	6.38	0.59	63⁰
Wall 3 (20 squares)	5.04	0.47	45⁰
Wall 4 (20 squares)	3.23	0.30	27⁰
Wall 5 (20 squares)	1.11	0.10	9⁰

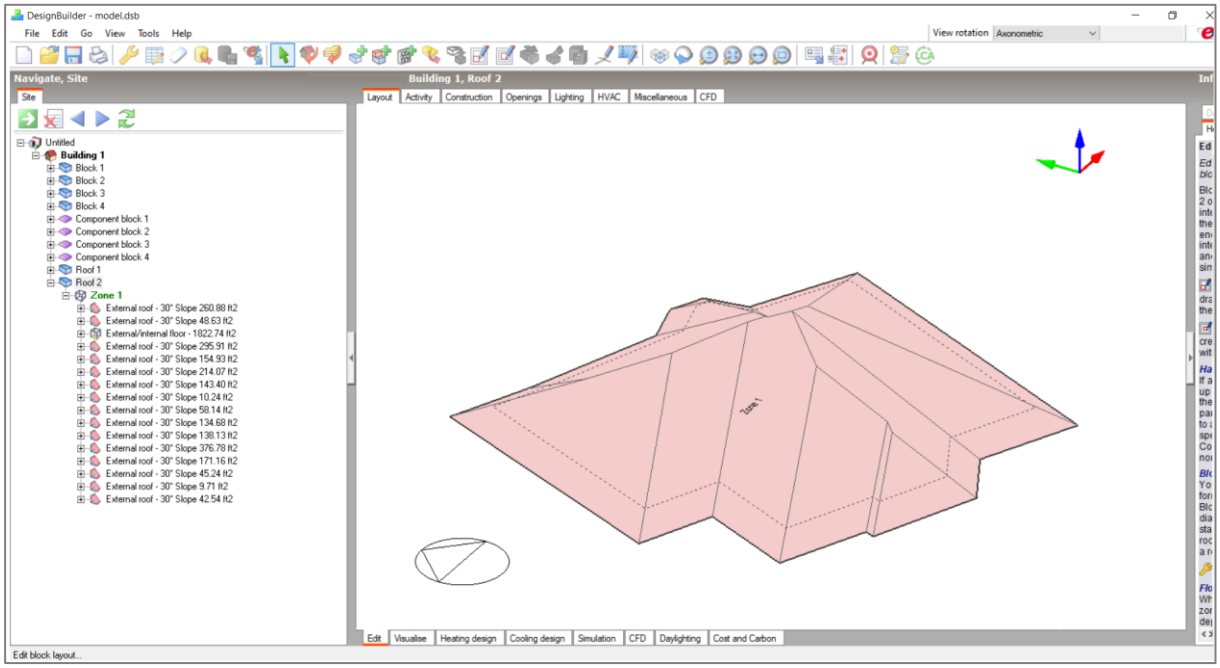


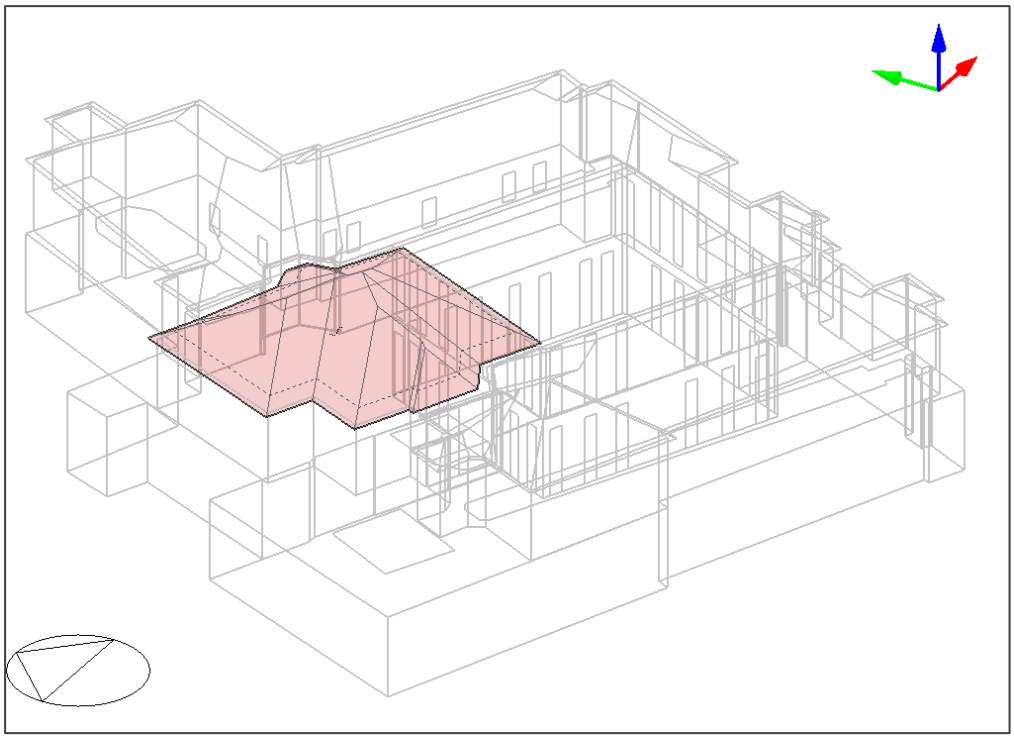
$A = \pi r^2$ π (r²)=27.82 r=2.98 m

Sloping Roof Simulation:

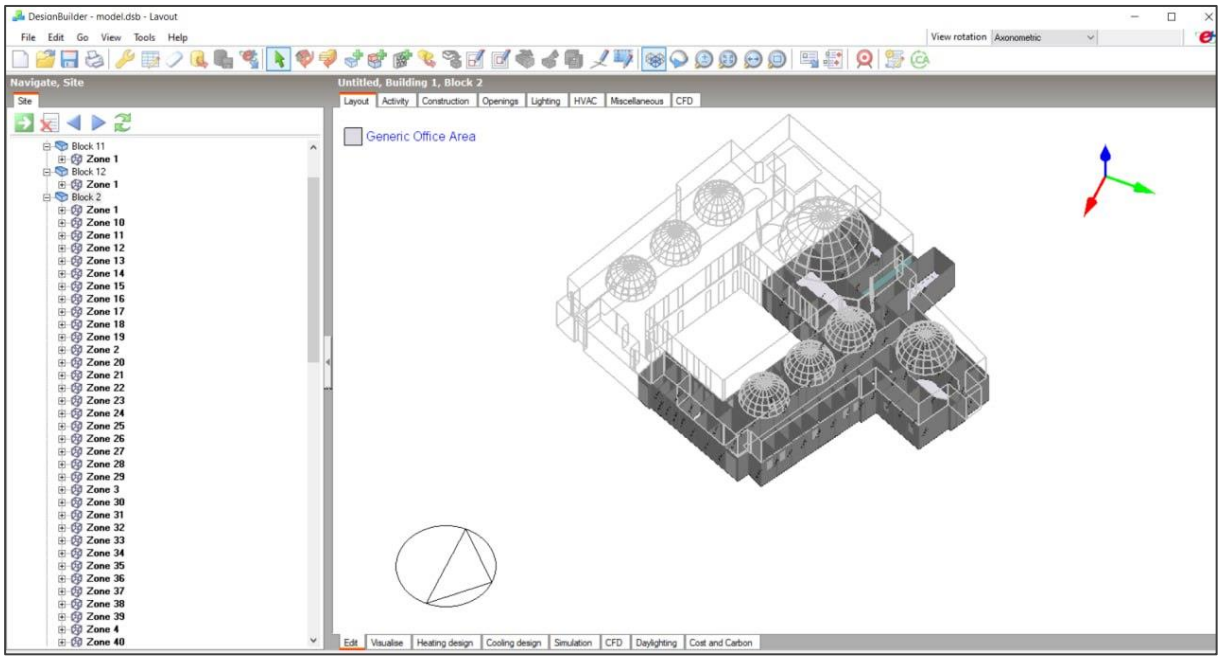


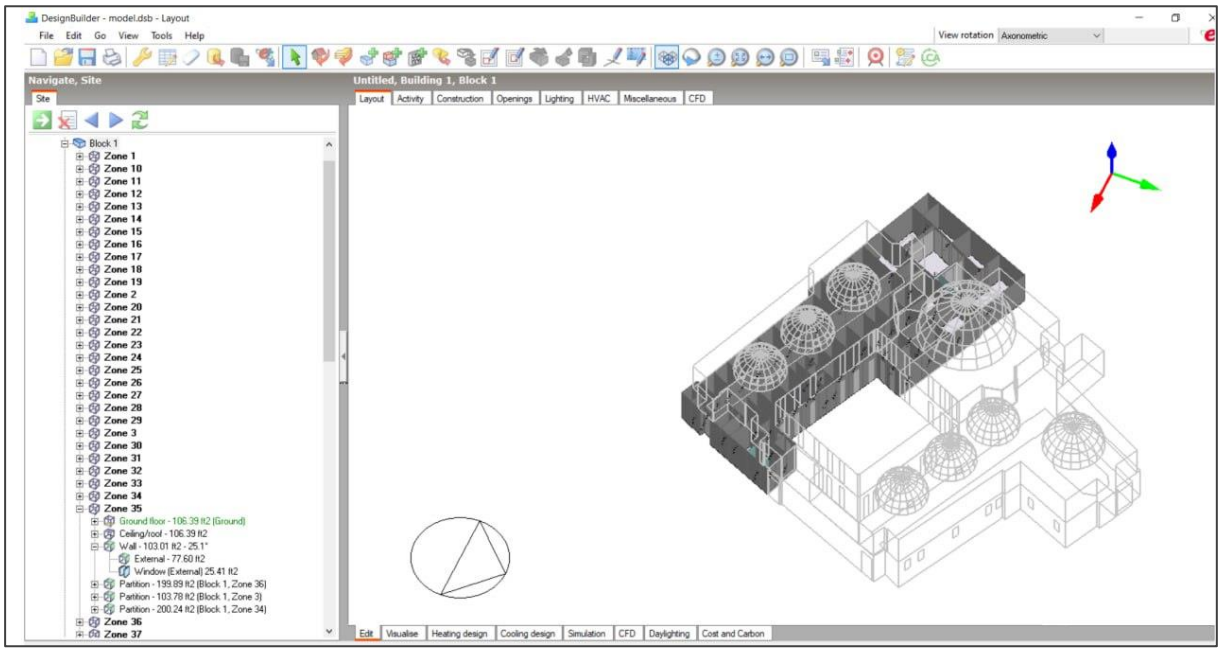



DesignBuilder - model.dsb
File Edit Go View Tools Help
View rotation Axonometric
Navigate, Site
Building 1, Roof 2
Site
Layout Activity Construction Openings Lighting HVAC Miscellaneous CFD
Untitled
Building 1
Block 1
Block 2
Block 3
Block 4
Component block 1
Component block 2
Component block 3
Component block 4
Roof 1
Roof 2
Zone 1
External roof - 30° Slope 260.88 ft2
External roof - 30° Slope 48.63 ft2
External/internal floor - 1822.74 ft2
External roof - 30° Slope 295.91 ft2
External roof - 30° Slope 154.93 ft2
External roof - 30° Slope 214.07 ft2
External roof - 30° Slope 143.40 ft2
External roof - 30° Slope 10.24 ft2
External roof - 30° Slope 58.14 ft2
External roof - 30° Slope 134.68 ft2
External roof - 30° Slope 138.13 ft2
External roof - 30° Slope 376.78 ft2
External roof - 30° Slope 171.16 ft2
External roof - 30° Slope 45.24 ft2
External roof - 30° Slope 9.71 ft2
External roof - 30° Slope 42.54 ft2
Zone 1
Edit Visualise Heating design Cooling design Simulation CFD Daylighting Cost and Carbon
Edit block layout...

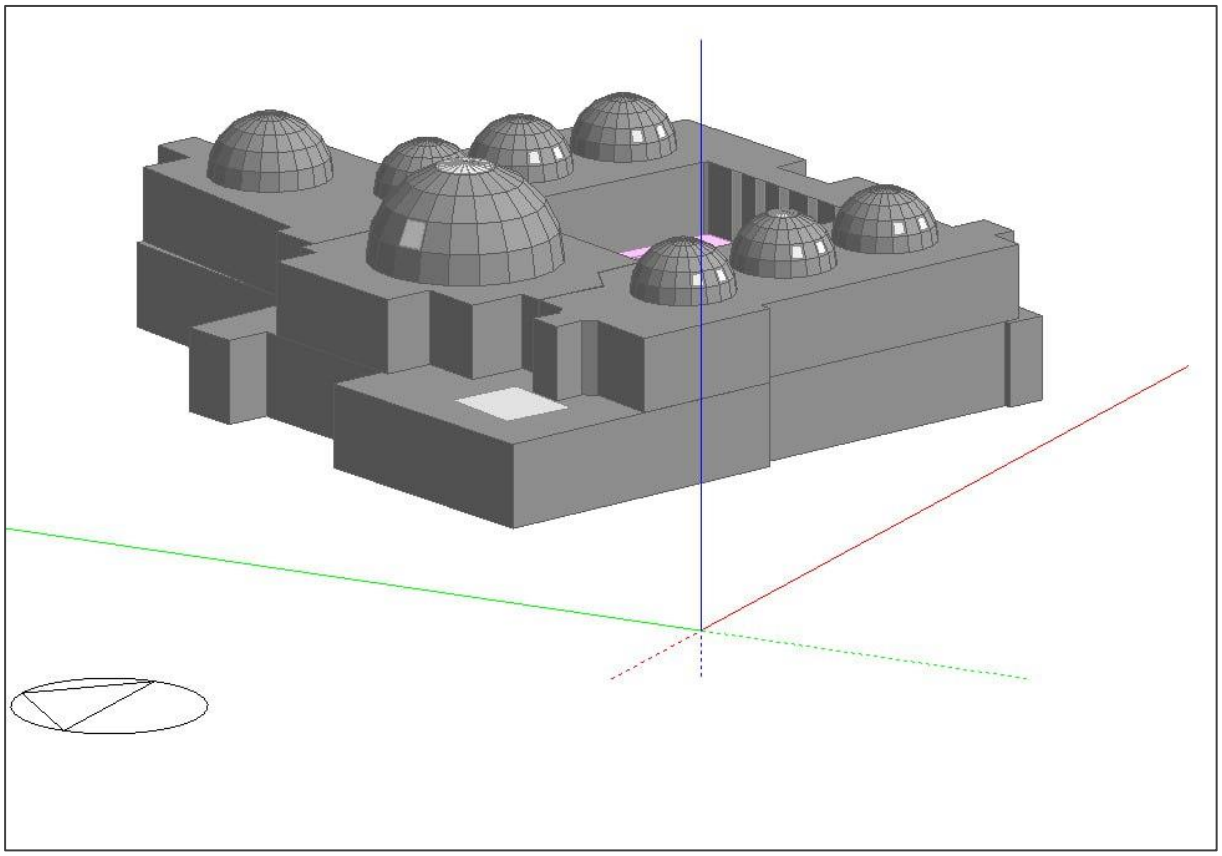


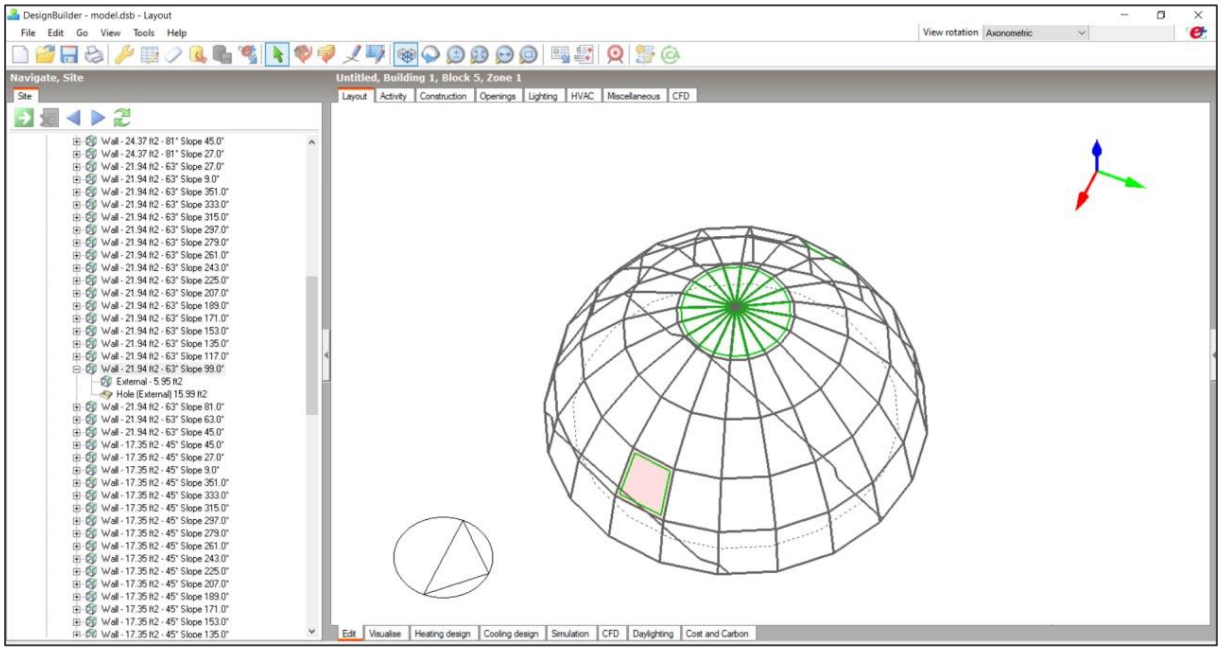
Windows and opening locations within the Nowzari Caravanserai

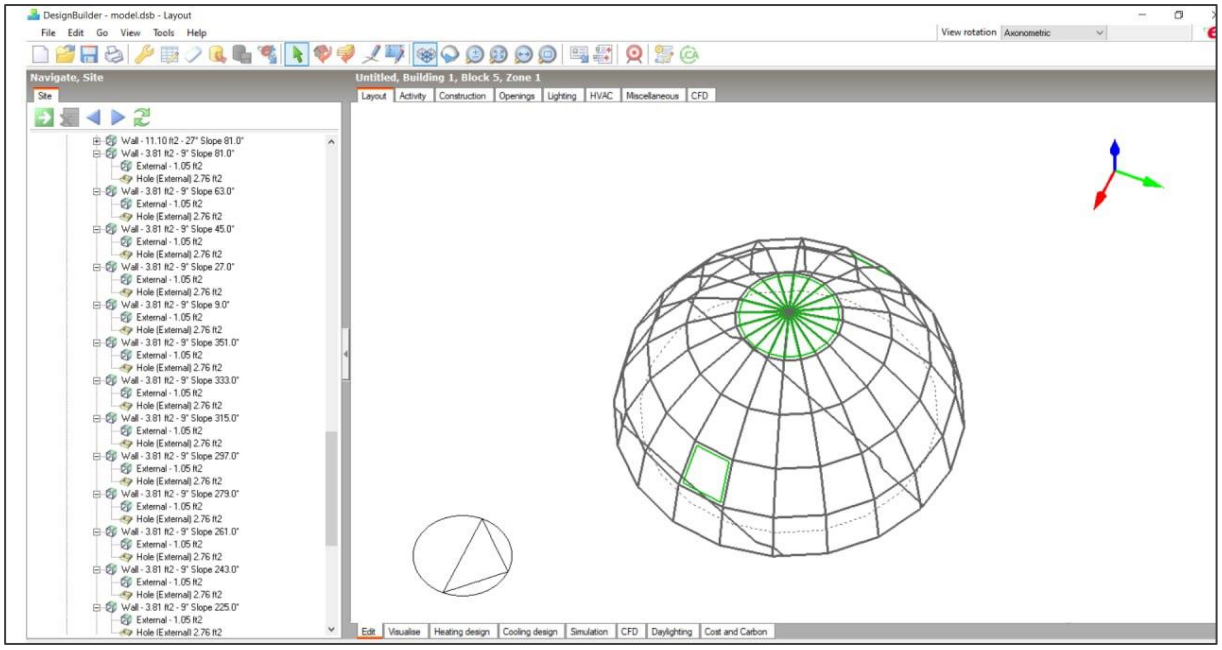


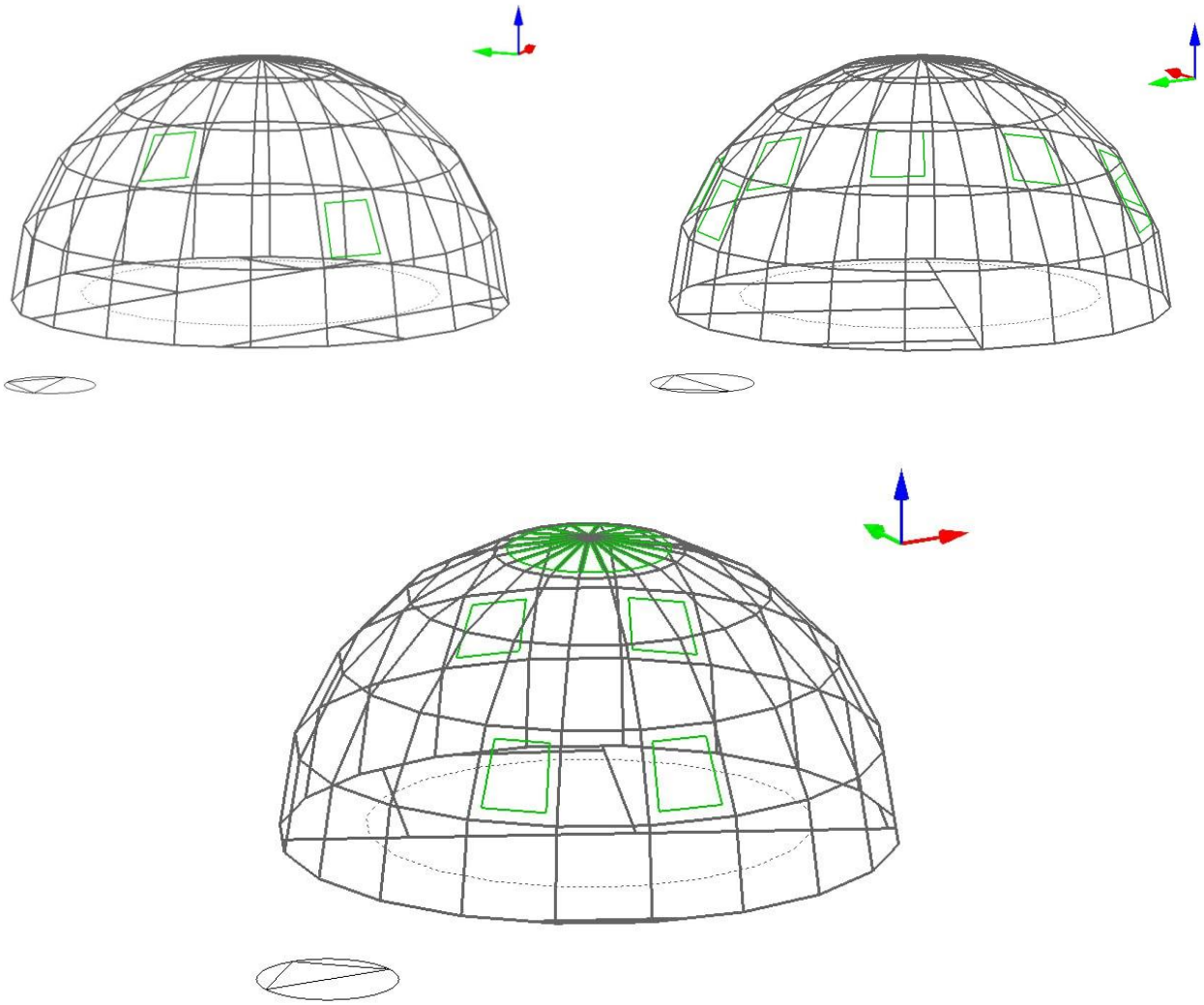


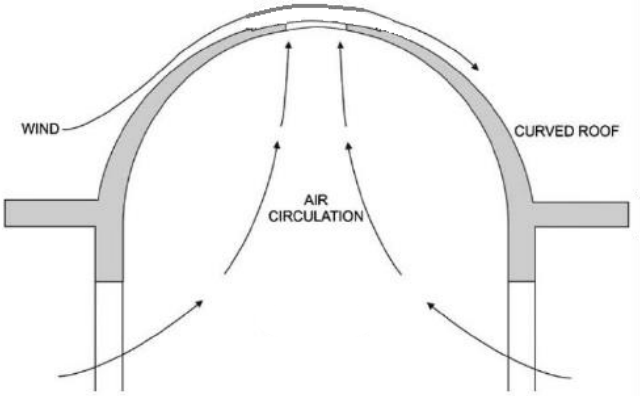
Ventilation holes on the domes of Nowzari Caravanserai





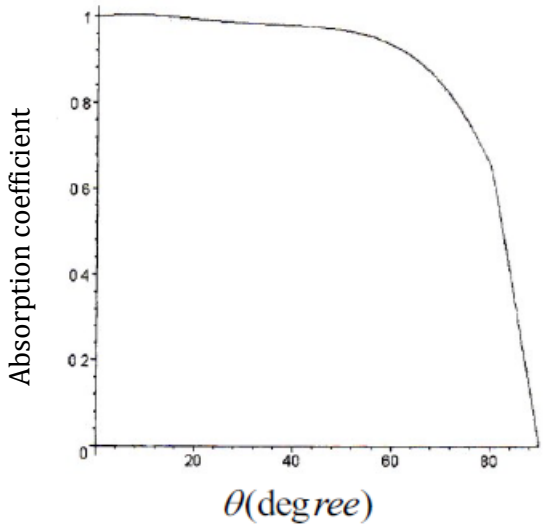

DesignBuilder - model.dsb - Layout
File Edit Go View Tools Help
View rotation Axonometric
Navigate, Site
Site
Untitled, Building 1, Block 5, Zone 1
Layout Activity Construction Openings Lighting HVAC Miscellaneous CFD
Edit Visualise Heating design Cooling design Simulation CFD Daylighting Cost and Carbon





Dependence of the solar absorption coefficient's angular value on the sun's incidence angle

The surface absorption coefficient is influenced by the angle of the sun's rays and the properties of the surface. As the angle of the sun's rays increases, the surface absorption coefficient falls, as shown in Figure below.



The angle of the sun's rays, denoted as Θ, ranges from 0 to 90 degrees. The radiation absorption coefficient, represented as a_n corresponds to the vertical incidence of the sun's rays on the surface. It is presumed that the solar radiation is uniformly distributed across the entire surface of the hemisphere.

$$\frac{a}{a_n}=1+2.0345\times10^{-3}\Theta-1.99\times10^{-4}\Theta^2+5.324\times10^{-6}\Theta^3-4.799\times10^{-8}\Theta^4 \qquad 0\leq\Theta\leq80 \qquad (1a)$$

$$\frac{a}{a_n}=0.064938(90-\Theta) \qquad 80<\Theta<90 \qquad (1b)$$

Hence, the mean value of the absorption coefficient an is determined by computing the weighted average absorption coefficient a throughout the entire hemisphere:

$$<a> = \int_0^{90} 2 \times \sin\theta \times \cos\theta \times a\,(\theta) d\theta \qquad (2)$$

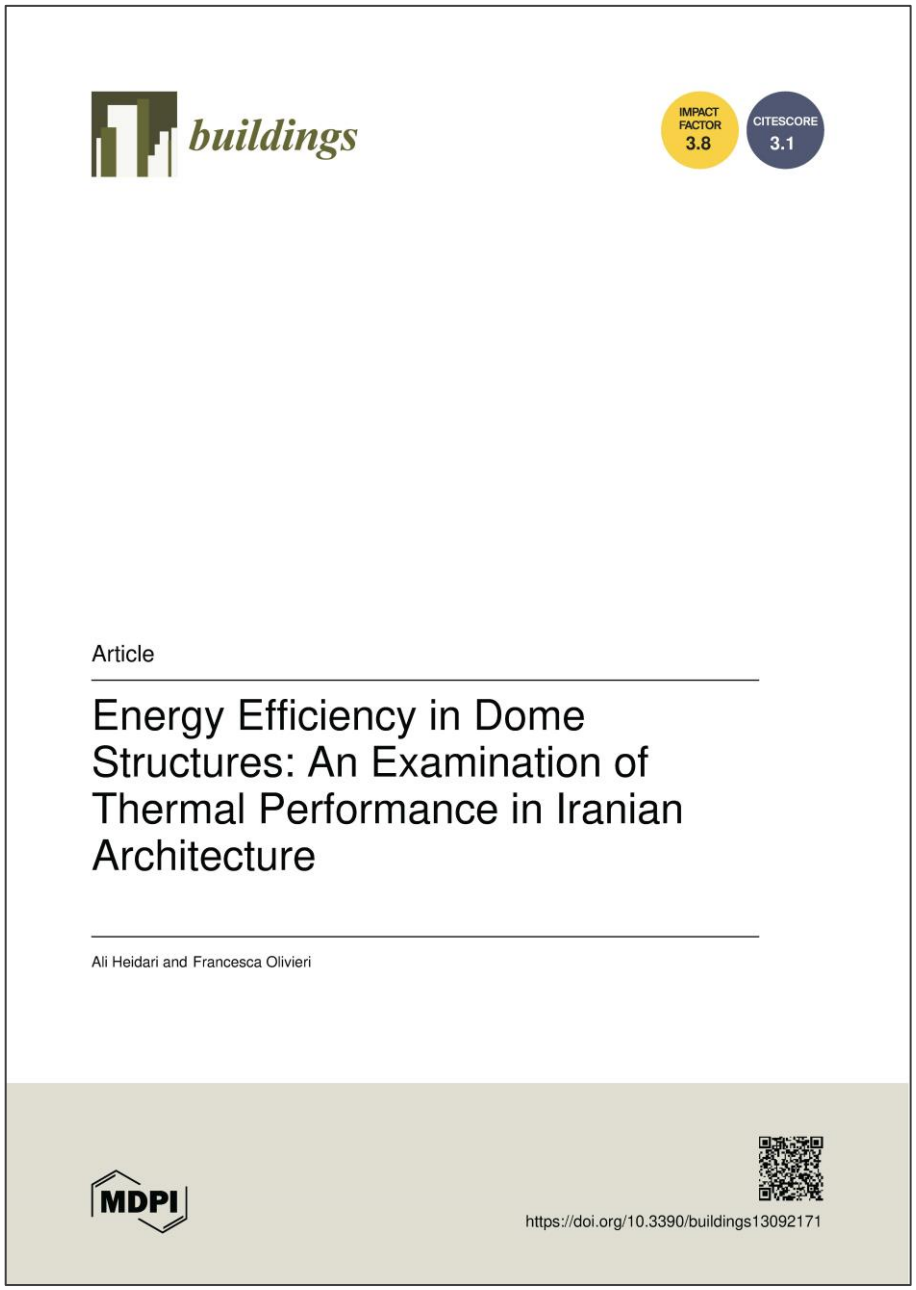
By substituting the values of relation 1a and 1b into equation 2 and doing numerical calculations on the integral mentioned above, the average value of the solar absorption coefficient may be determined.

$$<a> = 0.93335 \times a_n$$

Published Articles

1. **Energy Efficiency in Dome Structures: An Examination of Thermal Performance in Iranian Architecture**

Heidari, A., & Olivieri, F. (2023). Energy Efficiency in Dome Structures: An Examination of Thermal Performance in Iranian Architecture. MDPI AG. https://doi.org/10.3390/buildings13092171



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MDPI

Article

Energy Efficiency in Dome Structures: An Examination of Thermal Performance in Iranian Architecture

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* Correspondence: ali.heidari@alumnos.upm.es; Tel.: +34-64-470-9777

Abstract: This study investigates the energy efficiency of dome-shaped structures in traditional Iranian architecture in regions with cold winters and hot summers against the backdrop of rising energy consumption and environmental concerns. The present study employed Design Builder software to simulate three discrete models of Nowzari Caravanserai, featuring dome, flat, and sloping roofs. It was compared to the original model's dome-shaped roof in terms of energy consumption and internal temperature. The objective was to investigate the potential differences in thermal energy consumption across these distinct roof designs in all months of the year. The results indicate that the dome-shaped structures exhibit better efficacy in controlling indoor temperatures, as demonstrated by a marked increase in indoor temperatures during colder months and a decrease in indoor temperatures during hotter months, relative to alternative structures. Moreover, the results of the simulation of two domed-roof models with ventilation and without ventilation showed that in this climate zone, the ventilation holes built into the roof have a unique efficiency in adjusting the internal temperature. The implications of this research include that traditional architectural features such as domed structures can be incorporated into contemporary construction practices to foster energy-efficient buildings and sustainable urbanization. This holds true not only for hot and desert climate regions but also for areas characterized by both hot summers and cold winters. The integration of traditional expertise and modern technology can help create buildings that balance aesthetics and sustainability, creating a cleaner, more sustainable built environment.

Keywords: energy efficiency; dome-shaped structures; building simulation; traditional Iranian architecture; sustainable urban development

check for updates

Citation: Heidari, A.; Olivieri, F. Energy Efficiency in Dome Structures: An Examination of Thermal Performance in Iranian Architecture. *Buildings* **2023**, *13*, 2171. https://doi.org/10.3390/buildings13092171

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1. Introduction

The incorporation of sustainable building design has become a crucial aspect of architectural practice due to increasing energy consumption and environmental issues [1]. The optimization of energy performance in buildings is a crucial factor in mitigating the impact of the built environment, as buildings account for a substantial proportion of global energy consumption and greenhouse gas emissions [2]. As per the findings of the International Energy Agency (2021), it can be inferred that buildings contribute to nearly 30% of worldwide energy consumption and 27% of carbon dioxide emissions related to energy usage [3]. Despite a doubling of investment and financing for clean energy in the past decade, the rate of progress has not been sufficient to surmount the resistance of energy-consuming systems. Hence, it is imperative to enhance the energy efficiency of constructions with the aim of curbing the discharge of greenhouse gases and alleviating the ecological ramifications of buildings [4]. In light of the contemporary era's focus on energy preservation and the implementation of passive systems to promote environmental cleanliness, it is deemed imperative to revisit the fundamental design principles and climatic regulations that underpin traditional architecture. Iranian architecture that adheres to traditional design principles is a prime illustration of climatic architecture. It showcases optimal solutions with regard to

environmental preservation, human comfort, and the efficient utilization of natural energy sources [5]. Hence, through the identification of the underlying principles and regulations that govern this particular architectural style, coupled with the presentation of a model that takes into account the scientific comprehension of novel materials as well as the climatic and functional implications arising from technological advancements, it is indeed possible to apply the traditional architectural knowledge and process in novel constructions while still maintaining a contemporary outlook. For centuries, Iran's native architecture has offered its residents comfortable living conditions while consuming less energy, similar to numerous ancient civilizations [6]. The implementation of a dual-layered dome ceiling and a domed roof with ventilation is a prominent feature of indigenous architectural design in the parched and sweltering regions of Iran. This technique has been widely utilized in the construction of diverse structures, including but not limited to mosques, mausoleums, bazaars, and residential dwellings. Certain regions have managed to preserve valuable examples of constructions that have maintained their stability to date, owing to their superior design and construction quality [7]. Mirzazadeh Akbarpoor conducted a study that demonstrated the potential of combining domed roofs with earth-to-air heat-exchanger systems to enhance their energy-saving capabilities. This study can be considered innovative. The integration of modern technologies with traditional architectural methods is a promising strategy for constructing environmentally friendly and energy-efficient structures, as evidenced by this innovative approach [8]. Studying the structural characteristics of dome elements in traditional architecture is a complex area with abundant design variations, offering ample research prospects due to Iran's diverse architectural heritage [9].

However, only a few studies can be found that use energy-simulation software to investigate the effect of the domed roof with ventilation as a bioclimatic element in reducing energy consumption.

The utilization of domed roofs—a traditional architectural element that is prevalent in the Middle East—has been observed to possess a noteworthy capacity to preserve energy and enhance the thermal comfort of occupants. The implementation of domed roofs in various settings, including bustling marketplaces, revered places of worship, and intimate residences, is notable due to their unique architectural features that contribute to efficient energy utilization and improved thermal comfort. According to Mahdavinejad's findings, the domes present on the historical mosques in Isfahan, Iran, served as thermal buffers that effectively reduced energy loss during the night. The architectural design and materials used in constructing the dome hindered the transfer of heat between the inside and outside of the structure, resulting in energy conservation and ensuring comfortable thermal conditions for the occupants [10]. The roof plays a crucial role in the building envelope as it is responsible for managing a significant amount of solar radiation. This can account for as much as 60% of the cooling energy used in a given space [6,11]. The significance of roof design cannot be overstated in mitigating the discomfort of inhabitants, particularly in severe weather conditions [12]. Several prominent researchers, such as Runsheng [13] and Fathy [14], have advocated for the use of domed roofs instead of flat ones due to their superior ability to receive solar radiation. This results in lower indoor temperatures and improved thermal comfort. Other researchers, including Faghih and Bahadori [15] and Olgyay [16], have also supported this approach. Research has demonstrated that the incorporation of the dome structure and traditional materials such as adobe results in outstanding insulation, reduces heat transfer, and promotes thermal comfort. Moreover, domes have the potential to function as thermal buffers, thereby impeding nocturnal energy dissipation [7,10]. Due to their unique configuration, domed roofs serve as effective self-shading mechanisms. This is because half of the structure is exposed to direct sunlight while the other half remains in the shade. In their study, Soleimani (2016) [17] investigated the effects of wind and buoyancy-driven ventilation in a geodesic structure that was equipped with roof vents and open windows in a hot climate. The research results indicate that roof vents have the potential to serve as a passive strategy for ensuring adequate indoor thermal comfort and air quality throughout all seasons.

Previous research has demonstrated the advantageous outcomes of employing dome roofs in conjunction with earth-to-air heat-exchanger systems, resulting in heightened energy-conservation capabilities. The aforementioned innovative methodology prioritizes the potential for amalgamating modern technologies with longstanding architectural traditions, thereby ushering in a novel epoch of environmentally conscious and power-conserving edifices [9].

Besides the aforementioned benefits highlighted in the research regarding domed roofs, certain studies have revealed the suitability of flat roofs when compared to domed roofs. The underlying reasons for these preferences will be elucidated below.

A few experts [18] have analyzed the thermal characteristics of curved roofs under hot and dry weather conditions using numerical calculations. They determined that the heat transfer and daily heat flow through curved roofs are hardly impacted by the roof's radius, thickness, and thermal properties. However, they are noticeably affected by the half-rim angle of both domed roofs (DRs) and vaulted roofs (VRs), as well as the ambient temperature. The findings also establish that domed roofs are unsuitable for regions with elevated air temperatures and high levels of diffuse sky radiation, which are commonly found in hot and humid areas. Another study [15] conducted numerical simulation on a simplified model of a domed roof in a paper titled "Evaluation of Thermal Performance in Domed Roofs". They demonstrated that the thermal performance of the investigated domed-roof building surpasses that of a building with a flat roof on hot days. However, in conditions where there is no wind flow, the flat-roof building outperforms the domed structure. In addition, while taking into account both convection and solar radiation on the roofs, [19] examined the thermal efficiency of vaulted roofs and compared their heat transfer with flat roofs. These investigators clarified that the heat transfer to the building, based on a specific ceiling-design temperature, is significantly influenced by different wind patterns and vault shapes. Upon comparing the outcomes with those of a flat roof, it was discovered that the daily average heat flux of all vaulted roofs, except the one with a rim angle of 180°, was lower than that of a flat roof, and it diminished further with higher wind speeds.

It is important to mention that the majority of studies exploring the advantages of domed roofs have primarily concentrated on hot and desert regions characterized by consistently warm weather year-round [20]. One such study was conducted within the arid and scorching areas of southern Egypt [21]. According to this research, domed-roof structures can have a significant impact on reducing the intensity of solar radiation received by maximizing the ratio between the height and radius of the dome. As a result, they decrease the energy required for cooling in hot climates and thereby enhance indoor thermal comfort.

Another study was carried out in Cairo, Riyadh, and Istanbul [22]. This study reveals that pointed double-dome roofs are effective in Cairo and Riyadh's climatic conditions, while cases of half-circular/pointed domes and vaults yield similar outcomes in Istanbul's climate.

In Iran, as well as in the hot and dry regions of Egypt, North Africa, and Istanbul, traditional dome roofs have been widely utilized for their notable impact on enhancing internal thermal conditions over time. However, since some structures with domed roofs in Iran are situated in areas experiencing hot summers and cold winters, this study aims to address the following inquiries:

Do domed roofs, like those found in hot and dry regions, affect energy consumption for heating in areas with cold and dry winters?

Furthermore, by comparing the gas and electricity energy consumption for heating and cooling between a dome roof and two flat and sloping roofs throughout the year and across different seasons in these regions, what will be the resulting findings?

Walls That Whisper: Tracing the Timeless Traditions and Unique Architecture of Arak Bazaar

As shown in Figure 1 the Arak Bazaar's primary axis, oriented in a north-south direction, spans approximately 722.52 m and accommodates roughly 320 stores and 22 caravanserai entrances throughout its expanse. The total area of the Bazaar amounts to 140,000 square meters. The principal marketplace is encompassed by a roofed edifice featuring a dome-shaped structure that incorporates apertures for ventilation. The architectural design of the caravanserais or passageways linked to this axis exhibits a distinctiveness that is noteworthy. In general, caravanserais are comprised of a centrally located courtyard that is encompassed by interconnected stores [23]. The majority of caravanserais are designed with a dual-level structure, featuring aesthetically pleasing brick and plaster roofs that are constructed with ribbed vaults, arches, and springs. The architect responsible for the design of the Arak Bazaar demonstrated a discerning approach by avoiding a monotonous and standardized layout for the 22 caravanserais. The arrangement of enclosed and open spaces in relation to the primary axis of the Bazaar exhibits remarkable diversity, resulting in a visually captivating and multifaceted Arak Bazaar. The Nowzari Caravanserai, situated within the Bazaar, is a notable example of a vast and complex structure. Covering an expansive area of roughly 5480.93 square meters, it stands as one of the largest caravanserais in the region. The caravanserai in question features a central courtyard, which is connected to three long, covered corridors (known as Timchehs) that are easily accessible. Additionally, there are three entrances leading to the main axis of the Bazaar, as well as one entrance from the Chahar Suq passage [24]. The paved flooring of the courtyard is adorned with stones, and a diminutive pool has been constructed at its focal point. Surrounding the area are multiple establishments featuring stone columns that uphold brick arches. A thoroughfare extends from the central shopping area to the adjacent corridors, facilitating seamless access between disparate sections. The entirety of the caravanserai is comprised of two levels. The retail establishments are involved in the sale of carpets, as well as the creation of carpet patterns [25].



(**a**) (**b**)

Figure 1. A view of Arak Bazaar and Nowzari Caravanserai (**a**) A section of the north-south view of the Nowzari Caravanserai; (**b**) Part of Arak Grand Bazaar's plan.

2. Materials and Methods

The primary research methodology employed in this study is simulation. Simulation studies employ computational models to replicate a given system or process, with the aim of forecasting outcomes under varying circumstances [26]. The present study employed Design Builder software V7.0.1.004 to conduct a simulation of the Arak market, utilizing varying roof forms (flat, sloped, and arched) and roof heights. The objective was to investigate the impact of these factors on the internal temperature and energy consumption for heating and cooling during the season. The seasonal variations in temperature were assessed.

The present study can also be categorized as quantitative in nature as it entails the collection and analysis of numerical data to comprehend the effects of alterations. Quantitative research employs statistical techniques to scrutinize data and typically entails impartial measurements and numerical outcomes [27]. This study involved the collection and analysis of data pertaining to indoor temperature and energy consumption across various scenarios. The aim was to draw conclusions regarding the impact of roof forms on these factors.

Thus, it can be posited that the methodology employed in this study is an experimental design conducted within a virtual environment. This methodology is frequently employed in domains such as architecture and construction, where conducting physical experiments can be prohibitively costly, time-intensive, or unfeasible. By means of this approach, it became feasible to employ a software application for the purpose of evaluating diverse architectural configurations and parameters, amassing relevant data, and deducing inferences from said data.

2.1. Design Builder Simulation Software Validation

In order to assess the accuracy and validity of energy-simulation software, researchers have introduced a range of methodologies. Broadly speaking, these methods can be classified into three overarching categories: analytical, comparative, and experimental methods. Within the realm of building-energy software-validation research, two prevalent types of validation studies are experimental methods, which involve comparing simulation outcomes with field measurements, and comparative methods, which involve comparing the results of various energy-simulation software with one another. The objective of these studies is to elucidate the factors that contribute to the disparity between projected energy consumption and observed consumption, as well as to validate the software inputs in accordance with their respective application platforms. In developed countries, where simulation software is designed in accordance with established regulations and standards, several software programs have undergone validation [28]. These include Ecotect Autodesk [29], Green Building Studio [30], IES [31], Energy Plus [32], E-Quest [33], and Design Builder [34]. The investigation of the validity of Design Builder software in Iran was conducted to align with the specific conditions and methodologies of construction and operation, as well as equipment and climatic factors. This investigation utilized two experimental and comparative approaches. The findings indicate that the Design Builder software exhibits favorable performance in accurately forecasting energy-consumption levels and internal temperature variations within spaces, considering factors such as construction conditions, equipment specifications, and climatic conditions [35].

In this research, to check the validity of the software in the study area (Arak City), we used the experimental method and compared the results of the simulation with field measurements.

2.1.1. Site Visit and Energy Survey of Sarai Nowzari

The desired information was collected through the utilization of existing maps of the Arak market, as well as the acquisition of additional information from the General Department of Cultural Heritage, Handicrafts and Tourism of Arak City; the Meteorological Organization of the province; and a field visit. Subsequently, a comprehensive and precise documentation process was conducted, encompassing the verification and quantification of various elements such as dimensional and architectural data, executive particulars, specifications pertaining to walls, ceilings, doors, and windows, as well as general specifications concerning the mechanical and electrical systems of the building, including lighting. Additionally, meticulous records were compiled regarding the comfort conditions within the spaces, encompassing temperature and humidity values, as well as the conditions governing the utilization of the building. The quantification of electricity and gas energy consumption was derived from monthly billing records over the course of one year.

The gas meter consumption indicated in the bills was determined in cubic meters, which was subsequently converted to kilowatt-hours. This value was then divided by the building's infrastructure, which is measured in kilowatt-hours per square meter, to calculate the final amount. Additionally, we measured the internal temperature of a store located in Sarai Nowzari on 15 December 2022 (representing the coldest month of the year) and on 15 July 2022 (representing the hottest month of the year). As shown in Table 1 the measurements were conducted over an 16 h period, starting from the early morning. During the cold season, the lighting and heating systems were turned off, and during the hot season, the cooling system was nonactivated. Furthermore, the windows were kept closed throughout the experiment. A TESTO DATA LOGGER device was utilized to record the temperature at specific time intervals. It is important to note that the first part of the experiment was conducted without the presence of users and customers, while the remaining hours involved the presence of residents and customers. The duration of one hour was measured at the central location within the store.

Table 1. Comparison of measurement and simulation temperature results in a store in Sarai Nowzari on 15 July 2022.

Date/Time (July)	Relative Humidity %		Outdoor Dry-Bulb Temperature °C		Indoor Air Temperature °C	
	Simulation	Field Measurement	Simulation	Field Measurement	Simulation	Field Measurement
06:00:00	36.04403	35.0	23.002	23.2	26.03333	25.7
07:00:00	36.75922	36.5	23.407	23.9	25.3994	25.1
08:00:00	37.35827	37.0	24.35	24.6	24.62	24.3
09:00:00	38.39169	38.0	26.15	25.4	24.47424	24.0
10:00:00	39.72992	39.3	27.95	27.4	24.30419	23.6
11:00:00	40.81329	40.1	30.125	29.0	24.16153	23.4
12:00:00	41.35981	41.0	32.35	31.5	24.04242	23.0
13:00:00	41.7047	41.5	34.625	33.5	24.03182	22.6
14:00:00	41.94122	42.0	36.025	35.0	24.02612	22.3
15:00:00	42.48663	42.5	37.2	36.0	24.001	21.9
16:00:00	43.1832	43.0	38.325	37.0	24.0535	21.5
17:00:00	43.69019	43.5	37.325	36.0	24.40169	22.0
18:00:00	43.72846	43.8	35.55	34.6	25.02015	22.5
19:00:00	43.52163	43.2	33.825	33.3	25.76697	23.0
20:00:00	34.5239	35.9	33.025	32.2	26.41551	23.5
21:00:00	34.02543	33.1	32.45	31.5	27.34797	24.0

The results revealed a discrepancy between 1 and 3 percent between the temperature obtained from field measurements and the results obtained from simulation. According to other validation studies of the Design Builder simulation software [34,35], this discrepancy falls within the acceptable range, which is consistent with the reports reviewed in the previous sources.

In addition, Table 2 displays the internal temperature measurement of the Sarai Nowzari store on 15 December 2022 (the coolest month of the year) and the simulation data.

Table 2. Comparison of measurement and simulation temperature results in a store in Sarai Nowzari on 15 December 2022.

Date/Time (December)	Relative Humidity %		Outdoor Dry-Bulb Temperature °C		Indoor Air Temperature °C	
	Simulation	Field Measurement	Simulation	Field Measurement	Simulation	Field Measurement
6:00:00	20.2739	20.6	−2.87	−2.85	15.45966	15.28
7:00:00	19.34711	19.5	−2.075	−2.10	16.95825	16.48
8:00:00	17.93888	17.5	−1.875	−1.85	19.26227	18.87
9:00:00	17.75856	17.1	1.03	1.03	19.87473	19.63
10:00:00	18.33944	18.0	1.525	1.55	20.26867	19.78
11:00:00	18.96519	19.3	2.025	2.05	20.65415	20.21
12:00:00	19.42782	19.8	2.45	2.55	20.87272	21.13
13:00:00	19.61721	20.2	2.875	2.90	21.10908	21.49
14:00:00	19.79159	19.6	3.025	3.00	21.27316	21.10
15:00:00	20.12667	19.8	2.75	2.80	21.3349	20.90
16:00:00	20.296	20.4	0.825	0.82	21.44276	21.18
17:00:00	20.26794	20.3	0.25	0.25	21.511	21.77
18:00:00	19.53312	20.0	−1.85	−1.90	21.72228	21.43
19:00:00	18.79874	18.5	−2.45	−2.52	21.80025	21.40
20:00:00	21.59453	21.0	−3.975	−3.90	20.26762	20.69
21:00:00	22.26062	22.0	−4.55	−4.58	19.25935	19.45

The actual consumption of electricity and gas was extracted through monthly bills in a one-year period.

Using Equation (1), the information obtained from the monthly bills was compared to the results obtained from the case simulation.

$$\text{Difference Percentage} = |(\text{Actual Energy Consumption} - \text{Simulated Energy Consumption})| / \text{Actual Energy Consumption} + \text{Simulated Energy Consumption}/2) \times 100 \quad (1)$$

The simulation engine of this software is Energy Plus, which was developed by the US Department of Energy in 2011 and is known as one of the most reliable energy modeling software. The validity of Energy Plus software 9.4, which is the simulation engine of Design Builder, was confirmed based on BESTEST and ASHRAE-14 standards [36]. Energy Plus is among the dynamic energy software that have high flexibility, and the following factors are included within it:

- Geographic location and orientation of the structure;
- Specific local weather conditions;
- Intricate 3D geometry of the building, including shading from nearby structures and self-shading;
- Time lag in the response of the building envelope;
- Type and characteristics of utility systems (heating, ventilation, and air conditioning) installed in the building;
- Functioning of automated utility system controls during weather fluctuations;
- Building's operational schedule, accounting for varying usage throughout the day, week, month, and year;
- Nonlinear interconnection of utility system components within the building [37].

As can be seen in Table 3, the percentage difference between the actual consumption of electricity and gas and the results obtained from the simulation shows an average difference of 1.6%, which is consistent with the results obtained in similar studies [38].

Table 3. Comparison of the difference between predicted consumption with Design Builder software and actual consumption.

Date/Time Month	Dome Roof					
	Gas (kWh)			Electricity (kWh)		
	Simulation	Actual Consumption	Percentage Difference	Simulation	Actual Consumption	Percentage Difference
Jan	54,214.44	53,659.08	1.03%	219.5212	216.1801	1.53%
Feb	28,614.64	28,300.02	1.10%	576.7798	570.5030	1.09%
Mar	15,978.21	15,807.72	1.07%	2045.478	2016.1974	1.44%
Apr	5152.356	5078.193	1.45%	8003.493	7895.9567	1.35%
May	1370.026	1353.432	1.22%	22,415.59	22,041.8712	1.68%
Jun	0.0	0.0	0.0	37,432.63	36,912.6510	1.40%
Jul	0.0	0.0	0.0	56,717.68	56,127.1964	1.05%
Aug.	0.0	0.0	0.0	49,798.81	49,334.5298	0.94%
Sep	0.953908	0.935514	1.95%	31,352.17	31,038.2601	1.01%
Oct	1998.189	1973.200	1.26%	12,761.63	12,592.1292	1.34%
Nov	21,407.21	21,092.34	1.48%	852.084	842.6850	1.11%
Dec	40,989.13	40,489.30	1.23%	377.1165	372.4799	1.24%

2.1.2. Initial Settings of the Software for the Simulation Process

In order to acquire valid and reliable results from simulation, it is necessary to take certain factors into account. Therefore, the information gathered from the Bazaar's site visit was used as simulation input data and initial parameters in the software. Table 4 provides an example of input data.

Table 4. Input data and initial settings of Design Builder software.

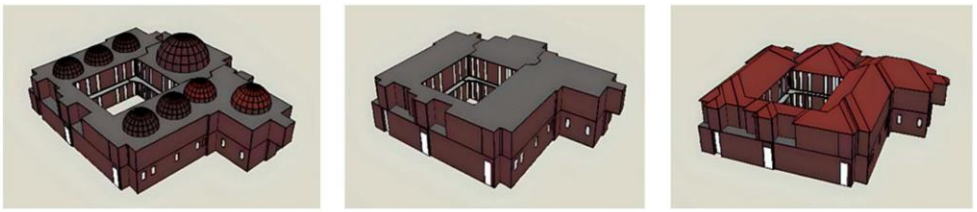
Wall **3 layers**	**Outermost layer** Brickwork outer Thickness (m)	0.1000	
	Layer 2 Brickwork outer Thickness (m)	0.5000	
	Innermost layer Gypsum plastering	0.1000	
Roof **3 layers**	**External layer** Thickness (m)	**Tile**	0.0200
		Brick	0.2000
	Air gap Thickness (m)	0.3000	
	Internal layer Thickness (m)	**Brick**	0.2000
		Plaster Board	0.0200
Convective heat transfer coefficient External Wall ($W/m^2/K$)		2.1000	
Convective heat transfer coefficient External Roof ($W/m^2/K$)		0.4900	

2.2. Simulation of Sarai Nowzari in Design Builder to Compare the Energy Consumption of Three Dome, Flat, and Sloped Roofs

In order to simulate the market conditions through the utilization of Design Builder software, it is imperative to initially establish the corresponding environment within the software.

The present study involves the simulation of "Sarai Nowzari", a Caravanserai located in Arak Bazaar. The aforementioned caravanserai is characterized by an unroofed central area and enclosed compartments, featuring a sizable central dome and seven minor lateral domes. It is noteworthy that certain particulars have not been taken into account due to constraints in the software, which could potentially result in inaccuracies. The objective of this study was to examine the impact of different roof types on the reduction of energy consumption and enhancement of passive thermal comfort in Nowzari Caravanserai, which is situated in Arak Bazaar. In order to guarantee the precision of the investigation, the simulation was meticulously crafted to closely emulate the present Bazaar reality, and pivotal parameters such as dimensions and materials were meticulously chosen to correspond with the factual Bazaar.

The present investigation involved the creation of three distinct models of Nowzari Caravanserai, involving dome, flat, and sloped roofing designs (As depicted in Figure 2) In the simulated scenario involving a sloped roof, the angle of inclination for the roof was uniformly established at 30 degrees across all orientations. The selection of a 30° roof pitch was based on its recommendation in the literature for the purpose of facilitating maintenance and promoting enhanced air circulation, as compared to alternative pitches [39]. The objective was to conduct a comparative analysis of the parameters associated with thermal energy consumption (measured via gas consumption) and cooling (measured via electricity consumption) across the three distinct roof shapes. Furthermore, the present investigation was carried out with the objective of contrasting alterations in temperature during the warmest and coolest months of the calendar year within the interior and exterior settings of the marketplace. The average monthly temperature of Arak City over a 10-year period was obtained from the Meteorological Department for the purpose of temperature analysis. This study aims to offer valuable insights into the potential advantages of utilizing domed roofs as a means of reducing energy consumption and enhancing passive thermal comfort in conventional marketplaces, such as Arak Bazaar.



(**a**) (**b**) (**c**)

Figure 2. "Sarai Nowzari" is a part of Arak Grand Bazaar: (**a**) Simulation of the original dome roof; (**b**) Simulation of the flat roof; (**c**) Simulation of the sloping roof.

3. Results

3.1. Energy Analysis

In order to facilitate a meaningful comparison, it is necessary to first provide a summary of the aggregate simulated energy consumption for each category within every type of commercial structure for the given year.

A comparative analysis was conducted on the energy consumption of various types of roofs (For additional information, please consult Table 1). The annual energy consumption for heating (using gas) and cooling (using electricity) in a flat-roof structure were recorded

as 189,649.95 kWh and 297,761.24 kWh, respectively. The aggregate energy usage of the flat-roof configuration over the course of a year amounted to 567,909.30 kWh.

On the contrary, the employment of a dome-roof structure resulted in reduced energy consumption. The recorded heating energy consumption was 171,525.12 kWh, while the cooling energy consumption was 271,874.11 kWh. As a result, the aggregate energy consumption of the dome-shaped roofing system was significantly lower, totaling 515,539.93 kWh on a yearly basis.

The energy consumption of the sloping roof structure was moderate. A total of 183,309.95 kWh was utilized for heating purposes, while 284,792.92 kWh was consumed for cooling purposes. The aggregate energy consumption of a slanted-roof configuration throughout the course of a year amounted to 540,243.57 kWh.

According to the data in Table 5, the percentage difference in total energy consumption between roof types during the coldest and warmest months was analyzed.

Table 5. Variations in simulated energy consumption (over the course of one year) of Nowzari Caravanserai with three distinct rooftops.

Date/Time	Flat Roof		Dome Roof		Sloping Roof	
	Heating (Gas)	Cooling (Electricity)	Heating (Gas)	Cooling (Electricity)	Heating (Gas)	Cooling (Electricity)
Month	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**
Jan	60,147.94	277.6499	54,214.44	219.5212	57,595.19	270.9657
Feb	31,765.94	771.796	28,614.64	576.7798	30,499.19	648.9638
Mar	17,657.38	2254.174	15,978.21	2045.478	16,742.15	2181.432
Apr	5451.338	8130.306	5152.356	8003.493	5383.951	8098.798
May	1425.126	23,978.4	1370.026	22,415.59	1400.365	23,161.36
Jun	0.0	40,649.91	0.0	37,432.63	0	38,801.34
Jul	0.0	61,990.3	0.0	56,717.68	0	59,805.05
Aug	0.0	54,601.4	0.0	49,798.81	0	52,211.26
Sep	1.454403	34,317.98	0.953908	31,352.17	1.1019	33,159.65
Oct	2048.211	13,820.44	1998.189	12,761.63	2025.542	13,182.91
Nov	23,408.87	1000.9152	21,407.21	852.084	22,795.53	978.3631
Dec	45,140.59	573.384	40,989.13	377.1165	41,367.28	466.3942

The mathematical expression used to calculate the percentage difference between two values is:

$$\text{Percentage Difference} = (|X - Y| / ((X + Y)/2)) \times 100 \quad (2)$$

The computations demonstrate the dissimilarity in energy usage across various architectural configurations, namely flat, dome, and sloping roofs, throughout the most frigid and sweltering periods of the year.

Highlighted by Table 6 during the month of December, the flat structure exhibits the greatest energy consumption, followed by the sloping roof and the dome, respectively. The flat type exhibits a notable dissimilarity from the other two variants, manifesting a higher energy-consumption rate of around 9.97% compared to the dome type and 8.95% in contrast to the sloping-roof type. Nonetheless, the energy usage of both the dome- and sloping-roof constructions exhibits a comparable pattern, with a marginal deviation of merely 0.97%.

Table 6. Variations in energy consumption (over the course of one year) of Nowzari Caravanserai with three distinct rooftops.

	Percentage Difference in December	Percentage Difference in July
Between Flat and Dome Roofs	9.97%	9.04%
Between Flat and Sloping Roofs	8.95%	4.26%
Between Dome and Sloping Roofs	0.97%	4.65%

During the month of July, which is typically characterized by high temperatures, it was observed that the flat structure consumed the highest amount of energy. However, the discrepancies in energy consumption between the various structures were comparatively smaller than those observed in the month of December. According to the data, the flat structure consumes 9.04% more energy compared to the dome, and a mere 4.26% more energy than the sloping roof. The energy consumption of the dome and the sloping roof exhibits a marginal variance of 4.65%.

Based on these findings, it can be deduced that:

The energy consumption of flat structures is higher for both heating and cooling, particularly during the coldest and hottest months, respectively. This implies that such structures may not be the optimal choice for extreme temperature conditions in terms of energy efficiency. This phenomenon may be attributed to various factors, such as an increased surface area that is subject to fluctuations in external temperature.

According to research, dome structures exhibit greater energy efficiency during colder months compared to flat- and sloping-roof structures, as they consume relatively lower amounts of energy. This phenomenon could potentially be attributed to the circular configuration of the object, resulting in a reduced surface area that is susceptible to colder temperatures and subsequently, a diminished amount of heat dissipation.

The structures with sloping roofs exhibit a commendable equilibrium in energy utilization under varying temperature conditions, consuming a lower quantum of energy than the flat structures but a marginally higher quantum of energy than the dome-shaped ones.

The data presented in Figure 3 indicate that:

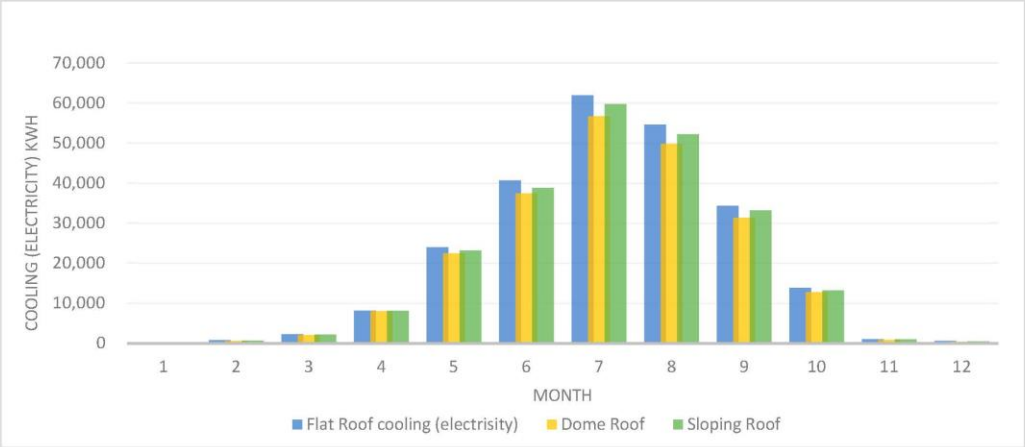


Figure 3. Comparison of electrical energy consumption for cooling purposes between two simulated roof models and the main dome-roof model of Nowzari Caravanserai during the hottest month of the year (July).

During the month with the highest temperatures (July), the flat roof exhibits the highest electrical energy to provide cooling inside, while the dome roof displays the lowest energy usage. The electrical energy of the sloping-roof commercial structure is marginally higher than that of the dome roof, yet lower than that of the flat roof.

The Arak Bazaar's dome roofs feature ventilation holes. Using Design Builder software, two scenarios were analyzed: one with the presence of ventilation holes and one without. The study aimed to determine the amount of electrical energy consumption required for cooling and the amount of gas energy consumption required for heating in both scenarios. An analysis was conducted on the months of the year to gather additional insights into the impact of ventilation apertures on energy usage (As depicted in Figure 4).

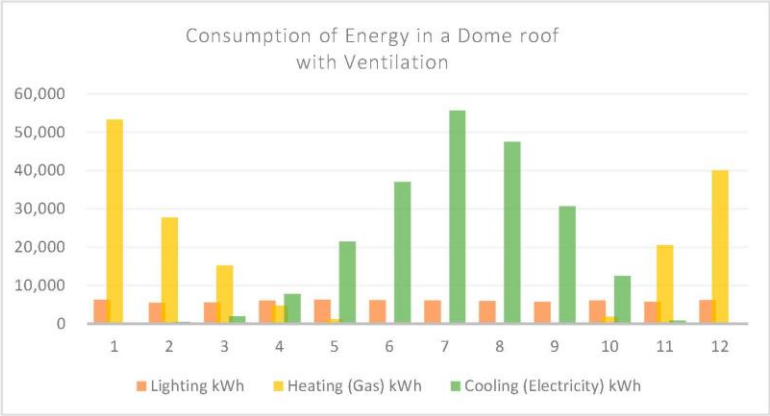


Figure 4. Diagram of consumption of energy in a dome roof with ventilation.

Upon comparing the data presented in Table 7 with those in Table 5, specifically in the domed-roof section, it is evident that the structure lacking ventilation exhibits higher energy consumption across all categories. The aforementioned statement suggests that the ventilation system within the edifice contributes to the mitigation of energy consumption by facilitating natural cooling and heating processes, thereby diminishing the necessity for artificial heating and cooling.

Upon analyzing the monthly data, discernible patterns can be observed.

In both configurations, the consumption of heating energy exhibits a peak during the colder months (January, February, November, and December) and diminishes to negligible levels during the warmer months (May through September).

The pattern of cooling energy consumption exhibits an inverse trend. The temperature exhibits a peak during the warmer months spanning from May to September and subsequently declines to a minimum during the colder months.

The energy usage for illumination appears to exhibit a degree of constancy over the course of the year in both edifices, with slight variations.

Typically, the energy consumption of a ventilated structure is lower than that of a non-ventilated structure.

Table 7. Energy consumption (over the course of one year) of Nowzari Caravanserai with ventilation.

Date/Time	Heating (Gas)	Cooling (Electricity)
Month	**kWh**	**kWh**
Jan	53,260.5	239.7364
Feb	27,724.76	479.9971
Mar	15,192.91	1943.613
Apr	4728.495	7786.682
May	1205.981	21,437.55
Jun	0	36,991.23
Jul	0	55,685.85
Aug.	0	47,481.87
Sep	0.385918	30,672.16
Oct	1816.613	12,478.89
Nov	20,505.58	820.495
Dec	39,980.93	301.8492

3.2. *Thermal Comfort*

The external weather information plays a crucial role in elucidating the internal temperature of spaces and determining the energy demand necessary to establish comfortable conditions. The climatic variables utilized in building-energy simulation, such as epw, wea, and TMY formats, are derived from meteorological station data and are employed while taking into account the environmental conditions surrounding the analyzed structure. The present study obtained weather data from the meteorological organization of Arak City, encompassing the average temperature, as well as the maximum and minimum temperatures, for the past decade. This information was subsequently utilized as input for the software, representing the weather conditions of the region. In accordance with the suggestions put forth by comparable scholarly articles [35,38], it is imperative to exercise control over various factors and parameters in order to enhance the dependability of predictions generated by simulation software. The relationship between the wind speed surrounding the market building and the level of radiation received is contingent upon the specific attributes of the surrounding area. Hence, the coefficients pertaining to wind and its reflection were regulated based on the market building's positioning relative to its surrounding context, in order to ensure that the software's outputs closely approximated the actual values.

Figure 5 presents data pertaining to the humidity, outdoor temperature, and indoor temperature of the warmest day of the warmest month in Nowzari Caravanserai, Arak Bazaar, for the purpose of comparison.

The outdoor dry-bulb temperature, measured in degrees Celsius, exhibits a diurnal pattern consistent with typical daily variations. The minimum temperature of 23.00 °C is recorded at 6 a.m., whereas the maximum temperature of 38.33 °C is recorded at 4 p.m. In this pattern, temperatures are at their lowest in the early hours of the morning prior to sunrise and at their highest during the afternoon.

The data suggest that there is a delay in the indoor air temperature in relation to the outdoor temperature. The indoor temperature reaches its minimum value of 24.00 °C at 3 p.m., which coincides with the outdoor temperature nearing its maximum value. Conversely, the indoor temperature reaches its maximum value of 31.34 °C at 1 a.m.

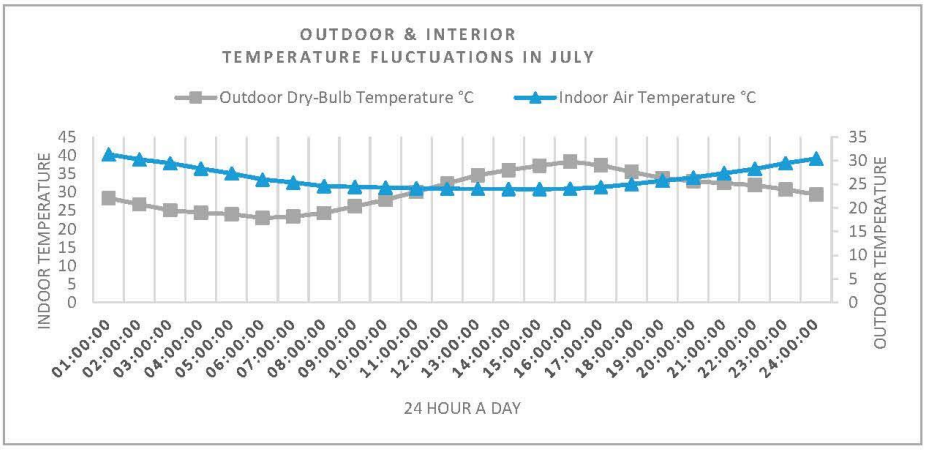


Figure 5. Diagram of outdoor and interior temperature fluctuations of Nowzari Caravanserai on the hottest day of July.

The mean absolute temperature difference between 6:00 a.m. and 6:00 p.m., as calculated from available data, is −6.44 °C.

The average absolute temperature difference during the nocturnal period, from 18:00 to 6:00, was found to be −1.54 °C. It should be noted that negative values indicate that the indoor temperature was lower than the outdoor temperature.

On average, the indoor temperature exhibits a decrease of 6.44 °C compared to the outdoor temperature during the day, and a decrease of 1.54 °C during the night.

Upon computation of the correlation coefficient, it was determined that the correlation between outdoor temperature and indoor temperature was −0.39534, which falls below the threshold of 0.5 and thus suggests a correlation that is weak to moderate in nature. This implies that the correlation between the ambient outdoor temperature and the indoor temperature is relatively weak.

Figure 6 displays information regarding the levels of humidity, outdoor temperature, and indoor temperature of the most frigid day of the chilliest month at Nowzari Caravanserai, Arak Bazaar, with the intention of facilitating a comparative analysis.

The minimum temperature of −5.925 °C is recorded at 1 a.m., whereas the maximum temperature of 3.025 °C is recorded at 2 p.m. The ambient temperature outdoors is subzero, whereas the indoor temperature is significantly elevated, maintaining a range of approximately 14 to 21 °C.

The diurnal temperature range exhibits an average absolute difference of approximately 19.32 °C, while the nocturnal temperature range displays an average absolute difference of around 21.94 °C. The aforementioned statement implies that the indoor temperature of the building maintains an average of being 19.32 °C higher during the daytime and 21.94 °C higher during the nighttime in comparison to the outdoor temperature.

The correlation coefficient calculation reveals that there exists a positive correlation of +0.704731 between the outdoor temperature and indoor temperature. This suggests that there is a positive correlation between outdoor temperature and indoor temperature, whereby an increase in one variable is accompanied by a corresponding increase in the other variable.

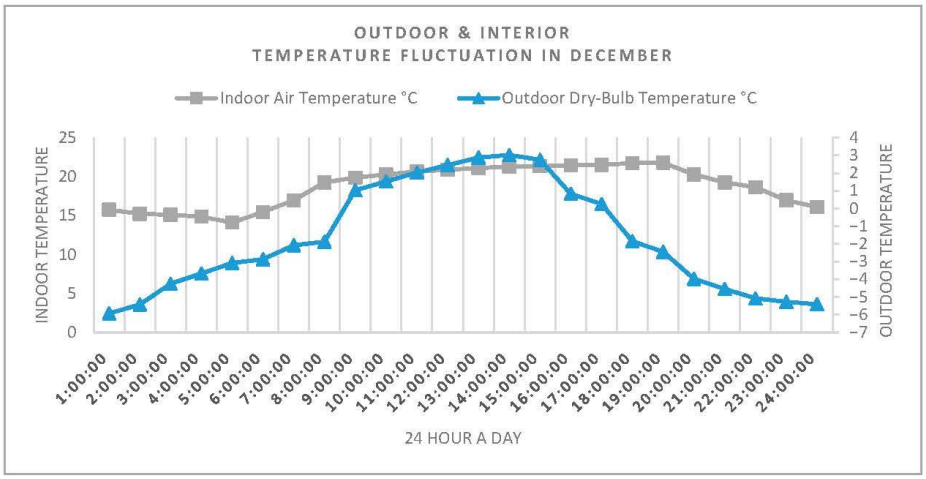


Figure 6. Diagram of outdoor and interior temperature fluctuations of Nowzari Caravanserai on the coldest day of December.

To construct the psychometric diagram representing ASHRAE's comfort conditions, it is essential to consider six primary factors that influence thermal comfort. The parameters to be considered in this study are as follows: air temperature (°C), mean radiant temperature (MRT—°C), air speed (m/s), relative humidity (%), metabolic rate (met), and clothing level (col).

The aforementioned parameters are evaluated based on the climatic conditions prevailing in the region during the peak heat of the warmest month and the extreme cold of the coldest month, as indicated in Table 8.

Table 8. Psychometric factors that affect thermal comfort of Nowzari Caravanserai.

Month	Mean Air Temperature (°C)	Mean Radiant Temperature (°C)	Air Speed (m/s)	Relative Humidity (%)	Metabolic Rate (met)	Clothing Level (col)
July	26.37	26	0.15	35.23	1.7	0.5
December	18.74	18	0.2	21.17	1.7	1

As is evident from the data in Table 8, the air temperature parameter encompasses the calculation of the average temperature on both the hottest and coldest days. During the peak of July, the prevailing atmospheric conditions are characterized by an average air humidity of 35.23% and an air speed of 0.15 m/s. The investigation of the comfort temperature within the market premises primarily focused on the activities commonly performed by its users, such as walking, passing through the market, and engaging in shopping activities. Consequently, a metabolic rate of 1.7 (met) (representing the standard for walking) was taken into account. The value of 0.5 (col) is commonly used to represent the clothing level parameter in the context of typical summer clothing.

Furthermore, on the coldest day of December, the average humidity is recorded as 21.17%. The air speed during this time is measured at 0.2 m/s, while the metabolic rate is estimated to be 1.7 (met). Additionally, the clothing level factor is assigned a value of 1 (col), representing typical winter clothing.

In order to generate the thermal comfort diagram for ASHRAE Standard 55-2020 [40] during the month of July, the six factors listed in the first row of Table 8 were utilized. Similarly, for the comfort temperature diagram in accordance with ASHRAE Standard

55-2020 during the month of December, the settings were configured based on the second row of Table 8.

The data depicted in Figures 7 and 8, which include relative humidity, were acquired via simulations conducted using the Design Builder software. The software was utilized to create an accurate model of the intended building, considering multiple parameters and conditions. Following this, the software generated results pertaining to relative humidity.

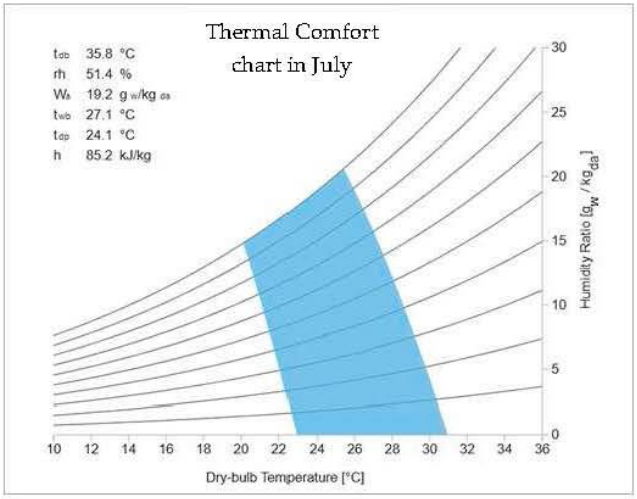


Figure 7. Thermal comfort chart [41] of Nowzari Caravanserai on the hottest day of July.

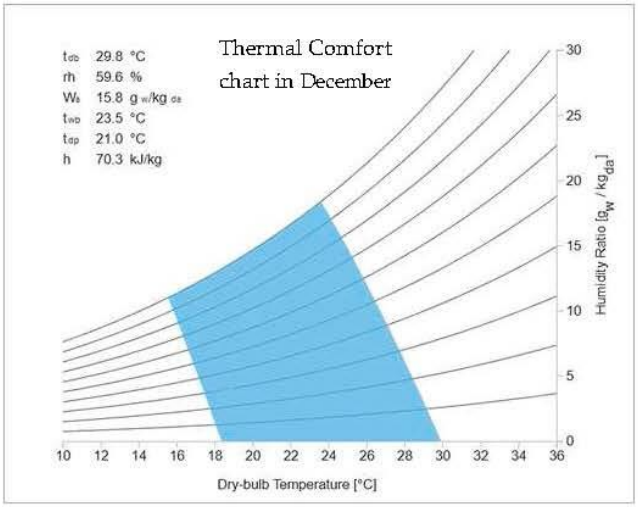


Figure 8. Thermal comfort chart [41] of Nowzari Caravanserai on the coldest day of December.

The temperature data provided are derived from the report obtained from the local meteorological institution.

The blue area depicted in Figures 7 and 8 represents the comfort zone, which signifies the range of dry-bulb temperature and humidity values deemed acceptable according to

the established standard. This interpretation assumes that the remaining four parameters remain unchanged.

Figure 7 presents thermal comfort charts that illustrate a spectrum of conditions in which individuals would experience thermal comfort, taking into account variables such as temperature, humidity, and other environmental factors. The provided chart illustrates the environmental conditions experienced at the Nowzari Caravanserai on the peak of July's hottest day and their implications for human comfort.

The thermal comfort chart depicted in Figure 8, similar to the July chart, illustrates the spectrum of conditions within which individuals would experience thermal comfort on the coldest day of December at the Nowzari Caravanserai.

4. Discussion

The results obtained from this investigation validate and broaden the scope of prior research activities that have investigated energy usage in various architectural configurations. The energy consumption of the flat-, dome-, and sloping-roof structures exhibited notable dissimilarities, particularly in the months with high temperature peaks.

During the month of December, it was observed that flat structures exhibited the highest energy consumption. This observation is consistent with the research conducted by Jimin et al. (2020), which indicated that flat roofs, as they have larger surface areas exposed to the cold, tend to require more energy for heating purposes [13,42]. By comparison, dome structures were observed to consume less energy as they have smaller surface areas exposed to temperature fluctuations. This observation is consistent with the findings of Abraham et al. (2016), who suggested that the energy-efficient characteristics of dome structures could be attributed to their geometric shape [43].

In the month of July, which is typically characterized by high temperatures, there was a decrease in the energy-consumption discrepancy among various architectural designs. However, it is noteworthy that flat structures continued to exhibit the highest energy-consumption levels. The dome structures exhibited commendable energy efficiency by consuming relatively low energy, as confirmed by the findings of [10,15,44], particularly during temperature extremes.

Regarding the temporal discrepancy between outdoor and indoor temperatures, the warm season of the year also plays a role in enhancing energy efficiency. Improved insulation can result in decreased energy consumption, as evidenced by a delayed indoor response to outdoor temperatures. The correlation coefficient of −0.39534 observed between outdoor and indoor temperature suggests a moderate association between these variables. This finding implies that changes in outdoor temperature do not necessarily result in corresponding changes in indoor temperature. These results are consistent with the research carried out by [6,45–47].

The supplementary discoveries serve to underscore the variations in thermal regulation and energy expenditure among diverse architectural arrangements, with particular emphasis on the dome-shaped edifices situated in Arak Bazaar.

During the month with the lowest temperatures, the minimum temperature of −5.925 °C was documented at 1 a.m., while the maximum temperature of 3.025 °C was recorded at 2 p.m. The aforementioned fluctuations were found to be uniform, as the indoor temperature levels displayed a mean absolute deviation of roughly 19.32 °C during daytime hours and 21.94 °C during nighttime hours, relative to the corresponding outdoor temperature levels. The significant contrast highlights the insulating capabilities of dome-shaped structures, which aligns with the research conducted by [7,48], demonstrating that dome structures demonstrate better thermal efficiency in comparison to alternative designs.

Furthermore, a statistically significant positive correlation coefficient of +0.704731 was observed between the outdoor and indoor temperatures. This represents a deviation from previous discoveries that indicated a feeble adverse association. The alteration in temperature regulation within the dome structures at Arak Bazaar can potentially be ascribed to

their distinct characteristics, including the presence of ventilation apertures. These features may have contributed to a heightened sensitivity to fluctuations in external temperature.

The Design Builder software was utilized to conduct a comprehensive assessment of the ventilation apertures present in the dome roofs. The study aimed to compare the energy consumption of two scenarios—one with ventilation holes and the other without—in order to determine their respective impacts. The findings indicate that structures featuring apertures for ventilation exhibit reduced energy consumption, corroborating prior scholarship that underscores the significance of passive ventilation in augmenting energy efficacy. The studies conducted by [17,48,49] are of academic interest.

This study revealed that the energy consumption pertaining to heating experienced a surge during the colder months, whereas the energy consumption for cooling reached its peak during the warmer months. The observed trends were in line with prevailing assumptions and align with the outcomes of prior research activities [8,50]. Additionally, the utilization of illumination exhibited consistency throughout the annual period, indicating that fluctuations in energy usage were predominantly attributable to the requirements for heating and cooling.

5. Conclusions

The current study conducted a comprehensive investigation into architectural configurations, focusing specifically on the energy efficiency and thermal comfort of various roofing structures. The study conducted a thorough analysis of the "Sarai Nowzari" Caravanserai in Arak Bazaar, with a specific focus on three different roofing designs: dome, flat, and sloped. This analysis was carried out using the Design Builder simulation software.

The results of this study emphasize the importance of architectural configuration in achieving energy efficiency, particularly in the context of dome-shaped buildings that integrate ventilation features. The Nowzari Caravanserai, situated in Arak Bazaar, serves as a prime example of how architectural design can effectively minimize energy usage by harnessing natural cooling and heating mechanisms.

Based on the findings of this study, it has been observed that dome structures demonstrate superior efficacy in the regulation of indoor temperature when compared to flat- and sloping-roof structures, particularly during periods characterized by extreme temperature conditions. The findings of the research demonstrate that the dome structures displayed enhanced thermal efficiency, as indicated by notably higher indoor temperatures in colder months and lower indoor temperatures in hotter months, in contrast to outdoor temperatures. Significant variations were observed in energy consumption across different roof types during the comparative analysis. The dome-shaped roofing system exhibited a decrease in energy consumption, amounting to 515,539.93 kWh per year, in comparison to flat- and sloping-roof structures. This discovery highlights the potential benefits of incorporating domed roofs into traditional marketplaces as a means to decrease energy usage.

A thorough evaluation of ventilation apertures in a dome roof was undertaken. The results of the study revealed that buildings with ventilation openings demonstrated lower energy consumption, providing further evidence for the importance of passive ventilation in enhancing energy efficiency.

The aforementioned findings highlight the notable advantages of incorporating traditional architectural elements, as exemplified by the Nowzari Caravanserai, into contemporary building designs. The achievement of energy efficiency is often a significant factor to be taken into account, particularly within the realm of commercial buildings.

The findings of the study indicate that there was a significant increase in energy consumption for heating purposes during colder months, whereas energy consumption for cooling purposes reached its maximum during warmer months. This observation is consistent with prevailing assumptions and previous research, suggesting that energy consumption is influenced by seasonal demands.

The current study emphasizes the importance of incorporating the inherent benefits of traditional architecture into modern constructions. Through the application of these principles and their adaptation to meet contemporary needs, it is possible to pave the way for the construction of buildings that are more sustainable and energy efficient. The integration of traditional knowledge and modern technology has the potential to address the challenge of constructing buildings that are environmentally sustainable and economically viable.

The integration of conventional architectural principles into contemporary construction methodologies holds the capacity to construct buildings that efficiently mitigate energy consumption, thereby fostering sustainable urban development.

The dome roof is a notable feature of traditional Iranian architecture and has been found to exhibit unique thermal properties that enable effective energy management, thermal comfort, and the optimal utilization of natural resources. Previous research has demonstrated the advantages of employing dome roofs in mitigating energy consumption and promoting energy conservation in various settings, including residential structures and places of worship, such as mosques. This study contributes further evidence to support the efficacy of dome roofs in enhancing energy efficiency, highlighting their importance within the realm of sustainable architectural principles.

In conclusion, the prioritization of improving energy efficiency in the construction sector is crucial for reducing the impact of built environments on global energy consumption and greenhouse gas emissions. This study highlights the significance of traditional Iranian architecture and its ability to provide a comfortable living environment for residents while minimizing energy consumption over a prolonged period. The proposition is that by discerning the principles and regulations that govern architecture, alongside the integration of new materials and technological advancements, it becomes feasible to employ the knowledge and methodology of traditional architecture in the development of groundbreaking structures that communicate a unique aesthetic. The findings of this research possess the capacity to make noteworthy advancements in the domains of architecture, engineering, and policymaking through the provision of valuable insights that can guide the development of sustainable and energy-efficient buildings. Consequently, this can facilitate the development of a more sustainable and ecologically conscious constructed environment.

The software limitations prevented the consideration of certain specific details, which may have led to potential inaccuracies. Subsequent investigations could further investigate these dimensions by examining supplementary factors and employing experimental methodologies to authenticate the simulation results.

In summary, this study adds to the expanding corpus of knowledge regarding energy-efficient architectural design, specifically within the framework of traditional marketplaces. Through an examination of the complex relationship between architectural configurations, energy consumption, and thermal comfort, this study provides valuable insights that can inform decision-making processes in the realm of sustainable building design and urban planning.

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Data Availability Statement: For this study, the data has not yet been uploaded to a public repository. We recognize the significance of data transparency in the research community. Currently, we are in the process of identifying suitable platforms where our data can be shared while upholding any relevant privacy and ethical guidelines.

Conflicts of Interest: The authors declare no conflict of interest.

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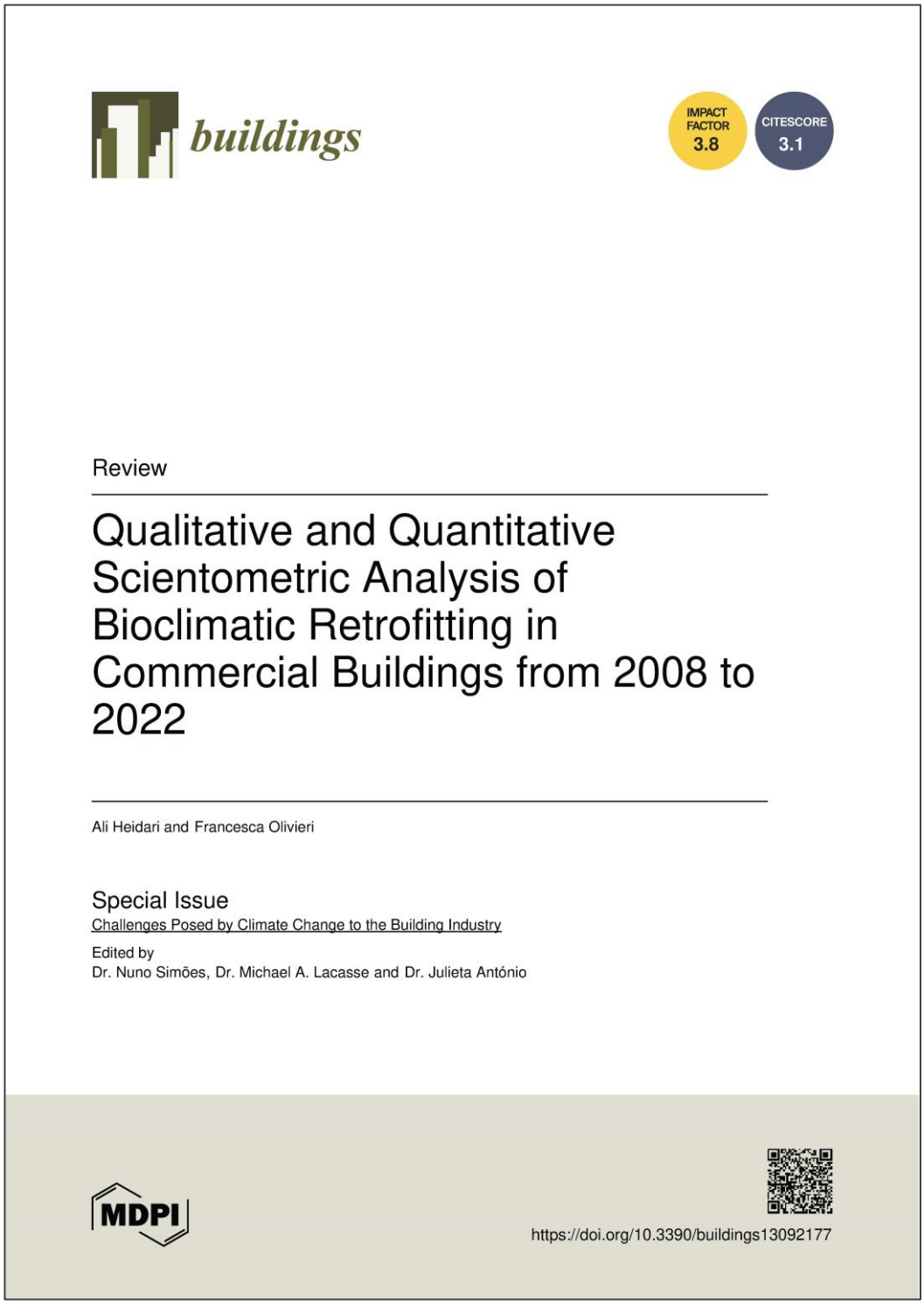
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2. Qualitative and Quantitative Scientometric Analysis of Bioclimatic Retrofitting in Commercial Buildings from 2008 to 2022

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Review

Qualitative and Quantitative Scientometric Analysis of Bioclimatic Retrofitting in Commercial Buildings from 2008 to 2022

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Abstract: The present study offers a thorough scientometric analysis of the practice of bioclimatic retrofitting in commercial buildings, which is considered a crucial approach for mitigating energy consumption and addressing the challenges posed by climate change. Since Scopus offers advanced tools for literature search and analysis, its database was used to acquire bibliographic data for nearly 400 published papers using a bibliometric search, a scientometric methodology, and an in-depth qualitative analysis. The scientometric procedure utilizes various quantitative dimensions, such as the number of intermediate citations, occurrences, average publication year, and general connection power. A retrospective examination of research publication patterns spanning 2008 to May 2022 has unveiled an upward trajectory in scholarly investigations pertaining to commercial buildings during this 15-year period. Nevertheless, research on the topics of bioclimatic design, retrofitting strategies, and green building practices in the context of commercial buildings exhibits a more gradual incline, displaying an almost linear trend between the years 2016 and 2020. Additionally, the study provides qualitative perspectives on the research environment. The paper delineates various focal points of research within the field, encompassing thermal comfort in the context of energy management and climate control, ventilation systems, sustainable development as it pertains to architectural designs and green buildings, retrofitting strategies in commercial buildings to enhance energy efficiency, the interplay between carbon dioxide levels and energy resources, the utilization of solar energy, the relationship between energy conservation and atmospheric temperature, and the application of building energy simulation techniques.

Keywords: bioclimatic retrofitting; energy conservation; commercial buildings; scientometric review; bibliometric

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1. Introduction

Buildings consume energy throughout their operational lifespan. The operational phase of a building's life cycle plays a crucial role in energy consumption. The key features encompassed within a building's infrastructure include heating, ventilation, air conditioning (HVAC), lighting, and appliances [1]. According to empirical data, the energy consumption attributed to buildings and their associated activities throughout their life cycle accounts for over 40% of the total global energy demand [2]. Approximately 50% of the total energy consumption is allocated to heating, ventilation, and cooling (HVAC) systems [3].

The energy consumption in question pertains to carbon dioxide emissions, which have exhibited an annual growth rate of 6.83% over the previous decade. The rate of growth of this phenomenon is increasing, as evidenced by the total emissions of 881 megatons (Mt CO_2) reported in 2018. In the realm of existing structures, mercantile edifices are presently the most widely employed buildings, as determined by their overall performance [4].

Hence, the imperative to mitigate carbon dioxide emissions resulting from the utilization of fossil fuels to generate energy for pre-existing commercial structures has become a crucial matter of policy and design for governments globally [2]. Consequently, a considerable body of research, investment, technological advancements, and regulatory efforts are directed toward reducing energy consumption in HVAC systems through the implementation of sustainable building practices [3].

According to the definition provided by the US Environmental Protection Agency (2012), green construction refers to the practice of designing and implementing environmentally responsible structures and processes while also ensuring the efficient utilization of resources throughout the entire life cycle. A Green Building (GB) can also be referred to as a High-Performance Building or a Sustainable Building. There are two distinct categories of GB design, namely new design (ND), which pertains to the construction of new buildings, and reinforcement design (RD), which focuses on enhancing the structural integrity of existing buildings [5]. Studies have demonstrated that the energy consumption of newly constructed buildings often exceeds the initial projections made during the design phase, despite the utilization of architectural elements such as Green Building practices. This disparity is frequently denoted as the "performance gap" [3].

A study conducted in 2013 [6] examined the annual energy consumption per unit area (square meter or square foot) of building infrastructure in a sample of 953 properties located in New York City. The researcher observed a lack of substantial energy conservation in LEED-certified buildings compared to non-LEED-certified buildings. LEED, which stands for Leadership in Energy and Environmental Design, is a widely recognized certification standard for environmentally friendly construction established by the US Green Building Council [6].

In a study conducted in 2014, a comprehensive analysis was carried out on 51 buildings that were previously classified as "high performance" in the United States, Europe, and Asia [7]. It is noteworthy that a considerable proportion, roughly 50%, of the structures examined failed to comply with the ASHRAE Standard 90.1-2004 Energy Standards, as established by the American Society of Heating, Retrofitting, and Air Conditioning Engineers [8].

A separate study conducted in 2019 [9] examined the operational efficiency of green buildings, with a particular focus on China and the United States. A comprehensive review of the literature identified a total of 106 studies that included substantial quantitative data analysis. A comparison was conducted between the energy intensity of 121 high-performance certified buildings from the United States and 31 buildings from China. According to the study, there has been a marginal improvement in the overall performance of the building.

In conjunction with the considerable energy consumption exhibited by contemporary commercial buildings constructed in accordance with the Green Building Rules, as previously delineated, a more disconcerting reality pertains to the majority of commercial buildings in prominent urban centers worldwide, which were erected prior to the advent of energy efficiency measures and are currently 20 to 30 years old. The primary issue at hand pertains to the fact that the majority of these structures are anticipated to be in use until the year 2050. Hence, as a result of their elevated energy consumption, current commercial buildings exert added strain on the emission of carbon dioxide derived from fossil fuel sources [10].

Due to its perceived comparative advantages in terms of energy-saving potential, the construction sector occupies a prominent position in addressing global energy and environmental concerns, surpassing other sectors such as industry and transportation. The existing structure serves as the backbone of the construction sector, making it imperative to enhance its performance in order to ensure stability. Therefore, it is crucial to enhance the energy efficiency and environmental impact of existing commercial buildings in industrialized nations [1].

The recognition of sustainable retrofit strategies as the sole acceptable approach to mitigating energy consumption and carbon emissions in buildings is growing. According to the available data, sustainable retrofitting of commercial buildings has been found to result in a consistent reduction of approximately 75% [2]. One of the sustainable energy-efficient solutions is bioclimatic design [11], which emphasizes the various components of energy consumption in buildings. Hence, it is imperative to take into account the incorporation of design interventions rooted in standards of bioclimatic design when undertaking the retrofitting and sustainable operation of commercial buildings [2].

Bioclimatic architecture refers to the study of weather conditions in the field of architecture, with the aim of improving the well-being and comfort of building occupants. This is achieved through the implementation of passive energy processes, formal plan components, and heat transfer management technology [11].

Prior studies have proven valuable in elucidating the significance of bioclimatic architecture. In addition, they provide us with practical remedies for retrofitting commercial buildings. A study conducted in 2021 aimed to identify and prioritize the key factors involved in the selection of suitable repair and maintenance (R&M) procedures for commercial buildings (CB). This issue holds considerable significance for the construction industry, as well as the fields of architecture and engineering. The study encompasses a set of 16 measures that are categorized into five distinct areas. These areas consist of flexibility, technical skill, risks, maintenance costs, facilities, technology, and human resources. The Fuzzy Analytic Hierarchy Process (FAHP) technique was employed to determine the relative importance of various criteria, and it was determined that the maintenance cost criterion is more relevant than other criteria [12]. In 2021, a study was conducted in Egypt that focused on a commercial building located in Giza, serving as a representative case study for an urban area with a significant population. In order to mitigate energy consumption, decrease CO_2 emissions, and attain ecological equilibrium, the researcher employed an alga in the retrofitting of the building facade as a means to enhance its outer layer.

According to the researcher's findings, the utilization of algae in the building facade resulted in a notable decrease in electricity consumption, ranging from 45 to 50%, as well as a reduction in CO_2 emissions [13]. Research conducted in Saudi Arabia in 2021 examined the feasibility of retrofitting commercial buildings with the aim of enhancing energy efficiency and indoor air quality. The study examines various retrofitting alternatives in relation to energy conservation and financial costs. Based on the findings, the implemented retrofitting techniques resulted in a reduction of a building's energy consumption by 39%. The significance of enhancing indoor environmental quality has also been underscored, particularly in relation to aspects such as lighting, thermal comfort, the mitigation of pollutants, which encompasses PM10 (particulate matter), TSP (total suspended particulate), CO (Carbon Monoxide), SO_2 (Sulphur Dioxide), NO_2 (Nitrogen Dioxide), and VOCs (Volatile Organic Compounds), and noise management [1].

A 3D simulation study was conducted in 2017 using integrated environmental solutions software with the virtual environment. The findings of the study demonstrated the need of utilizing energy-efficient HVAC systems and techniques to reduce building energy consumption. The recommended strategies arising from the simulation analysis were as follows;

- Creating a full-height internal atrium. (Analyses showed that the effects of solar radiation inside the atrium of the building were significant).
- The proposed air conditioning system also includes a cold roof and a chilled beam system served by a centrifugal water chiller located in the basement. The building's eastern and western peripheral areas are operated by chilled beams, which are served by an air handling unit (AHU). The central areas are served by passive cold roofs perched on the perforated roof of the building. Outdoor air is supplied to the central areas through an AHU mounted on the roof. Relieved and reciprocating air is forced to flow through the atrium. Heat dissipation from the chiller is dissipated into the

atmosphere through cooling towers located in the factory room on the roof. It is also recommended that the building be carefully configured during the commissioning period, in addition to providing cold roof technology, high efficiency, and a low-energy chiller [14].

The year 2008 witnessed a notable paradigm shift in the international community's attention toward the concept of sustainability. In accordance with the declaration made by the United Nations, the year 2008 was designated as the International Year of Planet Earth, with a primary focus on highlighting the imperative of sustainable development [15]. During this particular era, there was a notable surge in scholarly attention towards investigating energy efficiency and sustainability, encompassing the field of bioclimatic retrofitting [16].

The period from 2008 to 2022 was characterized by notable progress in the field of technology, particularly in the domain of bioclimatic retrofitting. This period witnessed the emergence and enhancement of various tools and methodologies pertaining to this field [16]. Hence, this particular timeframe holds significant importance in comprehending the development and influence of these technologies.

During this period, numerous countries implemented policy changes aimed at enhancing energy efficiency and promoting sustainability [17]. Gaining an understanding of the prevailing research trends during this specific period can yield valuable insights into the potential ramifications of these policies.

The selection of a 15-year timeframe enables a thorough examination of the existing body of scholarly works. The temporal scope of this study allows for the identification of trends and patterns, while concurrently ensuring the contemporaneity and applicability of the obtained findings.

While some manual assessments of commercial buildings have been conducted, this is one of the first compound procedure qualitative scientometric study analyses linking bioclimatic retrofitting and energy savings in commercial buildings. It also aims to improve on previous manual assessments by resolving errors and filling in knowledge gaps.

The study's objectives are as follows: (i) to critically assess and recognize the maximum influence of issuing venues, papers in climatology retrofitting in commercial buildings, and study keywords utilizing science topography; (ii) to recognize the composition of scheming studies on climatology retrofitting; and (iii) to identify knowledge gaps in the bioclimatic retrofitting domain. The study results contribute to the expansion of existing knowledge by delivering an exhaustive review of the present condition of climatology retrofitting in commercial building studies, scheming study compositions and collections, and suggesting positions for prospective research. The research can also be used as a guide for practitioners looking to maximize the advantages of bioclimatic retrofitting and planning, as well as as a policy tool.

A Bioclimatic Retrofitting Approach

In the 1950s, Olgyay [18] identified bioclimatic concerns in architecture and, in the 1960s, established a design approach. This design process integrates building physics, climatology, and human physiology and has recently been considered a cornerstone for achieving more sustainable buildings and included within the building design professions in the framework of regionalism in architecture [2].

Vernacular architecture is the cornerstone of climatology construction [19]. Cruz et al. believe that this includes evaluating historical design in relation to the climate and culture of a place, as well as providing inactive alternatives to construction and architecture [20].

The interest in vernacular architecture has been prompted by instances when HVAC and lighting systems failed to solve cooling and lighting problems [20]. The technologies used are adapted to the bioclimatic conditions in the area, and the indigenous benefits are unique due to the location of the building. Thus, soil or wood is used as a building material in local architectural designs [19].

Vernacular structures take advantage of natural resources such as the sun and wind, and research has shown that they have superior thermal execution. As a result, vernacular architecture and bioclimatic architecture are inextricably linked [21].

Because low- and medium-scale buildings are simple to make climatically interactive, with the form and fabric of the building matched to human and climate elements to increase climate reaction, the research that led to the development of bioclimatic design regulations was mainly focused on these types of structures [2].

Large-scale buildings have largely been overlooked because of the complexity of the process, the dense urban fabric in which these structures are generally found, and the availability of inexpensive energy for cooling. Bioclimatic factors have been largely overlooked in design concepts for large-scale buildings, with a good internal environment being instead achieved by employing energetic mechanical systems to restore comfort. Most commercial buildings in major cities around the world were built before energy efficiency became a goal and are between 20 and 30 years old, and these buildings will be operational until 2050. Thus, bioclimatic retrofitting of existing commercial buildings to increase energy efficiency and the environment is important [2].

The bioclimatic retrofitting approach uses passive low-energy techniques that relate to and are borne by the site's climate and meteorological conditions. The approach focuses on providing high-quality passive changes in buildings through a high-performance envelope, form, and fabric [21]. This results in a building that is climate-responsive and environmentally interactive with reduced energy consumption in operation and embodiment. A bioclimatic retrofitting approach gives a clear triple bottom line. The most convincing justification for the bioclimatic retrofitting for high-rise buildings is perhaps an economic one: the savings from lower consumption can be as much as 30–60% of the overall energy costs of the building [2].

A further justification is that bioclimatic retrofitting affords a more human experience of a commercial building. Bioclimatic retrofitting promotes better natural ventilation and awareness of place, resulting in healthier internal environments and increasing overall business productivity. A further and essential justification is the ecological rationale. By using passive devices to achieve thermal comfort, climatically retrofitted buildings have lower total carbon dioxide emissions, lowering overall air pollution, and help minimize global warming [2].

The growing demand for energy-efficient structures has resulted in a significant upswing in scholarly investigations pertaining to the application of bioclimatic retrofitting, with a specific focus on commercial edifices. Despite the extensive body of research on this subject, there exists a dearth of comprehensive literature reviews that amalgamate the outcomes of these studies and discern areas of knowledge deficiency.

This study employs an innovative methodology to investigate the concept of bioclimatic retrofitting and its impact on energy conservation within the context of commercial buildings. This preliminary and extensive analysis of scientometric data in this field rectifies inaccuracies and fills in gaps in current knowledge. This paper presents a comprehensive framework aimed at achieving near-zero energy buildings, thereby contributing to global efforts to address the energy crisis. The present study undertakes an analysis of bioclimatic retrofitting in the context of commercial building research, thereby contributing to the existing body of global knowledge on this subject. The text provides an overview of research clusters and proposes potential avenues for future research. This study aims to assist professionals in optimizing the benefits of bioclimatic retrofitting and planning, while also providing valuable insights for the development and implementation of policies. Therefore, this holds significant value in the realm of construction engineering and architectural research and application.

2. Methods

The combined approach to periodic reviews was utilized to achieve the research's objectives. The combined approach to periodic reviews mixes qualitative and quantitative

information to produce conclusions that are more comprehensive than either quantitative or qualitative analyses could produce on their own [22]. The subjective bias associated with manual systematic reviews was also removed by this method [23]. The study methodologies and instruments employed in this research are described in this section. Subsections were established to provide a comprehensive explanation of the study methods used.

2.1. Scientometric Analysis and Review of Scientific Maps

In analyzing the massive amounts of data available in the bibliographic literature, scientific topography may help to show basic trends and patterns [24]. This technology emphasizes keywords in contrast to the manual assessment process, which emphasizes researchers, publication outlets, and countries, to be linked in a study domain [25]. Bibliographic data were analyzed using scientometric investigation, a quantitative scientific mapping process.

This procedure requires the presentation of thought trends and the sketching of structural patterns in a research topic to visualize and analyze a large number of publications [26].

Scientometrics has also been used in this research. With applications in various fields [19], scientometric analysis is one of the most widely utilized methodologies for research development analysis [27].

2.2. Science Mapping Software Selection

The map visualized in this study was created using the textualization tool VOSviewer 1.6.17 (Visualization of Similarities), expanded by Ludo Waltman and Nees Jan van Eck [28]. Open-source software has been selected because of its ease of use when displaying massive networks based on distance techniques [28].

The connections among journals, researchers, and individual articles within extensive networks are established through citations, bibliographic references, or shared authorship [29]. Studies of building control, construction management, public–private partnerships, building information modeling (BIM), and on-site construction have all made use of VOSviewer. As a result, to achieve the objectives of the study, VOSviewer is suitable.

2.3. Bibliographic Data Extraction

The selection of the Scopus database as the primary source of the literature for this study was based on multiple factors. Scopus provides extensive coverage across a wide array of academic disciplines. The database comprises a collection of over 22,000 titles sourced from more than 5000 publishers worldwide, thereby offering a diverse range of research materials. The selection of Scopus was influenced by the considerable importance placed on the quality of its content. Scopus exclusively incorporates publications from publishers that are widely recognized for their credibility and reliability. This rigorous selection process serves to uphold the integrity of the research by ensuring that it is derived from reputable and dependable sources. One additional benefit of Scopus that was taken into account is its capability for tracking citations. The comprehension of the influence of a specific piece of work and the interconnections among various works is essential for conducting scientometric analysis [30].

In addition, Scopus provides sophisticated tools for literature search and analysis. These tools facilitate the identification of trends, the discovery of pertinent studies, and the execution of a thorough literature review on the subject of bioclimatic retrofitting in commercial buildings.

Although Scopus is widely acknowledged as a valuable resource, it is important to note that it is not the sole database accessible for academic research. In addition to PubMed, Web of Science, and Google Scholar, there are several other databases that provide comprehensive repositories of scholarly literature. The selection of a database is contingent upon various factors, including the particular research discipline, the extent of the research endeavor, and the unique requirements of the researcher. Due to the inevitable occurrence

of duplicate publications when merging multiple databases, the decision was made to utilize a single database [31].

Scopus was selected in this instance due to its extensive coverage of the construction engineering and architecture domain, its high-quality content, and its sophisticated search and analysis capabilities. Nevertheless, it is acknowledged that the exclusive reliance on a solitary database could potentially constrain the thoroughness of the literature review, as certain pertinent studies may not be contained within the Scopus database. The aforementioned constraint has been duly considered in the study. Published journal articles, review papers, and conference proceedings were used to conduct the literature search. Zheng et al. believe that journal articles and review articles are preferred because they are reliable sources of information that are accurate and precise [32]. As a result, the source discussed above has been designated as a trustworthy resource for preparing a literature review [33].

As shown in Figure 1, the keyword "Commercial Buildings" was used to find publications. These keywords were derived from the titles of publications.

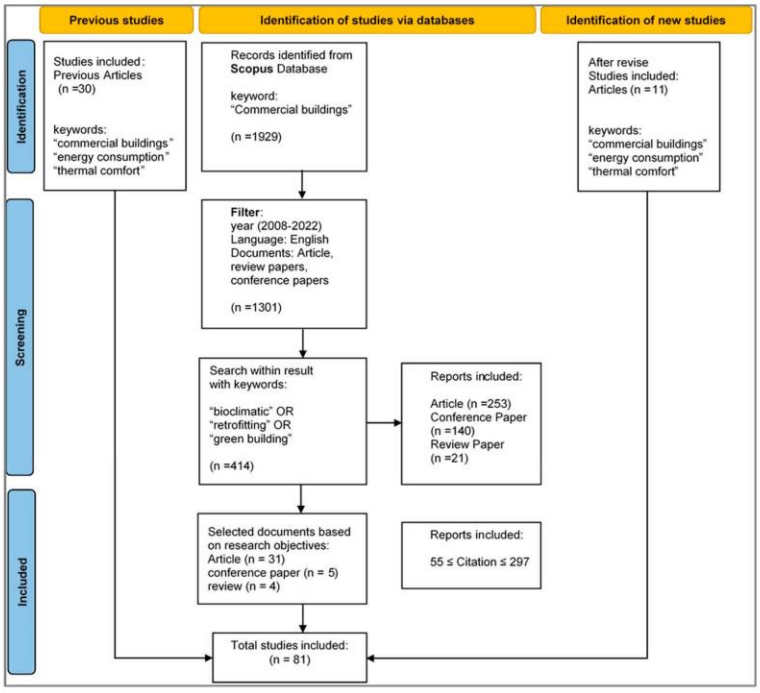


Figure 1. PRISMA [34] flow diagram for the systematic review process, which included searches of the Scopus database and previous studies.

The time frame for the search was 2008 through 2022. Furthermore, only papers in English were considered. There were 1301 publications in total.

The keywords "Retrofitting" OR "Bioclimatic" OR "Green Buildings" were used to further narrow these publications. These terms were chosen for their relevance to the subject of research. A total of 414 linked publications were obtained at the end of the refinements consisting of 253 journal articles, 140 conference papers, and 21 review papers. The catalog information was downloaded in CSV format (comma_separated values).

2.4. Scientometric Method

The downloaded bibliographic information was entered into the VOSviewer software (Figure 2). Network critique and visualization of those locations were performed. For network construction, network analysis including source investigation, citation investigation, keyword event investigation, and cluster investigation were used. Data congregation is an info-extracting process that uses similarity measurements to identify natural groupings in a multidimensional dataset [35]. Because it specifies and analyzes the connections among concepts and recognizes patterns, an essential part of the scientometric investigation is cluster analysis. Data related to research subject clusters are provided by VOSviewer. Objects of the same color belong to the same collection and are characterized by a mark in the keyword network investigation scheme. The relationship of the keyword to the distance between the circles is shown. Ultimately, tables and maps were prepared to show the networks and statistically describe their criteria.

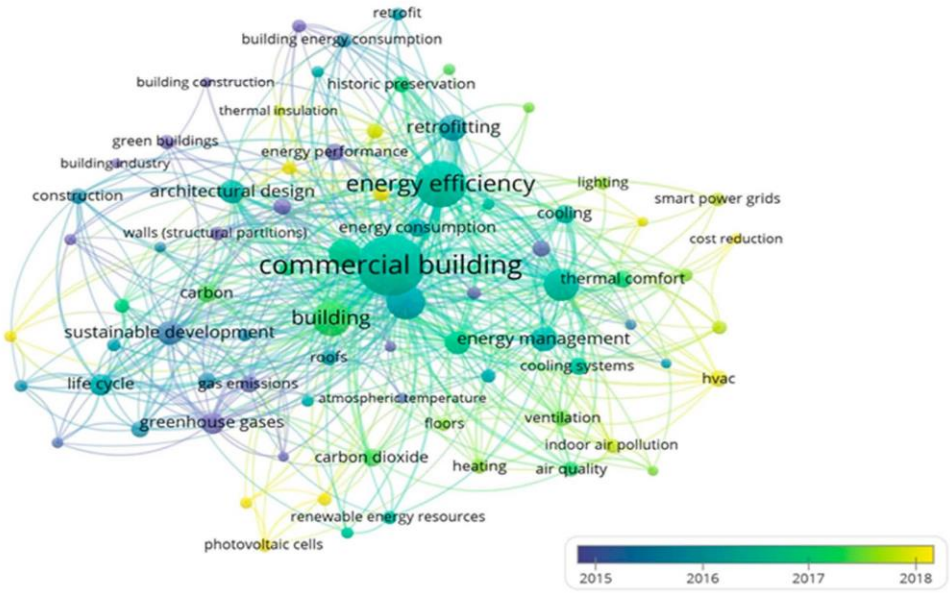


Figure 2. Overlay visualization map of co-occurring keywords (2008–2022).

3. Results and Discussion

3.1. Quantitative Analysis

A transition was made to a more data-driven process in the first quantitative analysis section. In this part, studies conducted in the field of commercial buildings over a 15-year period were statistically analyzed to find patterns and trends. During the period 2008 to 2022, a significant global shift towards sustainability took place. Scholars' focus was directed towards energy efficiency and bioclimatic retrofitting, resulting in significant advancements in technology. Policy adjustments were implemented in order to promote and support sustainability. Therefore, this 15-year timeframe is of great importance in understanding the development and influence of these technologies and policies [16].

This quantitative analysis could be utilized to ensure that the results of the qualitative analysis have quantitative significance and validity. The research was taken to a higher scientific and logical level by this quantification method. VOSviewer software was used in the second half of the study to display a scientific map of the investigations, and the results and discussion are presented here.

3.1.1. Publications per Year

Figure 3 depicts the annual number of commercial building-related publications from 2008 to 2022. The review was limited to articles with the keywords "bioclimatic", "retrofitting", and "green building".

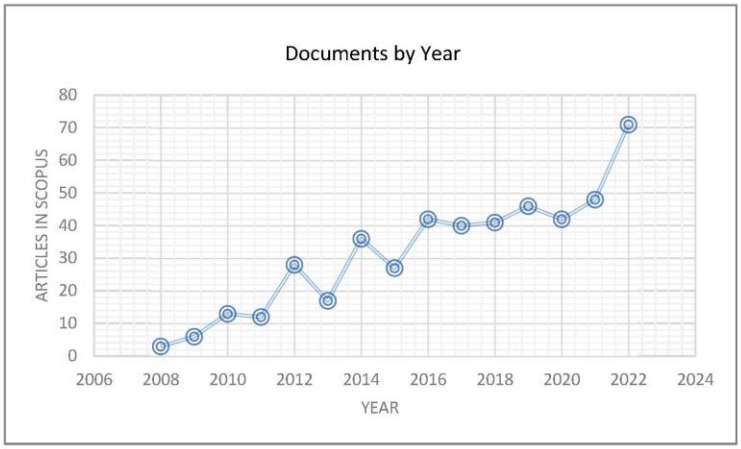


Figure 3. Number of publications per year.

The graph shows that the number of publications has been continuously increasing over the last 15 years, demonstrating a growing interest in commercial building research. However, the number of publications fell in 2020, owing to the significant impact of the coronavirus pandemic on research activity and academic publications. However, as seen in the graph, the slope begins to grow again in 2021, with the number of articles reaching a 15-year high in 2022. This growth in commercial building papers corresponds to the greater amount of research devoted to addressing these challenges in the twenty-first century, with the building industry being a major user of energy globally [2].

3.1.2. Publications per Document Source

The principal document sources for publishing academic contributions are journals. These journals give readers wells of material on a certain research topic, and they also supply authors with advice on where to publish their work [31].

Based on the data presented in the chart in Figure 4, it is apparent that the journal 'Energy and Buildings' has the highest number of articles, totaling 38, while 'Applied Energy' follows closely with 23 articles. The journals "Building and Environment" and "Energy" have made notable contributions to the field, with 14 and 12 articles, respectively. Additional noteworthy publishers in the field include 'Energies', 'IOP Conference Series Earth and Environmental Science', 'Energy Efficiency', 'Sustainability Switzerland', and The Journal of Architectural Engineering, each of which boasts a publication portfolio consisting of approximately 9 to 7 articles.

The chart in Figure 4 presents a visually accessible depiction of the allocation of articles across various publishers, effectively emphasizing the primary contributors within the respective domain. This information holds potential utility for researchers aiming to comprehend the scope of published literature within this field.

VOSviewer was used to obtain more data. The unit of analysis was "sources," and the type of analysis was "citation".

Table 1 shows 16 document sources after setting the minimum extraction to four documents. With 38 documents and 1264 citations, Energy and Buildings topped the list.

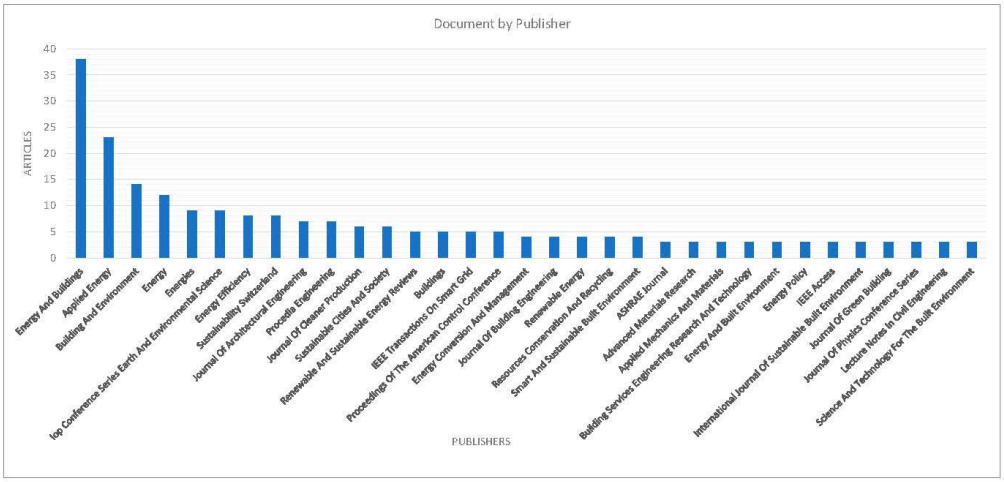


Figure 4. Research publishing trend 2008–2022.

Table 1. Summary of the number of publications per document source.

Document Source Title	No of Publications	Total Citations	Avg. Publication Year
Energy and Buildings	38	1264	2016
Applied Energy	23	949	2018
Building and Environment	14	485	2016
Energy	12	486	2018
Energies	9	77	2020
Energy Efficiency	8	223	2016
Procedia Engineering	7	84	2016
Architectural Engineering	6	53	2015
Cleaner Production	6	166	2019
Proceeding of American Control Conference	5	126	2016
Renewable and Sustainable Energy Reviews	5	374	2014
Building Engineering	4	33	2021
Renewable Energy	4	32	2019
IEEE Transactions on smart Grid	4	130	2017
Smart and Sustainable Built Environment	4	37	2018
Sustainable Cities and Society	4	128	2018

Energy and Buildings is a peer-reviewed international publication that publishes studies on how energy is used in buildings. This journal publishes cutting-edge research and tried-and-true methods for lowering building energy utilization and improving internal air quality. With an H-index of 184 and an impact factor of 5.879, the conclusion may not be surprising. The most significant publications from the results collected are Energy and Buildings and Applied Energy.

With an H-index of 212 and an impact factor of 9.746, Applied Energy acts as an association for information on invention, study, expansion, and corroboration in the fields of energy transformation and protection, energy efficiency, analysis, and optimization, energy processes, pollution reduction, and sustainable energy systems.

As a result, these two journals should be regarded the initial point of contact for everyone interested in bioclimatic architectural research.

3.1.3. Most Cited Publications

Scholars must identify the most referenced papers and their area of emphasis since they always identify with publications that have made a substantial contribution to the research community. To determine the influence of a piece of work, the total number of citations can be employed [21]. Setting the minimum number of citations at 55 produced a list of the 38 most-cited documents of the 414 identified by the search. Table 2 lists these documents.

Table 2. Quantitative summary of most-cited publications.

Article	Document Source Title	Citations
[36] Kneifel, J. (2010)	Energy and Buildings	297
[37] Balaji, B. et al. (2013)	Proceedings of the 11th ACM Conference on Embedded Networked Sensor	224
[38] Robinson, C. et al. (2017)	Applied Energy	185
[39] Lebinson, R., & Akbari, H. (2010)	Energy Efficiency	159
[40] Haq, M.A.U. et al. (2014)	Renewable and Sustainable Energy Reviews	158
[41] Onat, N.C. et al. (2014)	Building and Environment	117
[42] Hong, T. et al. (2015)	Applied Energy	112
[43] Lazos, D. et al. (2014)	Renewable and Sustainable Energy Reviews	112
[44] Zuo, J. et al. (2012)	Habitat International	98
[45] Liao, C., & Barooah, P. (2010)	Proceeding of American Control Conference	95
[46] Ma, M., & Cai, W. (2019)	Science of the Total Environment	94
[47] Ma, M. et al. (2019)	Cleaner Production	93
[48] Ma, M. et al. (2018)	Science of the Total Environment	92
[49] Dong, Y.H., & Ng, S.T. (2014)	Life Cycle Assessment	85
[10] Huang, Y. et al. (2013)	Applied Energy	84
[50] Hoffmann, S. et al. (2014)	Solar Energy Materials and Solar Cells	82
[51] Lee, S.H. (2015)46	Energy	79
[52] Ghai, S.K. et al. (2012)	IEEE International Conference on Pervasive Computing and Communications	77
[53] Yin, R. et al. (2012)	Energy and Buildings	77
[54] Fregosi, D. et al. (2015)	IEEE 1st International Conference on Direct Current Micro grids	76
[55] Ma, J. et al. (2014)	Process Control	75
[56] Maasoumy, M. et al. (2014)	Proceeding of American Control Conference	73
[57] Kua, H.W., & Wong, C.L. (2012)	Energy and Buildings	72
[58] Huang, Y., & Niu, J.L. (2015)	Energy	71
[59] Meegahapola, L.G. et al. (2014)	IEEE Transactions on Sustainable Energy	67

Table 2. *Cont.*

Article	Document Source Title	Citations
[60] Jo, J.H. et al. (2010)	Building and Environment	67
[61] Gulbinas, R., & Taylor, J. E. (2014)	Energy and Buildings	65
[62] Liu, F., et al. (2017)	Safety Science	62
[63] Hwang, B. G., et al. (2017)	Sustainable Cities and Society	60
[64] Hou, J., et al. (2016)	Energy Policy	58
[65] Qi, R., et al. (2014)	Energy Conversion and Management	58
[66] Jiang, M. P., Tovey, K. (2010)	Building and Environment	57
[67] Jiang, P., & Keith Tovey, N. (2009)	Energy Policy	57
[68] Luo, X. et al. (2017)	Applied Energy	56
[69] Papadopoulos, S., et al. (2019)	Building and Environment	55
[70] Kamilaris, A., et al. (2014)	Renewable and Sustainable Energy Reviews	55
[71] Wang, N., et al. (2010)	Building and Environment	55

The paper "Life-cycle carbon and cost study of energy efficiency measures in new commercial buildings" [36] has the most citations. The National Institute of Standards and Technology's Office of Applied Economics in Gaithersburg and the United States Fire Research Laboratory supported the article [36].

This paper uses an integrated design method to evaluate life-cycle energy savings, carbon emission reductions, and the cost-effectiveness of energy efficiency measures in new commercial buildings, as well as the cost of energy-based carbon emissions. For 12 archetypal structures in 16 cities, 576 energy simulations were performed with three building plans for each building–location combination. The cost-effective life cycle and carbon emissions of each design are calculated using simulated energy consumption and a building cost database. The findings show that traditional energy efficiency measures can reduce energy consumption in new commercial buildings by an average of 20 to 30% and in certain types of buildings and places by more than 40%. Because greater efficiency makes it possible to install smaller, less-expensive air conditioners, these savings are usually achieved with negative life cycle costs. This upgrade saves money and energy while reducing the building's carbon footprint by an average of 16%. Because energy is more expensive, the cost of carbon emissions from energy consumption increases the return on investment in energy efficiency and makes some economically viable initiatives possible [36]. This study offers significant insights regarding the potential for energy conservation through the implementation of efficient building design strategies. Nevertheless, it is important to acknowledge that the savings in energy costs do not exhibit a perfect correlation with reductions in energy usage. This discrepancy arises from variations in the marginal costs of electricity and natural gas among different states, the region-specific price projections provided by the Energy Information Administration (EIA), and the loads associated with the building processes. This observation underscores the intricate nature of the matter and implies that a more sophisticated methodology may be required to comprehensively comprehend the economic ramifications of energy-efficient design.

The study "Sentinel: Occupancy Based HVAC Actuation using Existing WiFi Infrastructure within Commercial Buildings" [37], sought to design and implement a system that detects occupancy patterns using commercial buildings' WiFi infrastructure. The Sentinel device accurately detects occupants to optimize the operation of HVAC systems. The project sought to improve commercial building energy efficiency by restricting HVAC system operation to occupied spaces. The Sentinel technology reduced HVAC system electrical energy consumption by 17.8% compared to static scheduling. Sentinel was used to regulate 23% of the building testbed's HVAC zones. The research also showed that the system accurately identified MAC addresses linked with changing occupancy status in an individual's personal space in most cases. This study shows how occupancy-based HVAC actuation can save energy. However, the system's functionality depends on consistent WiFi connectivity, which may be affected by network coverage, outages, or device power

depletion. The analysis also shows that the existing system only covers office personal spaces. This means that covering shared places could improve the system's effectiveness.

The authors of [38] estimate commercial building energy usage using machine learning. XGBoost, Bagging, MLP Regressor, Random Forest Regressor, and other machine learning models were tested on a dataset of over 5000 commercial buildings. The XGBoost model performed best in terms of mean absolute error, median absolute error, and r2 values, providing the maximum energy consumption forecasting accuracy. Energy usage was also predicted by square footage, cooling degree days, heating degree days, and building type. This study sheds light on whether machine learning can estimate commercial building energy use. However, the study relies on a dataset of commercial buildings, thus its conclusions may not apply to other building kinds or locales. Although XGBoost performed best, other models performed well too. This suggests that the use of various machine learning methods may benefit this approach.

In "Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants" [39], Levinson and Akbari explain how cool roofs reduce solar absorption and increase heat emission. This reduces roof-to-building heat transfer, lowering space-cooling energy consumption in conditioned structures. This study examines commercial cool roof benefits. Cool roofs can reduce cooling energy consumption, increase heating energy consumption, save energy, and reduce emissions, according to building energy models. At the same time, the authors note that cool roofs may increase heating energy demand in colder places. The paper thoroughly evaluates cool roofs' pros and disadvantages.

Energy efficiency in electrical engineering is highlighted in the article "A review on lighting control technologies in commercial buildings, their performance and affecting factors" [40]. The need to conserve world resources and reduce conventional energy's environmental impact drives this research. Lighting accounts for a large component of electricity use, especially in commercial buildings, thus reducing lighting consumption can have significant benefits. Researchers are also working to improve lighting efficiency to maintain ideal illumination settings while reducing energy use. This study reviews commercial building lighting control technology. The article discusses manual, occupancy-based, daylight-linked, and time-scheduled lighting controls. These control systems also conserve energy, according to the research. In evaluating these control systems, occupant behavior, occupancy patterns, daylight availability, and control parameter tuning are important.

"Scope-based carbon footprint analysis of U.S. residential and commercial buildings: An input-output hybrid life cycle assessment approach" [41] investigates US residential and commercial building carbon footprints. Since the building industry accounts for a large amount of US greenhouse gas (GHG) emissions, this study seeks to understand and reduce these emissions. Scope-based carbon footprint analysis uses an input-output hybrid life cycle assessment approach. Scope 2 emissions—indirect emissions from energy generation—make up the majority of residential and commercial buildings' carbon footprints, according to the study. Electricity, on-site natural gas, commuting, and the construction supply chain all contribute to the carbon footprint. A total of 91% of GHG emissions come from building use. This study analyzes the carbon footprint of US buildings, focusing on power usage and building operations. However, the study's dependence on past data may limit its capacity to correctly reflect current conditions. Energy efficiency and renewable energy technology have advanced significantly since the time of the study. In addition, the study's focus on national statistics may overlook regional differences in variables like power fuel source composition.

"Commercial Building Energy Saver: An energy retrofit analysis toolkit" [42] discusses the construction and use of the CBES, a toolkit for examining commercial building energy retrofits. The need to improve energy efficiency in business buildings—major energy consumers—drives the research. The CBES toolset provides energy benchmarking, load shape analysis, and preliminary retrofit analysis to discover energy conservation options.

This study uses the CBES toolbox on a medium-sized San Francisco office building. The toolkit benchmarking results showed that the building consumed 88% more energy than comparable buildings. This indicates energy conservation potential. Load shape analysis showed energy waste during non-operation. The initial retrofit analysis suggested installing an HVAC air economizer, plug load controllers, and lighting system upgrades. This study shows how the CBES toolset can identify commercial building energy conservation opportunities. However, this study focuses on a single case study; therefore, its applicability to other building types or geographical situations is unclear. In addition, the research does not evaluate the toolkit's accuracy or reliability.

"Optimisation of energy management in commercial buildings with weather forecasting inputs: A review" [43] examines commercial building energy management optimization strategies, focusing on weather forecasting inputs. Energy efficiency and cost reduction in commercial buildings drove this research. This study addresses statistical, machine learning, physical, and numerical methods for energy consumption prediction and management in buildings. The analysis shows that forecasting methods have pros and cons. ARMA and ARIMA models are simple, computationally efficient, and accurate. However, they cannot capture non-linear trends and require previous data. Artificial neural networks (NNs) model non-linear patterns accurately but are computationally costly. White- and grey-box engineering approaches are complex and slow but accurate and independent of historical data.

3.1.4. Keyword Analysis and Areas of Research Focus

For scientometric analysis, keywords must be determined and a map visualization must be provided. Keywords describe the most important aspects of a study and reveal the domain's focal regions [25]. To construct the co-occurrence map based on the bibliometric data, a minimal number of co-occurrence keywords is needed. This enables proper study theme clustering [21].

A total of 133 of the 3581 keywords were discovered using "Author Keywords" and "Index Keywords" as well as at least seven simultaneous repetitions of keywords, using VOSviewer. Table 3 summarizes the top 30 keywords in detail.

Table 3. Top 30 keywords.

Keywords	Avg. Citations	Occurrences	Total Link Strength
Commercial building	20	251	2120
Energy efficiency	23	146	1436
Energy conservation	29	106	1181
Air conditioning	23	70	749
Retrofitting	21	46	502
Sustainable development	22	39	446
Energy management	20	39	369
Architectural design	15	38	374
Intelligent buildings	18	36	400
Greenhouse gases	28	31	390
Life cycle	28	30	338
Cooling	29	23	296
Thermal comfort	16	22	223
Carbon dioxide	19	22	240
Energy performance	11	20	193
Ventilation	22	19	237
HVAC	32	18	179
Sustainability	18	18	142
Climate change	22	18	200
Climate control	33	18	169
Solar buildings	18	16	196

Table 3. *Cont.*

Keywords	Avg. Citations	Occurrences	Total Link Strength
heating	31	15	188
Air quality	21	15	172
roofs	33	15	190
Environment management	5	14	153
Indoor air pollution	11	14	147
lighting	32	13	114
Solar energy	28	13	163
Walls	20	13	143
Floors	23	11	114

Table 3 is in a standard output format from VOSviewer, which provides quantitative information about each keyword. Below is an explanation of each column:

- Keywords: These are the words that have been frequently used in the articles, abstracts, titles, or other textual data under analysis. These words usually represent key themes or topics in the set of documents.
- Avg Citations: This column shows the average number of times the papers associated with each keyword have been cited. This gives an idea of the impact or influence of the work associated with that keyword. A higher average citation count might indicate a keyword associated with high-impact or influential work.
- Occurrences: This is the total number of times each keyword appears in the dataset. A higher occurrence typically indicates a more common or important topic in the research field under investigation. However, a high occurrence does not always mean high importance, as it could also result from a large number of less significant papers mentioning the keyword.
- Total Link Strength: This measure provides an overview of the interconnectedness of each keyword with all other keywords. It is calculated by adding up all the weights of the links connected to a particular keyword. The strength of a link between two keywords usually represents the number of documents in which these two keywords co-occur. A higher total link strength indicates that the keyword is strongly associated with many other keywords, suggesting that it might be a central or foundational topic in the research field.

This table provides valuable information about the most commonly occurring and influential keywords related to "Commercial Buildings".

1. Frequency of occurrence: "Energy efficiency" is the most commonly occurring keyword, followed by "Energy conservation" and "Air conditioning". This shows that these are the most often discussed subjects in the commercial building context.
2. Average citations: The keywords with the highest average citations are "Climate control", "HVAC", and "Cooling". This suggests that articles on these topics are mentioned more frequently, implying that they are significant topics in the area. They could be linked to major works or significant advances.
3. Total link strength: "Energy efficiency", "Energy conservation", and "Air conditioning" have the highest total link strength, indicating that they have strong links with many other terms.

Although these metrics provide some insight into the importance and influence of certain topics, it is also worthwhile to examine keywords that are less frequently mentioned. For example, "Environmental management" and "Indoor air pollution" have low occurrences and total link strength, but they may reflect growing or specialist themes. Significantly, "Environmental management" has a notably low average citation count, indicating that it may be an understudied issue worthy of more inquiry.

Investigating the correlations between distinct keywords offered further insights. For example, "energy efficiency" and "retrofitting" both have high occurrences and overall link strength, indicating that they are not just important issues in their own right but are also tightly related to other topics.

Retrofitting and Energy Efficiency: Given the relatively high frequency and total link strength of both "Retrofitting" and "Energy efficiency" it appears that these two topics have a significant connection. This shows that retrofitting commercial buildings for energy efficiency is a priority. It may be worthwhile to look into how these areas interact, such as researching the most effective retrofitting strategies for increasing energy efficiency or comprehending the hurdles and enablers of energy-efficient retrofitting in commercial buildings.

Intelligent Buildings and Energy Management: Both "Intelligent buildings" and "Energy management" have a moderate frequency but a comparatively high link strength. This could imply an increase in interest in the intersection of these areas. For example, research might look into how intelligent building technologies can be utilized to improve energy management, as well as the function of AI and machine learning in energy management inside intelligent buildings.

Greenhouse Gases, Carbon Dioxide, and Climate Change: Because they all have an impact on the environment, the intersection of "Greenhouse gases" "Carbon dioxide" and "Climate change" could provide fascinating results. For example, studies might look into how commercial buildings contribute to greenhouse gas and CO_2 emissions, as well as the implications for climate change.

Architectural Design and Sustainable Development: These two terms have a moderate number of occurrences and a pretty high link strength, showing that they are related. Research could look into how sustainable development ideas can be incorporated into the architectural design of commercial buildings. This could include investigating how to use sustainable materials, create energy-efficient structures, or incorporate biophilic design aspects.

3.1.5. Keyword Maps of VOSviewer

Keyword maps are a popular type of visualization offered by VOSviewer that illustrate which terms are frequently related to one another in the literature.

Each circle (or node) in the VOSviewer map in Figure 5 indicates a keyword. The size of the circle usually corresponds to the keyword's weight. In a keyword map, for example, a larger circle could signify a keyword that is used more frequently. The lines (or edges) connecting the circles represent the entities' relationships or links.

In VOSviewer maps, the color of the circles represents clusters. A cluster is a group of entities that are tightly connected. Keywords that frequently appear together in the same papers would create a cluster in a keyword map. The colors are assigned by the software and serve no use other than to distinguish distinct clusters.

Clusters in VOSviewer can help researchers in a variety of ways:

- Identifying research trends: researchers can identify current trends and popular topics in their field by monitoring which terms are closely connected (i.e., belong to the same cluster).
- Identifying gaps in the literature: isolated or less connected clusters may suggest unexplored themes or research gaps.
- Understanding the structure of a research field: clusters can indicate how different subtopics within a research field are related, which can aid in the organization of literature reviews or the development of new research lines.

In Figure 5, the 133 keywords identified in the analysis are organized into five groups. Each cluster is made up of related keywords. The clusters are:

Cluster 1—Thermal Comfort in Energy Management: this is displayed in red and includes 23 keywords such as "air quality", "temperature control", HVAC, "lighting", "cooling", "heating", "ventilation", and so on.

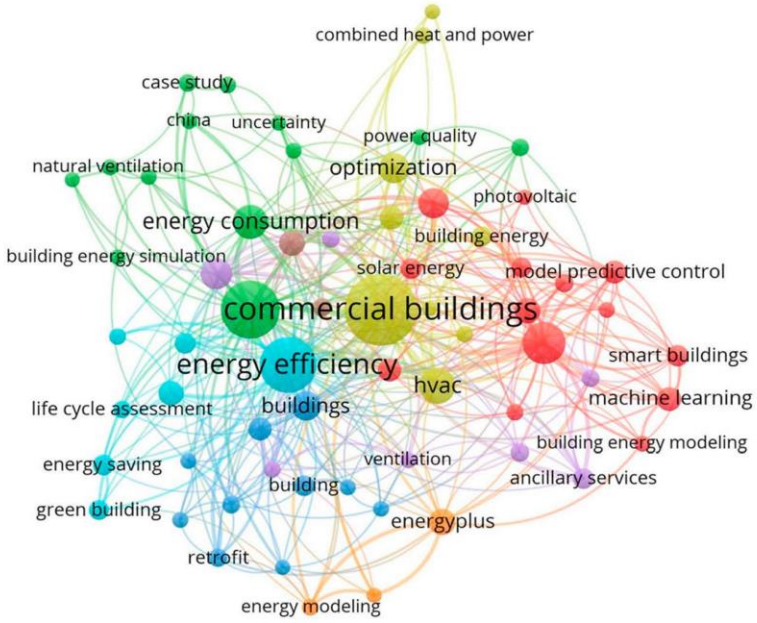


Figure 5. Network visualization map of co-occurring keywords.

Cluster 2—Architectural design sustainability: this is displayed in green and comprises 20 keywords. "Green structures", "building materials", "life cycles", and so forth are examples.

Cluster 3—Commercial Building Retrofitting: the 19 keywords in this cluster are displayed in blue in Figure 3. "Energy efficiency", "energy performance", "solar buildings", "walls", and other terms are among them.

Cluster 4—Carbon dioxide: this is displayed in yellow and includes 11 keywords including "renewable energy resources", "solar energy", "greenhouse gases", and so on.

Cluster 5—Commercial Building Energy Savings: this is shown in purple and is made up of four terms linked to "atmospheric temperature", "building energy simulation", "roofs", and "building energy".

In Figure 5, the map's connection lines also depict the relationship between two keywords. As portrayed, retrofitting is linked to energy efficiency and performance [10,64], carbon dioxide is linked to renewable energy resources and solar energy [36,41], and thermal comfort is linked to HVAC, air quality, climate control, and lighting [36,41], while thermal comfort is linked to HVAC, air quality, and climate control [39,69].

3.2. Qualitative Analysis

The qualitative analysis sought to identify the most-cited documents' primary findings, conclusions, and consequences. The results of the investigations were consistent with prior studies [23]. This approach allowed for a deeper understanding of the research topics and their significance in the field.

Summary of Most-Cited Articles

The most frequently mentioned documents were gathered and evaluated hermeneutically. Table 4 shows the results of the qualitative review of the most-cited documents.

One of the growing interests in commercial buildings sustainability research is building carbon emission analysis [41]. Evidence of these studies can be observed in the study by

Kneifel [36], which uses an integrated design method to estimate life-cycle energy savings, carbon emissions reduction, and the cost-effectiveness of energy efficiency measures in new commercial buildings, as well as to assess the consequences of the cost of energy-based carbon emissions. This study carries out a total of 576 energy simulations for 12 archetypal structures in 16 cities, with three building designs for each building–location combination [36].

The findings reveal that traditional energy efficiency measures can reduce energy consumption in new commercial buildings by 20–30% on average, and by more than 40% in specific building types and locations. These upgrades save money and energy while lowering a building's carbon footprint by an average of 16%. Because greater efficiency allows the installation of smaller, less expensive HVAC equipment, these savings can sometimes be accomplished at a negative life-cycle cost [37].

The authors of [37] point out that 39.6% of energy consumption in commercial buildings is related to HVAC systems.

Indeed, adhering to these guidelines in the construction of new buildings has been shown to effectively mitigate energy consumption. However, it is imperative to acknowledge the significant challenge associated with the task of diminishing energy consumption in existing buildings. The significance of this matter is of considerable magnitude, as evidenced by the dedicated efforts of the REHVA (The Federation of European Heating, Ventilation, and Air Conditioning) task force [72] comprising representatives from nine European nations. Their primary focus lies in the refurbishment of existing structures, with particular emphasis placed on the modernization of heating, ventilation, and air conditioning (HVAC) systems [73].

The role of HVAC systems in the deep renovation of existing buildings is crucial as it can help achieve significant energy savings when operated properly. The building envelope is also considered an essential aspect in initial efforts to reduce energy demand.

But renovation should not be limited to the building envelope; energy savings can be maximized, and payback time reduced by also focusing on HVAC systems and energy education of building occupants. Adapting HVAC systems to varying building energy demands can improve indoor environmental quality (IEQ) and occupant satisfaction [73].

Prior studies have advocated employing wireless occupancy sensors or even cameras for occupancy-based actuation to reduce HVAC energy use, with energy savings of up to 42%. However, most of these solutions necessitate the design, deployment, testing, and maintenance of these sensors and their accompanying networks within existing buildings, which is prohibitively expensive. Conversely, the authors of [37] present Sentinel, a system that uses existing WiFi infrastructure in commercial buildings, as well as smartphones with WiFi connectivity carried by building occupants, to offer fine-grained occupancy-based HVAC actuation. Similarly, the authors of [74] present a comprehensive review of research work on the existing technologies and applications of Internet of Things (IoT) technologies in residential and commercial buildings.

As shown in Table 4, the paper with the third highest number of citations is [38], published in the Applied Energy Journal. By teaching machine learning models using national data from the study of energy consumption of commercial buildings, this research proposes a new technique for estimating the energy consumption of commercial buildings from several building characteristics (CBECS). Their findings show that gradient amplification regression models are the most accurate models in predicting the energy consumption of a commercial building, with predictions that are often in the coefficient of two real values (with an r2 score of 0.82).

Urban and rural temperatures have diverged in recent decades. The urban heat island (UHI) effect—caused by urban design, human heat, air pollution, sun intensity, wind speed, and anticyclone conditions—is well documented. UHI increases greenhouse gas emissions and air conditioning energy demand. Human comfort and climate change mitigation requires UHI solutions. One of the best passive cooling solutions is increasing the building's exterior albedo, especially in relation to its roofs [80].

The majority of roofing materials absorb solar radiation and reflect only a small part of it. In warmer areas, for example, solar heat gain through the building's facade accounts for a significant part of the total heat gain. The energy entering a structure through its walls, floors, and ceilings is equally significant. Although a traditional dark-colored roof's total heat gain can be as high as 366 kJm^2, the heat loss through the same roof is only around 4.2 kJm^2; heat gain is the major process for these roofs throughout the day. On hot summer days, dark roofs can achieve temperatures of over 60 degrees in many regions, allowing significant heat transfer into the building through roof insulation. Any alteration to a building's roof that reduces solar heat gain will save the building owner money on energy costs and reduce the property's overall environmental impact [60].

Table 4. Qualitative Summary of Most-Cited Publications.

Authors	Year of Publication	Aim	Similar Articles
[36] Kneifel	2010	Estimate life-cycle energy savings, carbon emission reduction, and cost-effectiveness of energy efficiency measures	[57,71]
[37] Balaji et al.	2013	Propose strategies to reduce energy consumption in HVAC systems	[56,58,69]
[38] Robinson et al.	2017	Introduce a new technique for estimating the energy consumption of commercial buildings with machine learning models	[69]
[39] Levinson et al.	2010	Weathered cool white roof	[60,75,76]
[40] Haq et al.	2014	Automatic lighting control system	[62,77,78]
[41] Onat et al.	2014	Analyze building-related carbon emissions	[47,48]
[42] Hong et al.	2015	Introduce a toolkit of Commercial Building Energy Saver (CBES), that includes a web app for integrating CBES with other energy software tools	[51,79]
[43] Lazos et al.	2014	Analyze the dependence of various building components on weather conditions	[10]
[44] Zuo et al.	2012	Identify factors contributing to or impeding the achievement of carbon-neutral commercial building development	[66]
[45] Liao, & Barooah	2010	Apply an agent-based model to simulate the behavior of all the occupants of a building, for solving the problem of real-time estimation of occupancy	[71]

Green roofs and facades have high installation and operation costs, while solar reflecting materials like "cool roofs" can reject solar radiation over the visible and invisible solar spectrum. Solar reflectance (300–2500 nm) and thermal emissivity (4000–40,000 nm) are high. White cool roofs were introduced [80].

Cool roofs are designed to minimize the absorption of solar energy and maximize the emission of thermal energy, resulting in reduced heat transfer from the roof to the building. This, in turn, decreases the demand for space-cooling energy in air-conditioned buildings [39].

The cool roof system yields indirect environmental benefits, primarily through reductions in environmental damage and peak-time electricity demand, resulting in electricity savings [60].

In cold climates, the implementation of cool roofs may potentially result in an increased demand for heating energy. In the context of commercial buildings, it is commonly observed that the reduction in the annual cooling load tends to surpass the corresponding increase in the annual heating load [34].

However, in a study conducted by the authors of [76], the DOE-2.1E software was employed to model and analyze the energy usage of various office and retail buildings in four cold-climate cities in North America, namely Anchorage, Milwaukee, Montreal, and Toronto. A function was defined to calculate the daily U-value and absorptivity of the roof in order to simulate the impact of snow on it. The findings indicated that the

implementation of cool roofs in the simulated buildings led to significant reductions in annual energy expenditures across all cold climates [76].

The initial white and colored cool roof studies employed polymeric membranes and paints since these do not require long manufacturing cycles. Without maintenance, cool roofs last only a few years. Cool roofing in European towns using ceramic and clay roof tiles requires solar-reflective tile materials. This improves solar effectiveness and durability because tiled sloped roofs should not be cleaned. New glazed and engobed solar reflecting solutions are spreading this technology to ceramic and clay roof tiles. The use of ceramic glaze makes such objects weatherproof and durable. Traditional tile methods can improve solar reflection and insulation without changing the roof. Studies discuss the most often used pigments for external tile systems in ceramic glazes with gloss, matt, and Zirconium Silicate finishes and typical ceramics heating treatment, making first-generation glazed cool-colored tiles possible [80].

It is noteworthy to consider that the solar reflectance of cool roofs can be influenced by weathering, soiling, and biological growth. The solar spectral reflectances of 12 roofing membranes were measured in a study [69]. The measurements were taken before exposure and at various intervals of natural aging, specifically after 3, 6, 12, 18, and 24 months. The study was conducted in Rome and Milan, Italy. The findings indicated that the process of aging resulted in a decrease in the potential cooling load savings attainable from a new white membrane. Specifically, the reduction ranged from 14% to 23% in Rome and from 20% to 34% in Milan. Furthermore, in the case of Milan, there is evidence to suggest that an older, white roof with high insulation properties, possessing a solar reflectance value of 0.56, could potentially experience a surface temperature increase of 16 °C compared to a newer roof with a higher solar reflectance value of 0.80. Hence, with respect to the implementation of cool roofs in other urban areas, this aspect warrants due consideration [75].

Lighting is another important factor in commercial building energy use [40]. According to the authors of [80], artificial lighting is a large power consumer in commercial buildings, accounting for around 17% of overall electrical energy consumption. Therefore, intelligent control strategies are widely implemented to reduce lighting energy consumption [77]. As a result, adopting intelligent lighting control systems, such as the combination of sensor technologies (occupancy and light sensors), advanced designs (wireless- and network-based architectures), and intelligent control approaches, has huge potential to minimize energy usage (artificial intelligence and optimization). Furthermore, an intelligent control system can improve visual comfort for occupants while lowering electricity usage and greenhouse gas emissions. Lighting control systems can be divided into three types: controller, optimization-based control, and hybrid control [78].

The decarbonization of buildings is widely recognized as a significant challenge in the pursuit of achieving the United Nations' sustainable development goals by 2050. In conjunction with the objective of minimizing electricity usage, an equally significant concern in mitigating greenhouse gas emissions within the building sector pertains to the substitution of gas boilers. The potential of heat pumps, district heating, and hybrid solutions as alternatives has been highlighted by the REHVA task force. The aforementioned study has brought attention to the potential advantages of transitioning away from natural gas in buildings, including the reduction of greenhouse gas emissions, the enhancement of air quality, and the promotion of energy efficiency [81].

As shown in Table 4, computer simulation tools are an effective instrument for estimating building performance under various scenarios and giving a theoretical basis for retrofits that produce cost-effective energy savings. In their article, the authors of [42] introduce a toolkit of Commercial Building Energy Saver (CBES) that includes a web app for integrating CBES with other energy software tools.

In addition, the authors of [10,43] claim that the thermal performance of building envelopes is the deciding element of building energy consumption, and that envelope retrofitting is an extraordinarily successful technique for reducing energy consumption in existing structures (Table 4). Because variables like temperature, humidity, and solar

radiation directly affect heating and cooling in a structure, as well as the availability of solar and wind energy, multiple ideal retrofitting techniques may exist for different climates.

4. Conclusions

The implementation of bioclimatic retrofitting in commercial buildings is a nascent field, particularly in terms of its energy implications. This study investigated the bioclimatic retrofitting approach as a crucial strategy for mitigating energy consumption and adapting to climate change.

The authors carried out an examination of scholarly articles and conference papers pertaining to the implementation of bioclimatic retrofitting in commercial buildings. These sources were obtained from the Scopus database through the utilization of a bibliometric search, which is a scientific methodological approach. Additionally, a comprehensive qualitative analysis was performed to gain a deeper understanding of the subject.

The scientometric procedure utilized quantitative dimensions, including the number of intermediate citations, occurrences, average publication year, and general connection power.

A longitudinal examination of research publication patterns spanning from 2008 to May 2022 has indicated a discernible upward trajectory in scholarly investigations pertaining to the domain of commercial buildings during this 15-year period. Nevertheless, research on the topics of bioclimatic design, retrofitting strategies, and green building practices in commercial settings exhibits a more gradual rise, displaying an almost linear trend between the years 2016 and 2020. The disregard for bioclimatic effects in commercial buildings may be attributed to factors such as the intricate nature of the process, the dense urban fabric typically surrounding these buildings, and the ready availability of cooling and comfort activation technologies. Moreover, the potential impact of bioclimatic design on commercial buildings may have been overlooked as a result of insufficient comprehension and awareness. However, scholarly investigations into the field of bioclimatic design, retrofitting, and green buildings within commercial contexts have revealed an emerging trend that extends beyond the year 2020. This observation suggests a growing recognition of the importance of incorporating sustainable and energy-efficient principles in the design and operation of commercial buildings.

"Energy and Buildings", "Applied Energy", "Building & Environment", "Energy", "Renewable & Sustainable Energy Reviews", and "Energy Efficiency" were identified as useful publications outlets for studies on bioclimatic retrofitting in commercial buildings.

These publications have seen significant increases in citations in recent years, with 20 of the 38 most-cited works appearing in these publications. The citation analysis of documents indicates that articles [31–38] were the most-cited documents in the field of the bioclimatic retrofitting of commercial buildings and had a citation index above 100.

Furthermore, the keywords with the most citations were found to be climate control, roofs, lighting, HVAC, heating, cooling, energy conservation, life cycle, greenhouse gases, and solar energy. Conversely, keywords like commercial building, energy efficiency, energy conservation, air conditioning, retrofitting, sustainable development, architectural design, intelligent buildings, and energy management appeared more frequently.

Cluster analysis showed the research emphasis areas for this domain. These consist of thermal comfort in energy management and climate control and ventilation, sustainable development for architectural designs and green buildings, retrofitting in commercial buildings and energy efficiency, carbon dioxide and energy resources and solar energy, energy-saving and atmospheric temperature, and building energy simulation. The results of the in-depth qualitative content analysis revealed certain grey areas that will be investigated more in the future.

Suggestions for future research are offered below based on the information gained in this study:

Utilizing Bioclimatic Strategies for Optimal Energy Efficiency and Environmental Sustainability:

In order to initiate a trajectory toward sustainable retrofitting, it is imperative to effectively utilize bioclimatic strategies. These novel methodologies utilize the inherent characteristics of the location and its natural components to optimize energy usage and improve the comfort of occupants. Through the examination of the complex relationship between site attributes, microclimatic conditions, and architectural design, scholars will have the potential to discover innovative approaches to reducing energy usage while optimizing the utilization of sustainable resources.

Architectural Design Sustainability: One prospective field of study pertains to bio-inspired or biomimetic design principles, which involve the examination and emulation of natural phenomena, with the aim of enhancing the sustainability of commercial buildings. An intriguing field of study involves the utilization of 3D printing and digital fabrication methodologies for the production of environmentally sustainable components in the construction industry.

The incorporation of passive design principles:

The other fundamental principle in retrofitting commercial buildings involves the incorporation of passive design principles. The focal point of this approach lies in the optimization of the building envelope, thermal insulation, and natural ventilation in order to minimize the dependence on mechanical systems. The investigation of novel materials, including advanced phase-change materials, presents a promising opportunity for researchers to expand the limits of energy-efficient architecture. Through the integration of these novel materials, structures have the capacity to efficiently modulate variations in temperature and substantially reduce energy consumption.

Energy Savings in Commercial Buildings:

Research could focus on the role of smart meters and energy management systems in optimizing energy consumption. Another area of research might be the deployment of energy-saving techniques such as daylighting and natural ventilation. Furthermore, research into passive design solutions can aid in energy savings while maintaining comfort.

The Adoption of Technological Innovations:

The incorporation of advanced technologies is of the utmost importance in our pursuit of sustainable retrofitting. Recent technological advances in the field of sensor networks, building automation systems, and data analytics have provided architects and engineers with the ability to effectively monitor and optimize energy consumption in real time. Researchers can achieve optimal energy performance and maintain a comfortable indoor environment by incorporating intelligent automation and machine learning algorithms to enable buildings to dynamically adapt to occupants' needs.

Thermal Comfort in Energy Management:

Research can concentrate on the incorporation of IoT (Internet of Things) devices in the management and optimization of HVAC systems for improved thermal comfort and energy efficiency. Furthermore, research might be conducted to investigate the application of AI and machine learning algorithms for predictive control of HVAC systems based on occupancy trends and weather forecasts.

Commercial Building Retrofitting:

Research might be devoted to incorporating smart building technologies, such as smart windows and responsive building envelopes, into retrofitting. Further research could focus on the integration of renewable energy technology such as solar panels, as well as upcoming technologies such as building-integrated photovoltaics (BIPV).

Carbon dioxide:

Research could concentrate on carbon capture and storage (CCS) technology for commercial buildings. The net-zero energy building (NZEB) concept could potentially be investigated with the goal of balancing the amount of energy consumed with the amount of renewable energy generated on-site, thereby minimizing the building's carbon footprint.

Building resilience:

The imperative of cultivating resilience has become increasingly apparent in light of escalating risks posed by natural disasters and other disruptive phenomena. Consequently,

there is a pressing demand to advance the development of building designs and materials capable of withstanding the formidable challenges presented by extreme weather events and other unforeseen shocks. Subsequent investigations may be directed towards the advancement of building systems with enhanced resilience, encompassing the exploration of modular construction techniques and the utilization of advanced materials capable of absorbing impact and exhibiting resistance to damage.

Energy storage:

The utilization of renewable energy sources, such as solar and wind power, is increasingly common in the design of commercial buildings. However, the effective storage of energy continues to pose a significant obstacle. Future research may prioritize the exploration and advancement of energy storage solutions that exhibit enhanced efficiency and cost-effectiveness, including but not limited to advanced battery technologies and thermal storage systems.

Circular economy:

The construction industry is accountable for a substantial quantity of waste and carbon emissions, necessitating a shift towards a circular economy framework that emphasizes the reuse and recycling of materials. Subsequent investigations may delve into avenues for devising architectural structures that possess the capacity to be dismantled and repurposed upon reaching the culmination of their functional lifespan. Additionally, the pursuit of novel materials and construction techniques that exhibit heightened sustainability merits further scholarly attention.

Health and safety in the post-COVID era:

The significance of indoor air quality, ventilation, and other factors that affect the well-being and safety of individuals within buildings has been underscored by the COVID-19 pandemic. Future research may be directed towards the advancement of design solutions and technologies aimed at mitigating the transmission of airborne pathogens and other contaminants, thereby fostering an indoor environment that is both safer and healthier.

Researchers, practitioners, and government agencies will benefit from the findings of this study. Graduate students and researchers can theoretically study research gaps. In practical terms, the information supplied in this study can assist stakeholders in the construction industry in making decisions.

It is important to acknowledge that this study has its limitations. These limitations extend from the use of a single database (Scopus) and only picking texts written in English. As a result, the study may not have addressed all of the existing literature on the topic under consideration. However, despite these flaws, the research's purpose of evaluating the current status of research on bioclimatic retrofitting in commercial buildings and identifying areas for further research was met. To aid comparisons, future research that avoids these restrictions can be carried out.

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3. Investigation of Passive Thermal Comfort in Traditional Bazaar of Iran with Dome Roof (case study; one hundred years old Bazaar of Arak)

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Investigation of Passive Thermal Comfort in Traditional Bazaar of Iran with Dome Roof (case study; one hundred years old Bazaar of Arak)

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Dome Roof; Climate Architecture; Thermal Comfort; Energy Conservation; DesignBuilder

Abstract
One of the essential challenges of contemporary architecture, especially in harsh climate conditions, is to determine architectural elements that can provide comfort standards for residents, and at the same time, reduce carbon emissions due to low energy resources and air pollution. The traditional architecture of Iran is one of the best examples of climate architecture, which has the most favorable solutions in terms of the survival of the environment and human comfort, and the optimal use of natural energies. Thermal comfort in hot and dry areas, especially in summer, is always considered one of the most prominent issues, and the old architects of Iran built the roofs of buildings in a dome shape to create passive thermal comfort conditions. Building a dome roof in Iran has an exceedingly long history. About six decades ago, when energy consumption optimization debates were raised, the question arose as to what effect such roofs have on the amount of heat input or output from the building. To answer this question, this research was formed with the aim of knowing the effect of roof form and height on energy consumption in a hot and dry climate based on the examination of the domes of the traditional bazaar of Arak (100 years old), using modelling and simulation of consumption energy in DesignBuilder software. The results of the analyses show that the shape and form of the roof as well as its height are effective in creating thermal comfort. Therefore, it can be stated that; the shape of the dome and its height in the hot and dry climate of Iran are designed as a climatic element based on the thermal conditions and the amount of sunlight absorption throughout the year.

INTRODUCTION

With the rise of energy consumption and environmental concerns, sustainable building design has become an essential component of architectural practice [1]. Buildings are responsible for a significant portion of global energy consumption and greenhouse gas emissions, making the optimization of energy performance in buildings an important factor in reducing the impact of the built environment [2]. According to the International Energy Agency (2021), buildings account for approximately 30% of global energy consumption and 27% of energy-related carbon dioxide emissions [3]. And this is while, in the last decade, investment and financing for clean energy have doubled, but the pace has not been enough to overcome the inertia of energy-consuming systems. Therefore, it is crucial to optimize the energy performance of buildings to reduce greenhouse gas emissions and mitigate the environmental impact of buildings [4]. Considering the current century's approach and the strong emphasis on energy conservation and passive systems for a clean environment, it is felt that a re-examination of the design foundations and governing climatic principles of traditional architecture is necessary at this point in time. Traditional Iranian architecture is one of the best examples of climatic architecture, possessing the most desirable solutions in terms of environmental conservation, human comfort, and optimal use of natural energies [5]. Therefore, by identifying the principles and rules governing this architecture and presenting a model that takes into account the scientific understanding of new materials and the climatic conditions and functionalities resulting from technological advancements, we can, in fact, apply the knowledge and the process of traditional architecture with a fresh expression in new constructions. Iran's indigenous architecture, like many ancient civilizations, has provided comfortable living conditions for its inhabitants with lower energy consumption for centuries [6]. The double-layered dome ceiling is one of the native elements of the architecture in Iran's hot and arid regions, which has been used in various structures such as mosques, mausoleums, bazaars, and even houses. In particular, some valuable examples have been preserved in certain areas due to their high-quality design and construction, which have maintained their stability to this day [7].

Investigating the structural features in traditional architecture with dome elements is a rich field due to the diversity of designs, providing the opportunity for extensive research, given the richness of Iran's architectural heritage. However, few studies can be found that have used energy simulation software to investigate the effect of the double-layered dome ceiling as a bioclimatic element in reducing energy consumption.

THE MULTIFACETED IMPLICATIONS OF DOME ROOFS IN ENERGY CONSERVATION

The dome roof, a prevalent feature in traditional architecture, has been lauded for its potential to curb energy consumption. Across diverse settings, from bustling bazaars to sacred mosques and cozy residential structures, the efficacy of dome roofs in energy management has been well-documented. In their in-depth analysis, Sedighi, focused on the old Ganj-Alikhan bazaar in Kerman, Iran. They discovered that the dome roofs' unique thermal properties contributed to stabilizing indoor temperatures and, consequently, lessened the energy used for heating and cooling. The dome's form, coupled with the utilization of indigenous materials like adobe, resulted in superior insulation, minimizing heat transfer and elevating thermal comfort [7]. Likewise, Mahdavinejad, reported that the domes adorning Isfahan's historical mosques in Iran functioned as thermal buffers, curbing energy loss during nighttime. The dome's form and employed materials impeded heat transfer between the structure's interior and exterior, conserving energy and securing thermal comfort for inhabitants [8]. In an innovative study, Mirzazadeh Akbarpoor, demonstrated how merging domed roofs with earth-to-air heat exchanger systems could bolster their energy-saving capabilities. This cutting-edge approach underscores the possibility of blending contemporary technologies with time-honored architectural practices, paving the way for sustainable, energy-efficient buildings [9]. Investigating the hot and arid climate of Varzaneh, Iran, Hatami Varzaneh, accentuated the significance of dome roofs. Providing a comfortable indoor environment and preserving energy, dome roofs are an indispensable element in sustainable architectural design [6]. To sum up, dome roofs play a critical role in conserving energy within the realm of traditional Iranian architecture. Through their distinct shape, regional materials, and the integration of innovative technologies, these roofs present sustainable solutions that cater not only to energy efficiency but also adapt to the specific environmental conditions of the region.

THE IMPACT OF DOMED ROOFS ON SOLAR RADIATION AND THERMAL COMFORT IN HOT CLIMATES

The domed roof, a time-honored architectural feature, particularly in the Middle East, boasts a remarkable ability to conserve energy and elevate the thermal well-being of inhabitants. With their distinctive design, domed roofs grace various environments, from teeming bazaars and hallowed mosques to cozy dwellings, showcasing their prowess in energy management and thermal comfort enhancement. Serving as the building envelope's linchpin, the roof contends with a substantial amount of solar radiation, accounting for up to 60% of cooling energy expenditure in spaces [6, 10]. As such, roof design is vital in alleviating occupants' discomfort, especially in harsh climates [11]. Pioneering researchers, including Runsheng [12], Fathy [13], And after them, other researchers including, Faghih & Bahadori [14], Olgyay [15], have championed domed roofs over their flat counterparts, given their heightened insolation reception, which translates to lower indoor temperatures and improved thermal sensations. Studies have shown how the integration of the dome shape and indigenous materials like adobe yields exceptional insulation, curtails heat transfer, and fosters thermal comfort. Also, domes can act as thermal buffers and prevent energy loss at night [7, 8]. Owing to their configuration, domed roofs act as self-shading devices, as half the structure basks in sunlight, while the remaining part finds solace in shade. Soleimani [16], probed wind and buoyancy-driven ventilation in a geodesic edifice equipped with roof vents and open windows in a torrid climate. Their findings suggested that roof vents could be harnessed as a passive technique to secure satisfactory indoor thermal sensations and air quality throughout the year. In other ground-breaking studies, the benefits of integrating dome roofs with earth-to-air heat exchanger systems to increase energy saving capacities have been shown. This avant-garde approach emphasizes the possibility of uniting contemporary technologies with age-old architectural customs and begins a new era of sustainable and energy-efficient structures [9]. In summation, domed roofs wield significant sway over solar radiation management and thermal comfort in scorching climates. Their singular form, regional materials, and innovative technology integrations proffer sustainable solutions that cater to energy efficiency while adapting to the distinct environmental conditions of the area. As architects and designers relentlessly pursue sustainable building solutions, the domed roof epitomizes the harmony between tradition and innovation.

ARAK BAZAAR: A JOURNEY THROUGH UNIQUE ARCHITECTURE AND TIMELESS TRADITIONS

The main axis of the Arak Bazaar, which extends from north to south, is approximately 722.52 meters long and has about 320 shops and 22 entrances to caravanserais (passages) along its length. The main bazaar is covered and has a domed structure with ventilation holes. The architecture of the caravanserais or passages connected to this axis is very unique. Generally, the caravanserais include a central courtyard surrounded by connected shops. Most caravanserais have two floors, and their roofs are beautifully constructed with bricks and plaster in ribbed vaults, arches, and springs. The tasteful architect of the Arak Bazaar did not use a repetitive and uniform design for these 22 caravanserais. The placement of enclosed and open spaces and their connection to the main axis of the bazaar is very diverse and different, creating a beautiful and varied Arak Bazaar next to each other. One of the most intricate and largest caravanserais in this bazaar is the Nozari Caravanserai, which occupies an area of approximately 5,480.93 square meters. This caravanserai has three entrances to the bazaar's main axis and one entrance from the Chahar Suq passage, and it has a central courtyard, to which three long, covered corridors (Timchehs) are connected and accessible. The courtyard floor is paved with stones, and a small pool has been built in the center of it. Around it, numerous shops

with stone columns support brick arches. There is a passage from the middle of the shops to the surrounding corridors, and there is a complete connection between different sections. All parts of the caravanserai are on two floors. The shops are engaged in carpet sales, and carpet pattern drawing [17].

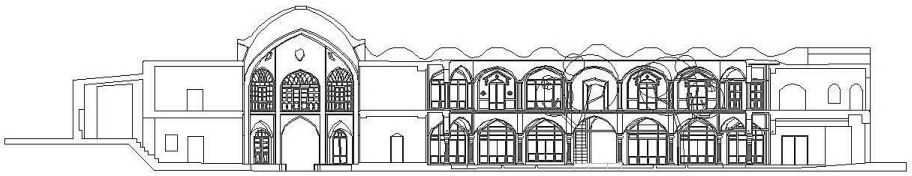


Figure 1. A section of the East-West view of the bazaar (Nozari Caravanserai).

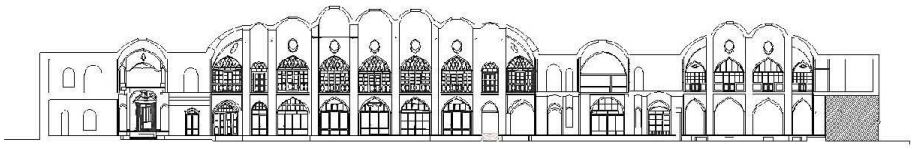


Figure 2. A section of the North-South view of the bazaar (Nozari Caravanserai).

METHODS

When delving into the realm of thermal comfort simulation for bazaars, a plethora of software options await. Despite this, finding an application that effectively tackles spaces with domed roofs can prove to be a daunting task. However, DesignBuilder emerges as a solution capable of handling such intricate scenarios. Carrier and eQuest, while boasting impressive capabilities in assessing air conditioning systems and thermal comfort [18, 19], stumble upon limitations in modeling spaces crowned with dome-shaped ceilings. At times, these software applications may even find themselves at a loss, unable to simulate spaces adorned with domes. In stark contrast, DesignBuilder leaps over these hurdles, empowering researchers to not only compare but also scrutinize buildings with domed roofs, shedding light on energy consumption impacts—a feat that distinguishes it from other research approaches. To simulate the Bazaar environment using this software, it is first necessary to create the environment within the software. Given that it is not feasible to design the entire bazaar within the software, one of the caravanserais, called Sarai Nozari, has been recreated instead. This caravanserai features an open courtyard and closed sections, a large central dome, and seven small side domes. It is important to note that due to the software's limitations, some details have not been considered, which could result in errors. This study aims to investigate the effect of a dome roof in reducing energy consumption and passive thermal comfort in Nozari Caravanserai, which is located in Arak bazaar. To ensure the accuracy of the research, the simulation was designed to closely resemble the current reality of the bazaar, with main parameters such as dimensions and materials chosen to match the real bazaar as closely as possible. The study involved modeling Nozari Caravanserai in two forms: with a dome roof and with a flat roof. The goal was to enable a comparison of the parameters of thermal energy consumption (measured through gas consumption), cooling (measured through electricity consumption), and lighting between the two forms of roof. Additionally, the study aimed to compare temperature variations during a 24-hour period on the hottest and coldest days of the year. The results of this study are expected to provide insights into the potential benefits of using dome roofs in reducing energy consumption and improving passive thermal comfort in traditional marketplaces such as Arak bazaar.

RESULTS & DISCUSSION

This study aims to analyze the energy consumption patterns of bazaar building with a flat roof and bazaar building with a dome roof in different months of the year in order to investigate their thermal comfort performance. Tables 1 and 2 provide data on the energy consumption of the bazaar, while Figures 3 and 4 illustrate the distribution of energy consumption during different months of the year. The data of the Meteorological Organization of Arak region in a period of 10 years shows that indicate that the months of May through September are the hottest months of the year in the region, with July being the hottest. Conversely, the months of November through February are the coldest months of the year, with January being the coldest. Based on the data presented in Tables 1 and 2, it can be concluded that during the hot months of the year, the consumption of electrical energy required to provide environmental cooling is high regardless of whether the roof is domed or flat. On the other hand, during the cold months of the year, gas energy consumption for heating the environment is high regardless of the roof type. However, the simulations conducted in this study reveal differences between the two roof types in terms of energy consumption for cooling and heating. These differences will be discussed in detail below.

Table 1. Changes in energy consumption (over a one-year period) of Nozari Caravanserai with a Flat roof.

Date/Time (Month)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)
Jan	7142.126	60147.94	277.6499
Feb	6210.544	31765.94	771.796
Mar	6521.072	17657.38	2254.174
Apr	6831.599	5451.338	8130.306
May	7142.126	1425.126	23978.4
Jun	6210.544	0.0	40649.91
Jul	7142.126	0.0	61990.3
Agu	6831.599	0.0	54601.4
Sep	6521.072	1.454403	34317.98
Oct	7142.126	2048.211	13820.44
Nov	6521.072	23408.87	1000.9152
Dec	6831.599	45140.59	573.384

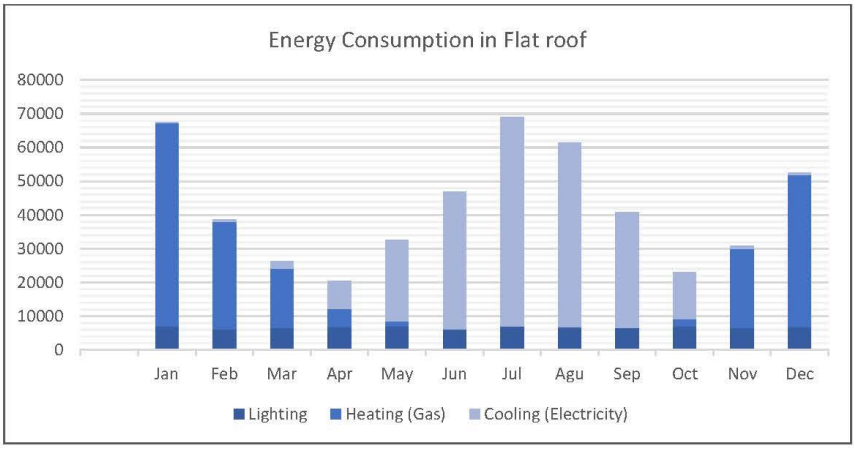


Figure 3. Diagram of changes in energy consumption (in a year period) of Nozari Caravanserai with a Flat roof.

Table 1 and Figure 3 show the energy consumption of the bazaar with a flat roof. According to the data, the amount of electric energy consumption required to provide cold comfort in July is 61990.3 kilowatt hours. In contrast, gas energy consumption required to provide thermal comfort in January is 60147.94 kilowatt hours.

Table 2. Changes in energy consumption (over a one-year period) of Nozari Caravanserai with a Dome roof.

Date/Time (Month)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)
Jan	6387.757	54214.44	219.5212
Feb	5554.571	28614.64	576.7798
Mar	5832.3	15978.21	2045.478
Apr	6110.028	5152.356	8003.493
May	6387.757	1370.026	22415.59
Jun	5554.571	0.0	37432.63
Jul	6387.757	0.0	56717.68
Agu	6110.028	0.0	49798.81
Sep	5832.3	0.953908	31352.17
Oct	6387.757	2098.189	12761.63
Nov	5832.3	21407.21	852.084
Dec	6110.028	40989.13	377.1165

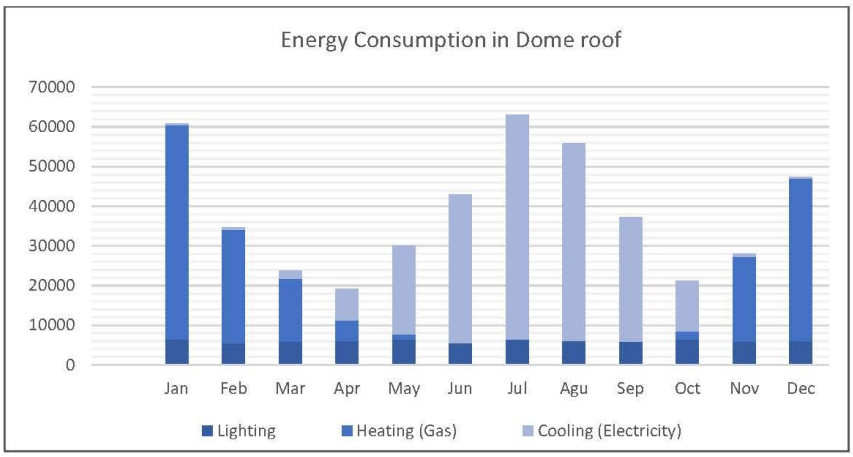


Figure 4. Diagram of changes in energy consumption (in a year period) of Nozari Caravanserai with a Dome roof.

Table 2 and Figure 4 show the energy consumption of the bazaar with a dome roof. According to the data, the amount of electric energy consumption required to provide cold comfort in July is 56717.68 kilowatt hours. In contrast, gas energy consumption required to provide thermal comfort in January is 54214.44 kilowatt hours.

Comparing the energy consumption data of the flat roof and dome roof indicates that the consumption of electrical energy to provide cold comfort in July with a dome roof is 9.3% less than that of a flat roof. Additionally, the consumption of gas energy to provide thermal comfort in January shows a 10.9% decrease when comparing the dome roof and flat roof. Overall, the results suggest that buildings with dome roofs may have advantages in terms of energy consumption for cooling during the hottest months of the year, while also reducing energy consumption for heating during the coldest months of the year.

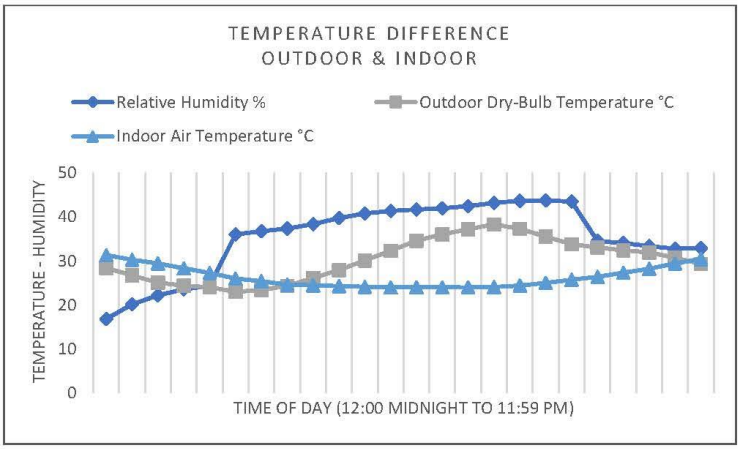


Figure 5. Diagram of outdoor and indoor temperature changes of Nozari Caravanserai on the hottest day of July.

Figure 5 illustrates the variations in temperature both inside and outside the bazaar on the hottest day of the hottest month of the year (July). At 4:00 p.m., the outdoor temperature reached its maximum value of 38.3°C, while the indoor temperature of the bazaar, which has a dome roof, was 24.05°C at the same hour. According to the annual report of the Arak Meteorological

Organization for this date, the air temperature outside Bazaar varied between 38°C and 23°C. The minimum temperature was reported at 6:00 a.m., and the maximum temperature was reported at 4:00 p.m. The highest indoor temperature with a domed ceiling was 31.3°C, occurring at 1:00 a.m. The lowest indoor temperature was recorded at 3:00 p.m., which was 24°C.

The comparison of indoor and outdoor air temperatures on the hottest day of the year provides important insights into the performance of the domed roof of Nozari Caravanserai. Figure 5 illustrates that the air temperature inside the market is consistently lower than the air temperature outside from around 9 am to 11 pm. This can be attributed to the angle of sunlight on the dome roof, which exposes only a small portion of the roof to direct sunlight, with a larger part remaining in the shade. Another key factor is the orientation of the caravanserai and its impact on solar radiation. With the domes located on both the north-south and east-west axes, they not only cast shadows on themselves but also on adjacent domes. Furthermore, Figure 5 shows that, between 12:00 PM and 8:00 AM, while the outdoor temperature decreases, the indoor temperature gradually increases. This is due to the storage of heat in the walls and the gradual transfer of heat to the indoor environment. The roof absorbs heat during the day, but due to its thermal capacity, the heat is not immediately transferred to the indoor environment. These findings suggest that the domed roof can effectively regulate indoor temperatures and improve thermal comfort in marketplaces, especially during the hottest hours of the day.

CONCLUSIONS

In this study, the energy consumption patterns of bazaar of Arak with flat and dome roofs were analyzed to investigate their thermal comfort performance. The results reveal that buildings with dome roofs have advantages in terms of energy consumption for cooling during the hottest months of the year and for heating during the coldest months of the year. The comparison of indoor and outdoor air temperatures on the hottest day of the year showed that the air temperature inside the market with a dome roof is consistently lower than the air temperature outside, indicating that the domed roof can effectively regulate indoor temperatures and improve thermal comfort in marketplaces, especially during the hottest hours of the day. The dome roof, a prevalent feature in traditional Iranian architecture, has been found to possess unique thermal properties that contribute to energy management, thermal comfort, and optimal use of natural energies. Previous research has documented the advantages of dome roofs in curbing energy consumption and preserving energy in a variety of settings, including mosques, and residential structures. This study further supports the efficacy of dome roofs in energy conservation, emphasizing their importance in sustainable architectural design. In conclusion, the optimization of energy performance in buildings is crucial for reducing the impact of the built environment on the global energy consumption and greenhouse gas emissions. The study highlights the significance of traditional Iranian architecture and its potential for providing comfortable living conditions for its inhabitants with lower energy consumption for centuries. It suggests that by identifying the principles and rules governing this architecture and integrating new materials and technological advancements, we can apply the knowledge and the process of traditional architecture in new constructions with a fresh expression. These findings can provide valuable insights for architects, engineers, and policymakers to design more sustainable and energy-efficient buildings in the future, contributing to a cleaner and greener built environment.

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An illustration of a Monthly Gas and Electricity Bill of Nowzari Caravanserai



شرکت توزیع برق استان مرکزی

شرح	تاریخ	میان باری	اوج باری	کم باری	دوره
قرائت کنونی	۱۴۰۱/۰۷/۱۷				
قرائت پیشین	۱۴۰۱/۰۴/۱۲				۱۴۰۱/۰۵
مصرف (kwh)		۲۸۰۶۴	۱۱۷۸۷	۱۶۳۷۶	

مصرف کل دوره: ۵۶۱۲۷ kwh — متوسط مصرف ۳۰ روز — تعداد روز دوره: ۳۰

مصرف ۳۰ روزه	نرخ(ریال)	مصرف ۳۰ روز	مبلغ ۳۰ روزه	فرمول محاسبه و مبلغ
میان باری	۷۰۰۰	۲۸۰۶۴	۱۹۶۴۴۸۰۰۰	
اوج باری	۱۵۰۰۰	۱۱۷۸۷	۱۷۶۸۰۵۰۰۰	تعداد روز ۳۰ (۳۰ | مبلغ ماهانه) ۳۰
کم باری	۶۰۰۰	۱۶۳۷۶	۹۷۶۵۶۰۰۰	

مبلغ مصرف (ریال) ۴۷۰۹۰۰۰

شرح مصرف	نرخ(ریال)	مصرف	شرح مبلغ	مبلغ
میزان مصرف در اوج بار	۱۵۰۰۰		هزینه مصرف اوج باری	
میزان مصرف در کم باری	۶۰۰۰		تخفیف مصرف کم باری	

تاریخ صدور: ۱۴۰۱/۰۷/۳۰ — مراجعه بعدی — واحد حوادث و ۳۸۱۷۴۰ پاسخگویی ۱۵۲۱

مشترک محترم [redacted]

نشانی: [redacted]

کدپستی: [redacted] پلاک: — تعداد خانوار: ۳/۷/[redacted]

پرونده: [redacted] شناسایی: [redacted] — رمز رایانه: [redacted] بدنه کنتور: [redacted]

نوع فعالیت: ۱۰۱۰ — تعرفه: تجاری

فاز/آمپر: ۳/۱۰۰ — تاریخ نصب اولیه:

ارقام/ضریب: ۱/۵ — تاریخ آخرین تعویض:

نحوه قرائت: مامور — تاریخ انقضا پروانه:

	۱	۲	۳	۴	۵	۶
متوسط ۳۰ روزه						
سال گذشته						
سال جاری	۳۰۱۶	۷۸۹۶	۲۲.۴۱	۳۶۹۱۲		

کد اقتصادی: — شناسه ملی:

منطقه برق: مدیریت توزیع برق شهرستان اراک

آدرس منطقه: اراک ، خیابان طالقانی نبش کوچه شهید جودکی

دوره ۲ ماهه — ۱۳۹۸-۸۱۱۱ — ۴۱۲۳

عنوان	مبلغ (ریال)
مبلغ مصرف	۴۷۰.۹۰۹.۰۰۰
هزینه مصرف اوج بار	
تخفیف مصرف کم باری	
آبونمان	[redacted]
تفاوت تعرفه انشعاب آزاد	۰
تخفیف مدیریت مصرف	
تخفیف کم مصرفی	۰
تخفیف	۰
بهای برق دوره	
مالیات بر ارزش افزوده	[redacted]
مبلغ بیمه	
بیمه همگانی حوادث طبیعی	
عوارض برق	
بستانکاری قبلی	
کسر هزار ریال	
مبلغ قابل پرداخت	۴۷۰.۹۳۳.۰۰۰
مهلت پرداخت	۱۴۰۱۰۷/۲۹

مبلغ قابل پرداخت ✓ — شناسه پرداخت ✓ — شناسه قبض ✓

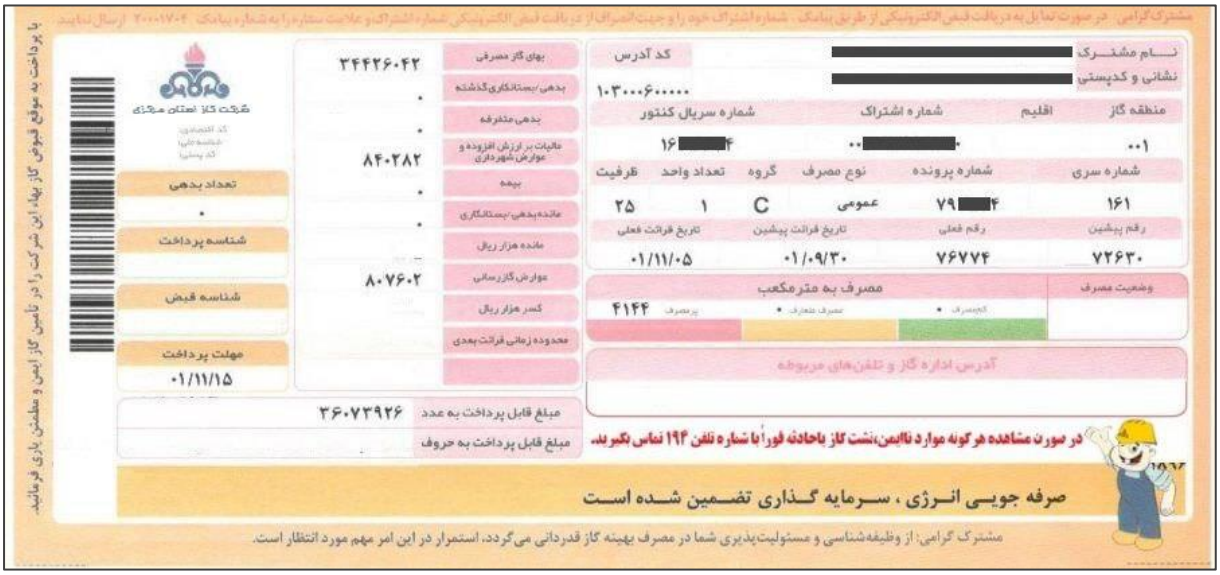
پرداخت آسان و مطمئن با ۱۵۲۱

شرکت توزیع برق استان مرکزی

رمز رایانه	دوره	سال	کد اقتصادی
[redacted]	۰۵	۱۴۰۱	[redacted]۱

مهلت پرداخت مشمول بدهی قبلی نمی باشد

Electricity Bill



شرکت گاز استان مرکزی

کد آدرس					
۱۰۳۰۰۰۶۰۰۰۰۰					
منطقه گاز	اقلیم	شماره اشتراک		شماره سریال کنتور	
۰۰۱		۰۰[redacted]۰		۱۶[redacted]۴	
شماره سری	شماره پرونده	نوع مصرف	گروه	تعداد واحد	ظرفیت
۱۶۱	۷۹[redacted]۴	عمومی	C	۱	۲۵
رقم پیشین	رقم فعلی	تاریخ قرائت پیشین		تاریخ قرائت فعلی	
۷۲۶۳۰	۷۶۷۷۴	۰۱/۰۹/۳۰		۰۱/۱۱/۰۵	

وضعیت مصرف — مصرف به مترمکعب: کیومصرف ● — تصرف متعارف ● — پرمصرف ۴۱۴۴

آدرس اداره گاز و تلفن‌های مربوطه

بهای گاز مصرفی	۳۴۴۲۶۰۴۲
بدهی/بستانکاری گذشته	۰
بدهی متفرقه	۰
مالیات بر ارزش افزوده و عوارض شهرداری	۸۴۰۲۸۲
بیمه	۰
مانده‌بدهی/بستانکاری	۰
مانده هزار ریال	
عوارض گازرسانی	۸۰۷۶۰۲
کسر هزار ریال	
محدوده زمانی قرائت بعدی	

تعداد بدهی: ۰ — شناسه پرداخت — شناسه قبض — مهلت پرداخت: ۰۱/۱۱/۱۵

مبلغ قابل پرداخت به عدد: ۳۶۰۷۳۹۲۶

مبلغ قابل پرداخت به حروف

در صورت مشاهده هر گونه موارد ناایمن، نشت گاز باحادثه فوراً با شماره تلفن ۱۹۴ تماس بگیرید.

صرفه جویی انرژی ، سرمایه گذاری تضمین شده است

مشترک گرامی: از وظیفه‌شناسی و مسئولیت‌پذیری شما در مصرف بهینه گاز قدردانی می‌گردد. استمرار در این امر مهم مورد انتظار است.

با پرداخت به موقع قبوض گاز بهای این شرکت را در تأمین گاز ایمن و مطمئن یاری فرمایید.

Gas Bill

To convert the amount of gas consumed in cubic meters (m^3) to kilowatt-hours (kWh):

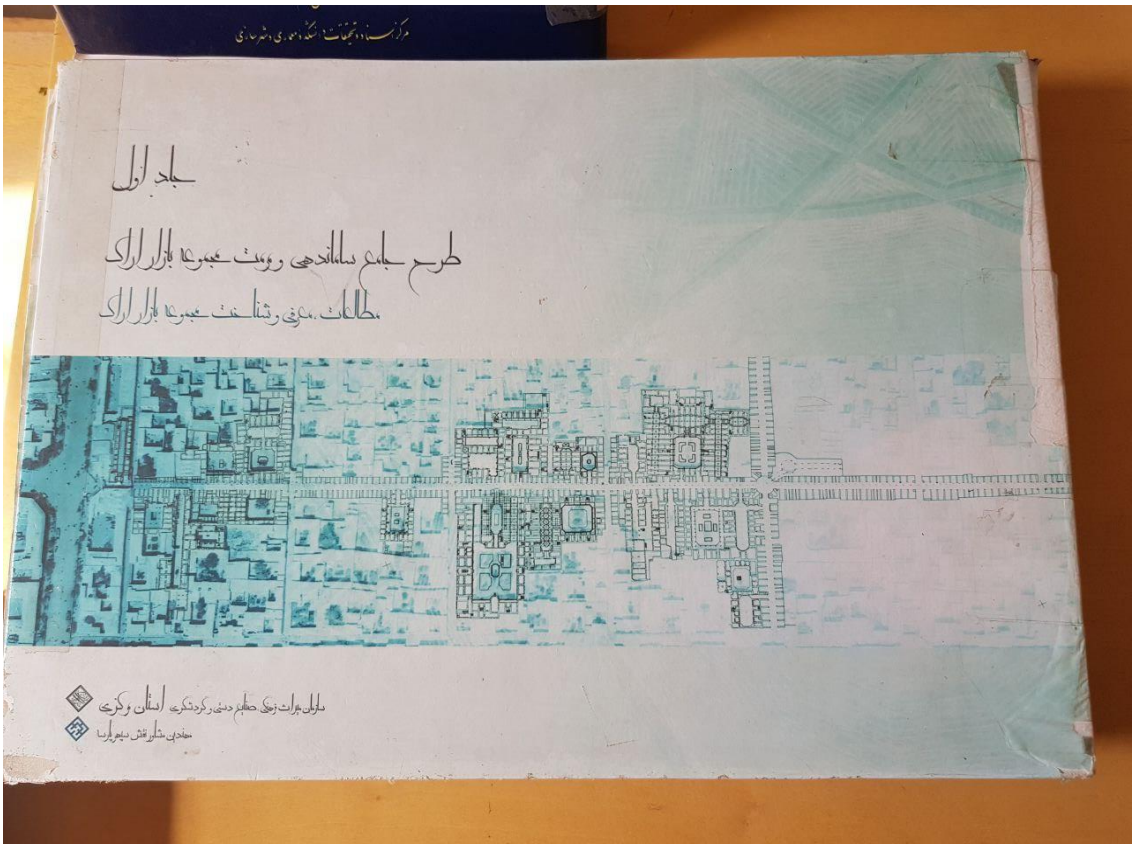
Kilowatt Horus = cubic meter (m^3) × calorific value (MJ/m^3) × 0.28

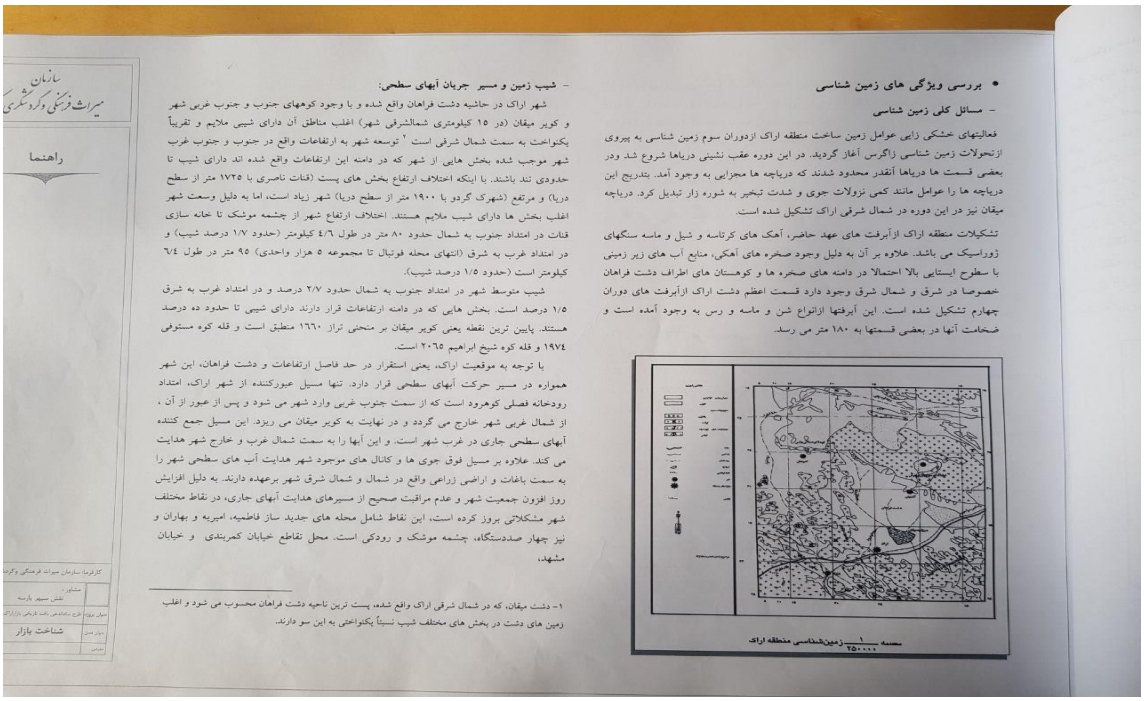
Historical documents of Arak Bazaar

In the following pages, a part of the historical documents and documents of Arak market available in the central library of the Ministry of Cultural Heritage, Tourism and Handicrafts of the Central Province of Iran - Arak city are presented.

In adherence to all protective protocols, photographs have been taken of every historical document housed in the central library of Arak Province, with the intention of preventing any potential damage to the documents.

Furthermore, for the purpose of conducting in-depth research and study, the Ministry of Cultural Heritage, Tourism, and Handicrafts of Arak city has furnished me with a copy of the historical documents and data that were accessible in scanned, Word, and photo formats. For forthcoming investigations and evaluations, scholars may obtain it via electronic mail or direct communication with me.





• **بررسی ویژگی های زمین شناسی**

- مسائل کلی زمین شناسی

فعالیتهای خشکی زایی عوامل زمین ساخت منطقه اراک ازدوران سوم زمین شناسی به پیروی ازتحولات زمین شناسی زاگرس آغاز گردید. در این دوره عقب نشینی دریاها شروع شد ودر بعضی قسمت ها دریاها آنقدر محدود شدند که دریاچه ها مجزایی به وجود آمد. بتدریج این دریاچه ها را عوامل مانند کمی نزولات جوی و شدت تبخیر به شوره زار تبدیل کرد. دریاچه میقان نیز در این دوره در شمال شرقی اراک تشکیل شده است.

تشکیلات منطقه اراک ازآبرفت های عهد حاضر، آهک های کرتاسه و شیل و ماسه سنگهای ژوراسیک می باشد. علاوه بر آن به دلیل وجود صخره های آهکی، منابع آب های زیر زمینی با سطوح ایستابی بالا احتمالا در دامنه های صخره ها و کوهستان های اطراف دشت فراهان خصوصا در شرق و شمال شرق وجود دارد قسمت اعظم دشت اراک ازآبرفت های دوران چهارم تشکیل شده است. این آبرفتها ازانواع شن و ماسه و رس به وجود آمده است و ضخامت آنها در بعضی قسمتها به ۱۸۰ متر می رسد.

محمدیه ۱ زمین‌شناسی منطقه اراک

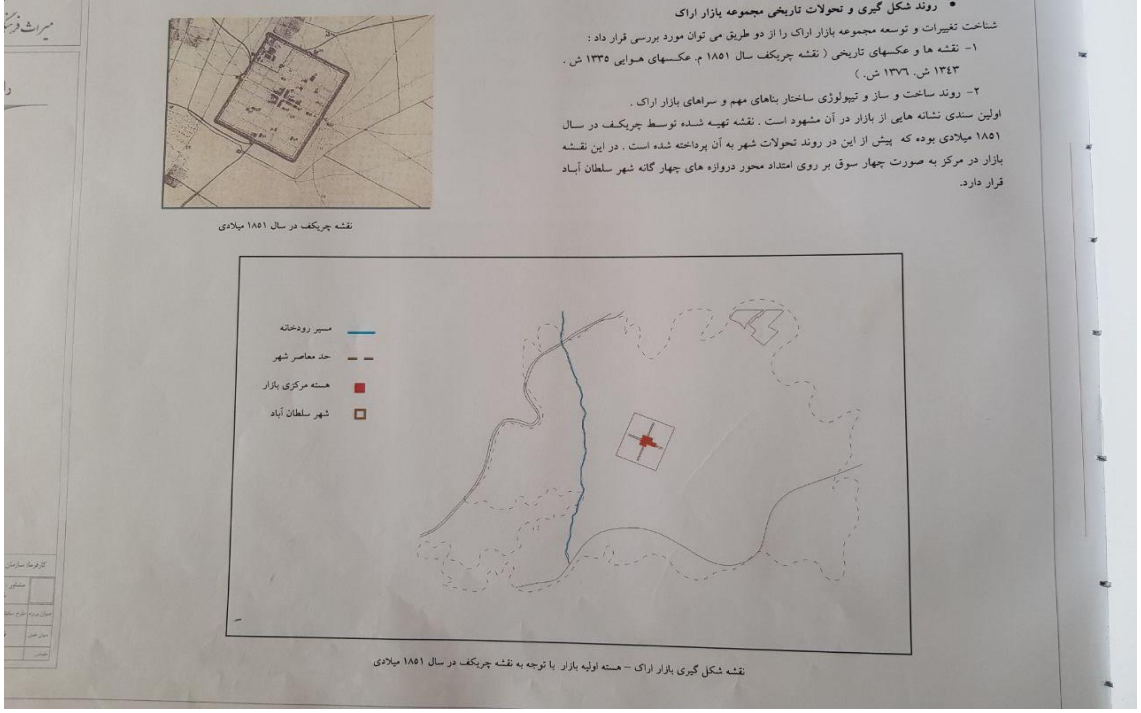
- شیب زمین و مسیر جریان آبهای سطحی:

شهر اراک در حاشیه دشت فراهان واقع شده و با وجود کوههای جنوب و جنوب غربی شهر و کویر میقان (در ۱۵ کیلومتری شمالشرقی شهر) اغلب مناطق آن دارای شیبی ملایم و تقریباً یکنواخت به سمت شمال شرقی است [۲] توسعه شهر به ارتفاعات واقع در جنوب و جنوب غرب شهر موجب شده بخش هایی از شهر که در دامنه این ارتفاعات واقع شده اند دارای شیب تا حدودی تند باشند. با اینکه اختلاف ارتفاع بخش های پست (قنات ناصری با ۱۷۲۵ متر از سطح دریا) و مرتفع (شهرک گردو با ۱۹۰۰ متر از سطح دریا) شهر زیاد است، اما به دلیل وسعت شهر اغلب بخش ها دارای شیب ملایم هستند. اختلاف ارتفاع شهر از چشمه موشک تا خانه سازی قنات در امتداد جنوب به شمال حدود ۸۰ متر در طول ٤/٦ کیلومتر (حدود ۱/۷ درصد شیب) و در امتداد غرب به شرق (انتهای محله فوتبال تا مجموعه ۵ هزار واحدی) ۹۵ متر در طول ٦/٤ کیلومتر است (حدود ۱/۵ درصد شیب).

شیب متوسط شهر در امتداد جنوب به شمال حدود ۲/۷ درصد و در امتداد غرب به شرق ۱/۵ درصد است. بخش هایی که در دامنه ارتفاعات قرار دارند دارای شیبی تا حدود ده درصد هستند. پایین ترین نقطه یعنی کویر میقان بر منحنی تراز ۱٦٦۰ منطبق است و قله کوه مستوفی ۱۹۷٤ و قله کوه شیخ ابراهیم ۲۰٦۵ است.

با توجه به موقعیت اراک، یعنی استقرار در حد فاصل ارتفاعات و دشت فراهان، این شهر همواره در مسیر حرکت آبهای سطحی قرار دارد. تنها مسیل عبورکننده از شهر اراک، امتداد رودخانه فصلی کوهرود است که از سمت جنوب غربی وارد شهر می شود و پس از عبور از آن ، از شمال غربی شهر خارج می گردد و در نهایت به کویر میقان می ریزد. این مسیل جمع کننده آبهای سطحی جاری در غرب شهر است. و این آبها را به سمت شمال غرب و خارج شهر هدایت می کند. علاوه بر مسیل فوق جوی ها و کانال های موجود شهر هدایت آب های سطحی شهر را به سمت باغات و اراضی زراعی واقع در شمال و شمال شرق شهر برعهده دارند. به دلیل افزایش روز افزون جمعیت شهر و عدم مراقبت صحیح از مسیرهای هدایت آبهای جاری، در نقاط مختلف شهر مشکلاتی بروز کرده است، این نقاط شامل محله های جدید ساز فاطمیه، امیریه و بهاران و نیز چهار صددستگاه، چشمه موشک و رودکی است. محل تقاطع خیابان کمربندی و خیابان مشهد.

۱- دشت میقان، که در شمال شرقی اراک واقع شده، پست ترین ناحیه دشت فراهان محسوب می شود و اغلب زمین های دشت در بخش های مختلف شیب نسبتاً یکنواختی به این سو دارند.



• **روند شکل گیری و تحولات تاریخی مجموعه بازار اراک**

شناخت تغییرات و توسعه مجموعه بازار اراک را از دو طریق می توان مورد بررسی قرار داد :

۱- نقشه ها و عکسهای تاریخی (نقشه چریکف سال ۱۸۵۱ م. عکسهای هوایی ۱۳۳۵ ش . ۱۳۴۳ ش. ۱۳۷٦ ش.)

۲- روند ساخت و ساز و تیپولوژی ساختار بناهای مهم و سراهای بازار اراک .

اولین سندی نشانه هایی از بازار در آن مشهود است . نقشه تهیه شده توسط چریکف در سال ۱۸۵۱ میلادی بوده که پیش از این در روند تحولات شهر به آن پرداخته شده است . در این نقشه بازار در مرکز به صورت چهار سوق بر روی امتداد محور دروازه های چهار گانه شهر سلطان آباد قرار دارد.

نقشه چریکف در سال ۱۸۵۱ میلادی

مسیر رودخانه
حد معاصر شهر
هسته مرکزی بازار
شهر سلطان آباد

نقشه شکل گیری بازار اراک – هسته اولیه بازار با توجه به نقشه چریکف در سال ۱۸۵۱ میلادی

۱-۱-۲ مطالعات کالبدی و فضایی

۱-۱-۱-۲ موقعیت و جایگاه محدوده تاریخی در کل شهر



موقعیت بافت تاریخی شهر اراک در قدیمی ترین عکس هوایی مربوط به سال ۱۳۳۵

۷- چهارسو

یا چهارسوق محل برخورد دو راسته اصلی، مرکزتجارت ممتازی پدید می آوردکه معمولاً ٤ بازار از آن منشعب می شود و معماری آن از سایر قسمتهای راسته با طرافت و تزئینات داخلی بیشتری اجرا گردیده است . دربعضی از شهر ها چهار سو به صورت هسته مرکزی اقتصاد شهر درمی آید .(دانشنامه جهان اسلام ، ۱۳۷۲) متمایز و دارای چهارسوها معمولاً هشت گوش هستند وکار کنج سازی درآنها با دقت وظرافت خاص صورت گرفته و در هر کنج یک تا سه حجره ویک راه پله بنا شده است. سقف همه آنها گنبدی شکل است . کاربندی زیر این گنبدهای بلند وتزئینات کج بری در قوسهای آن جلوه چشمگیری به چهارسوها بخشیده است . درگذشته چهارسو محل استقرار داروغه و محتسب بود که به امور انتظامی بازار و نظارت بر اوزان ومقادیر و قیمتها می پرداخته اند . درهنگام برپای جشنهای ملی ومذهبی بازاریان در آراستن چهارسوها هنرنمای می کردند. به گفته سفرنامه نویسان، برخی از شاهان ایران به ویژه شاه عباس صفوی از مهمانان خارجی درداخل بازار و درمحل چهار سو پذیرایی می کردند .چهار سوی بزرگ بازار اصفهان، چهارسوی بازار لار، چهارسوی بازار کرمان و.... ازنمونه های خوب باقی مانده اند.



چهار سوق بازار اصفهان

۸- کارگاه

کارگاهها مکانهای برای تولید صنعتی بوده اند. کارگاهای تجاری نمونه ای ازآنها بود کارگاهای کوچکتر معمولاً دارای یک مغازه خورده فروشی نیز بودند و درطول راسته بازار قرارداشتند وصنعتگران حرفه هـای مشابه کارگاههایشـان را مجـاور یکـدیگر دریـک راسته بـازار انتخـاب مـی کـردند. (پوراحمد، ۱۳۷٦)

۹- کارخانه

کارخانه ها مکانهای برای تولید صنعتی و سوار کردن قطعات به شمار می رفتند و شامل چندین ساختمان وسیع متصل به هم بودند .طرح ومعماری هر ساختمان از ساختمان مجاور خود متفاوت و وابسته به نوع عملکردی بود که درآن وجود داشت.کارخانه در بازار نزدیک کاروانسراها یا درحاشیه بیرونی مجموعه بازاربین مناطق تجاری ومسکونی قرار می گرفتند.برخی ازکارخانه ها مانند دباغ خانه ها خارج از بازار درحاشیه شهر قرارداشتند .زیرا اثرات منفی مرتبط با عملکرد خود داشتند .وبوی نـاخوشـایندی منتشر مـی کردند.متداولترین نـوع کارخـانه در مجموعه بازار کارخانه پارچه بافی بود. (پوراحمد، ۱۳۷٦)



راسته بازار اصفهان



• **ساختار فضایی بازار اراک**

به جهت نظام شهر سازی منظم از پیش تعیین شده در شهر اراک ، نقطه آغازین بازار و گسترش آن نیز تابع این نظم بوده و مجموعه ای پیوسته شامل تمامی عناصر و اجزا مورد نیاز بازار را در خود جای داده است

بازار به مرکزیت چهار سوق دارای دو مسیر شمالی- جنوبی (طولی) و شرقی- غربی است که از چهار جهت به دروازه های شهر (قبله ، راهزان ، شهر جرد ، حاج علیقی) متصل می شود ؛ بدان معنی که با توجه به برج و باروهای شهر ، ورودی شهر نیز از چهار سوی ، از بازار آغاز می گردد. این مرکز تبادل اقتصادی به نحوی استقرار یافته که در حالت مجاز مستقل بودن از نظر فضایی ، به عنوان محور اصلی کالبد شهر ، بر تمام شهر استیلا داشته باشد.

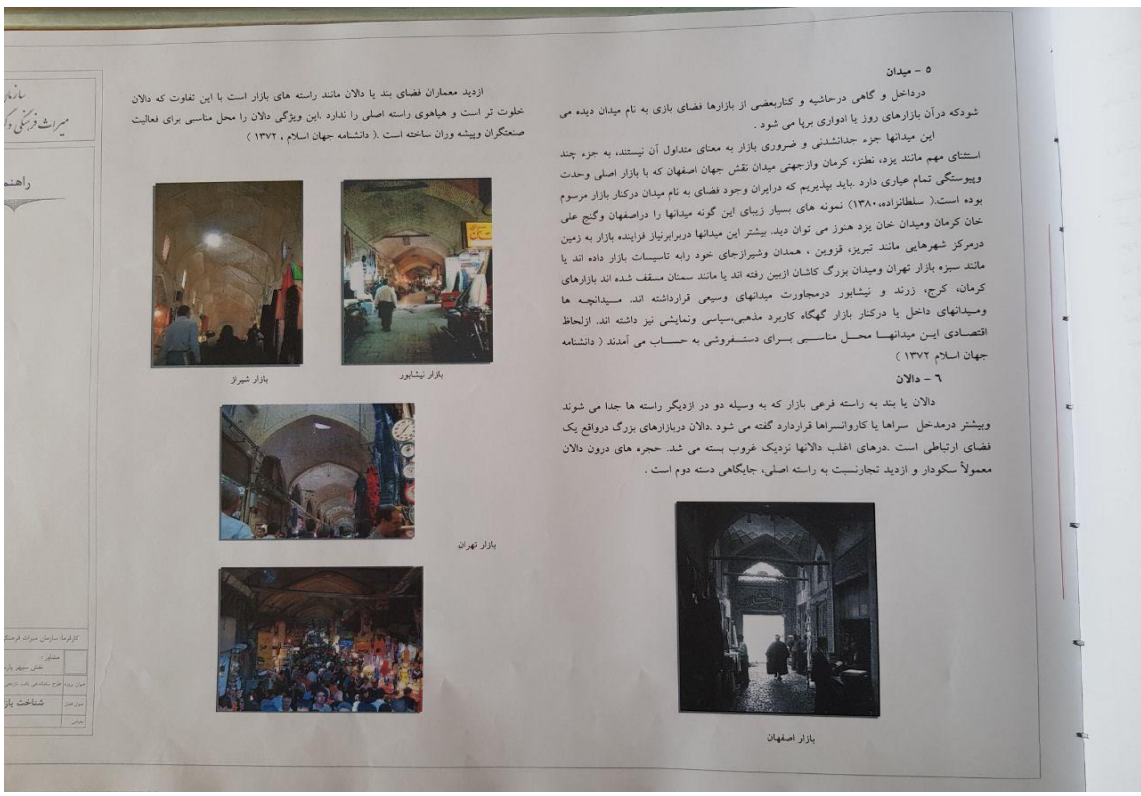
بازار شهر قدیمی ، در دروازه های خود نیازمندی های خرید مسافران را مرتفع می سازد و بر طول خود و در چهار جهت ، محل عرضه کالاهای مختلف است . با توجه به متقاطع بودن راه ها در هر قسمت از بازار ، هنگام تلاقی با راه های منتهی به اماکن مسکونی (گذرهای بازار) اماکنی جهت رفع احتیاجات روزمره مردم مانند نانوایی، قصابی ، آرایشگاه و بقالی وجود دارد . هنوز هم چنین شرایطی بر بازارهای باقیمانده شهر حکومت فرماست که بعضی از آنها به مرور زمان تغییر عملکرد داده است . گذرهای « لوطی هاشم » ، « سپهداری » ، « حاج ملاقاسم » ، « آقا ضیاءالدین » و کوچه « حمام شیخ السلام » نمونه هایی از این اماکن است.

نمای بعضی از بناهای داخلی این کاروانسراها به نحوی است که علی رغم گذشت زمان چنین به نظر می آید که از تاریخ ایجاد آنها بیش از چند سال یا چند دهه نمی گذرد . حال آنکه بیش از یک قرن با بدون مرمت و بازسازی پشت سر نهاده اند.

راسته بازارها بافت قدیمی اراک مانند غالب بازارهای سنتی ایران ، محل عرضه دسته بندی شده ای از کالاها بوده ست . مانند بزازان ، دباغان ، خامه فروشان ، سقط فروشان . در کاروانسراها نیز کالاها به صورت کاروانسراها معمولاً عمده فروشی ها و در راسته بازارها خرد فروشی ها مستقر بوده اند. در بعضی از کاروانسراها کار تعمیر و ترمیم فرش و در برخی از آنها ریسندگی نخ یا پشم نیز صورت می گرفته است .

- بازار اراک از لحاظ فیزیکی

بازار اراک دارای یک محور شمالی جنوبی اصلی ، کاملاً سیستماتیک و طراحی شده در مرکز شهر قدیمی از دو دروازه قبله در جنوب به دروازه راهزان در شمال امتداد داشته است که [متأسفانه دو گذر از قسمت شمالی آن تخریب شده است[۱]]. راسته های شرقی غربی به صورت محور عمود بر راسته اصلی قرار دارند . دو راسته اصلی بازار (گذر چهار سوق و گذر شمالی – جنوبی) دارای پوشش قوس دار هستند و در محل چهار سوق یکدیگر را قطع می کنند . سقف بازار از طرف جنوب تا یکصد متر (یک گذر) دو طبقه بوده و ارتفاع سقف آن ۸ متر می باشد . ولی در سال های گذشته به علت بی توجهی مسئولین و مالکین قسمتی از سقف ابتدای آن فرو ریخته و سر در زیبای آن در زمان ساختمان بانک ملی[۲] (اول بازار) از بین رفته است . عرض راسته بازار از ابتدا تا انتهای ۵ متر است . ارتفاع چهار سوق حدود ۱۳/۳ متر دو پوش بوده که از لحاظ زیبائی و فن معماری از بناهای در خور توجه است .



۵ – میدان

درداخل و گاهی درحاشیه و کناربعضی از بازارها فضای بازی به نام میدان دیده می شودکه درآن بازارهای روز یا ادواری برپا می شود .

این میدانها جزء جدانشدنی و ضروری بازار به معنای متداول آن نیستند، به جزء چند استثنای مهم مانند یزد، نطنز، کرمان وازجهتی میدان نقش جهان اصفهان که با بازار اصلی وحدت وپیوستگی تمام عیاری دارد .باید بپذیریم که درایران وجود فضای به نام میدان درکنار بازار مرسوم بوده است.(سلطانزاده،۱۳۸۰) نمونه های بسیار زیبای این گونه میدانها را دراصفهان وگنج علی خان کرمان ومیدان خان یزد هنوز می توان دید. بیشتر این میدانها دربرابرنیاز فزاینده بازار به زمین درمرکز شهرهایی مانند تبریز، قزوین ، همدان وشیرازجای خود رابه تاسیسات بازار داده اند یا مانند سبزه بازار تهران ومیدان بزرگ کاشان ازبین رفته اند یا مانند سمنان مسقف شده اند بازارهای کرمان، کرج، زرند و نیشابور درمجاورت میدانهای وسیعی قرارداشته اند. میدانچه ها ومیدانهای داخل یا درکنار بازار گهگاه کاربرد مذهبی،سیاسی ونمایشی نیز داشته اند. ازلحاظ اقتصادی این میدانها محل مناسبی برای دستفروشی به حساب می آمدند (دانشنامه جهان اسلام ۱۳۷۲)

٦ – دالان

دالان یا بند به راسته فرعی بازار که به وسیله دو در ازدیگر راسته ها جدا می شوند وبیشتر درمدخل سراها یا کاروانسراها قراردارد گفته می شود .دالان دربازارهای بزرگ درواقع یک فضای ارتباطی است .درهای اغلب دالانها نزدیک غروب بسته می شد. حجره های درون دالان معمولاً سکودار و ازدید تجارنسبت به راسته اصلی، جایگاهی دسته دوم است .

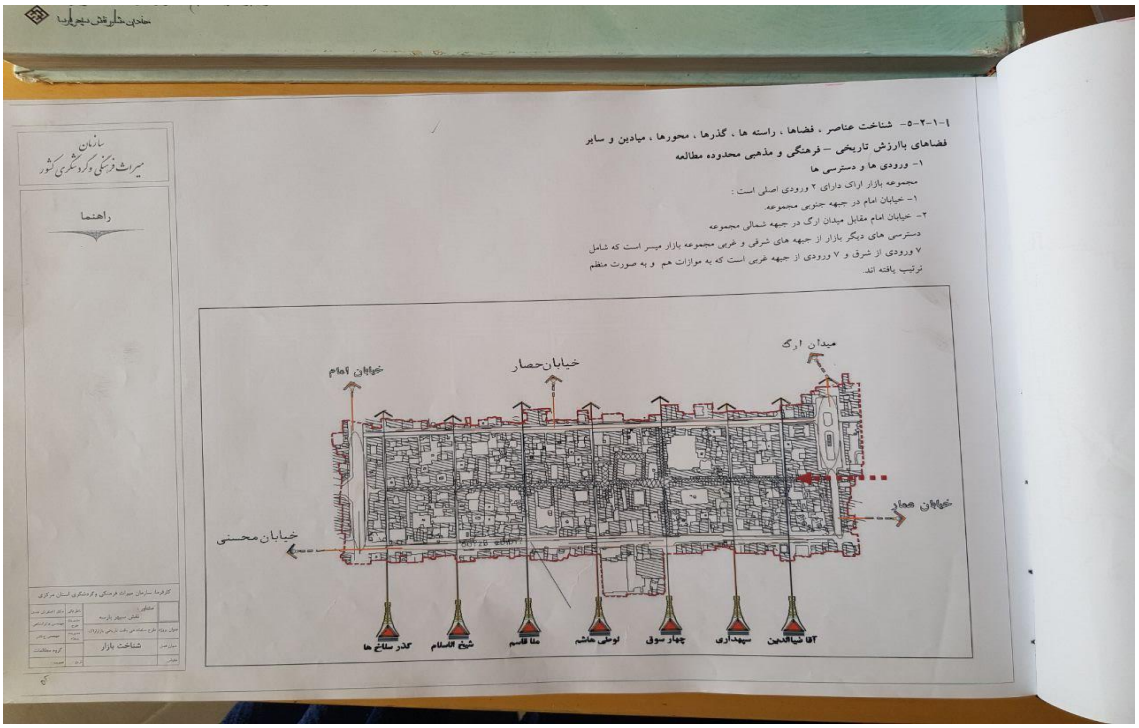
ازدید معماران فضای بند یا دالان مانند راسته های بازار است با این تفاوت که دالان خلوت تر است و هیاهوی راسته اصلی را ندارد .این ویژگی دالان را محل مناسبی برای فعالیت صنعتگران وپیشه وران ساخته است .(دانشنامه جهان اسلام ، ۱۳۷۲)

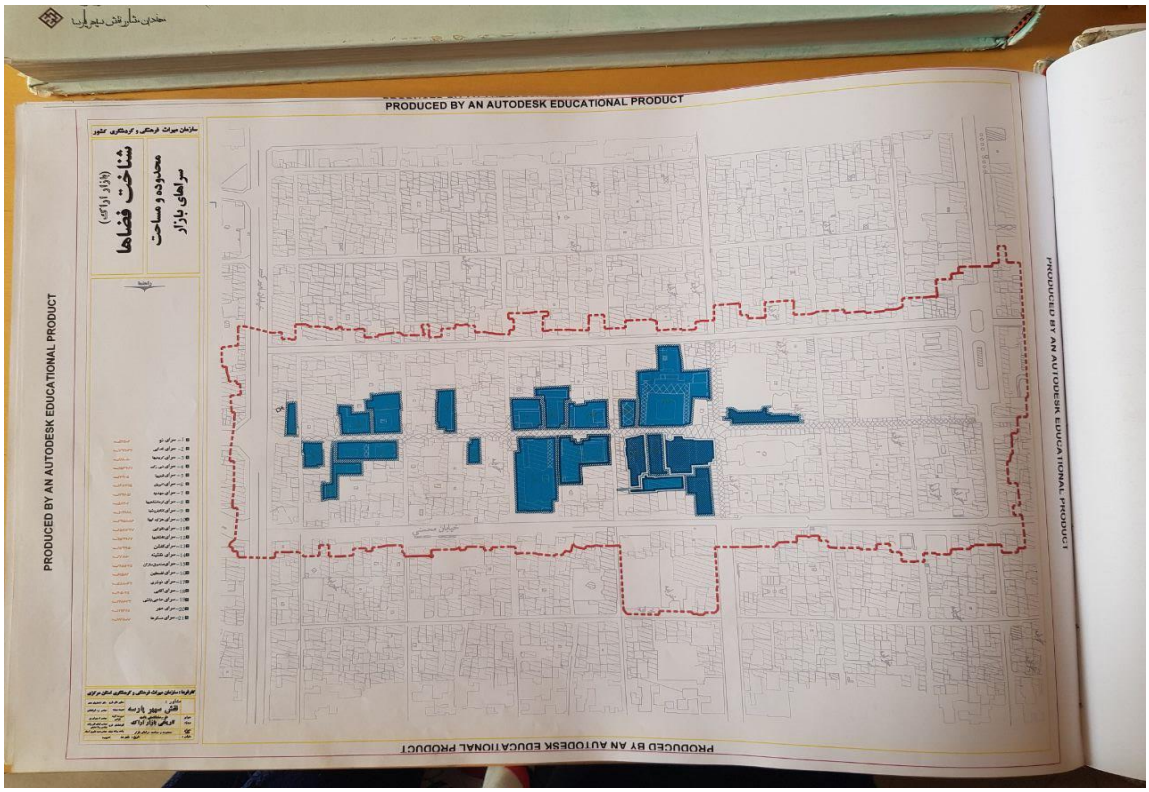
بازار نیشابور

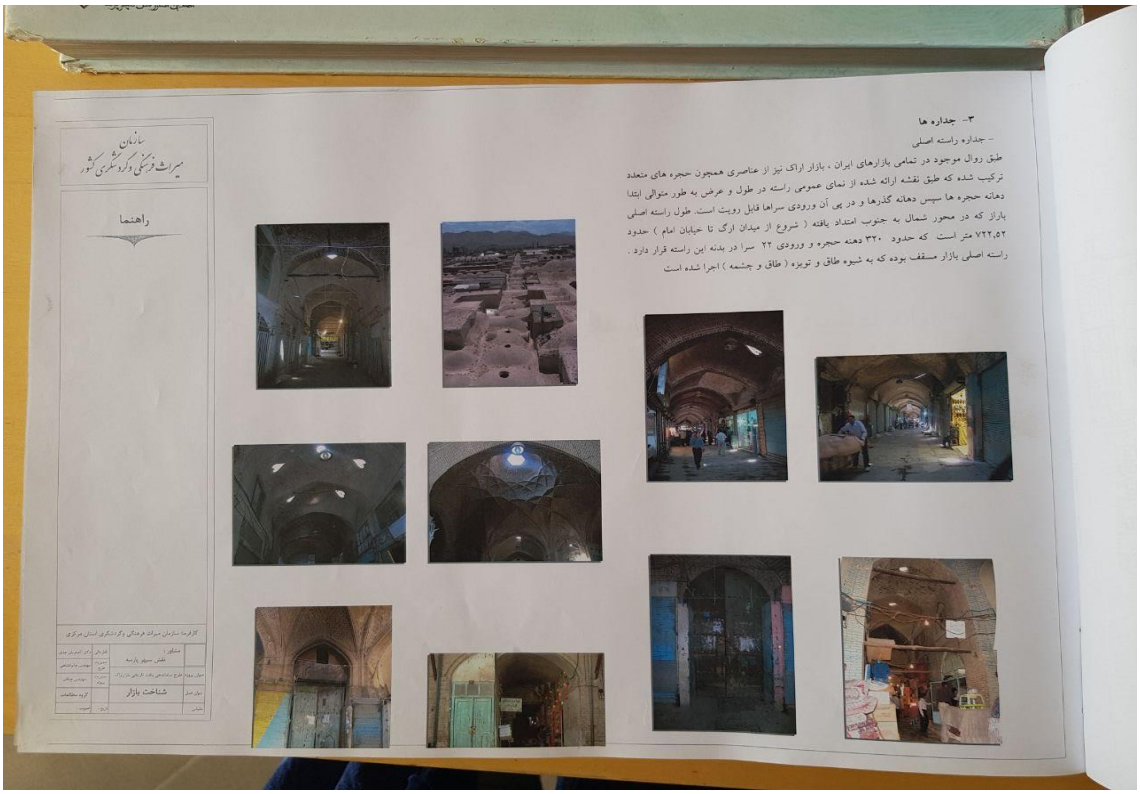
بازار شیراز

بازار تهران

بازار اصفهان


میدان ارگ
خیابان امام
خیابان حصار
خیابان عمار
خیابان محسنی
کذر سلاح ها
شیخ الاسلام
نظامی
لوطی هاشم
چهارسوق
بهداری
آقا شیخ الدین


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
شناخت فضاها
محدوده و ساحت
سراهای بازار



سازمان
میراث فرهنگی و گردشگری کشور

راهنما

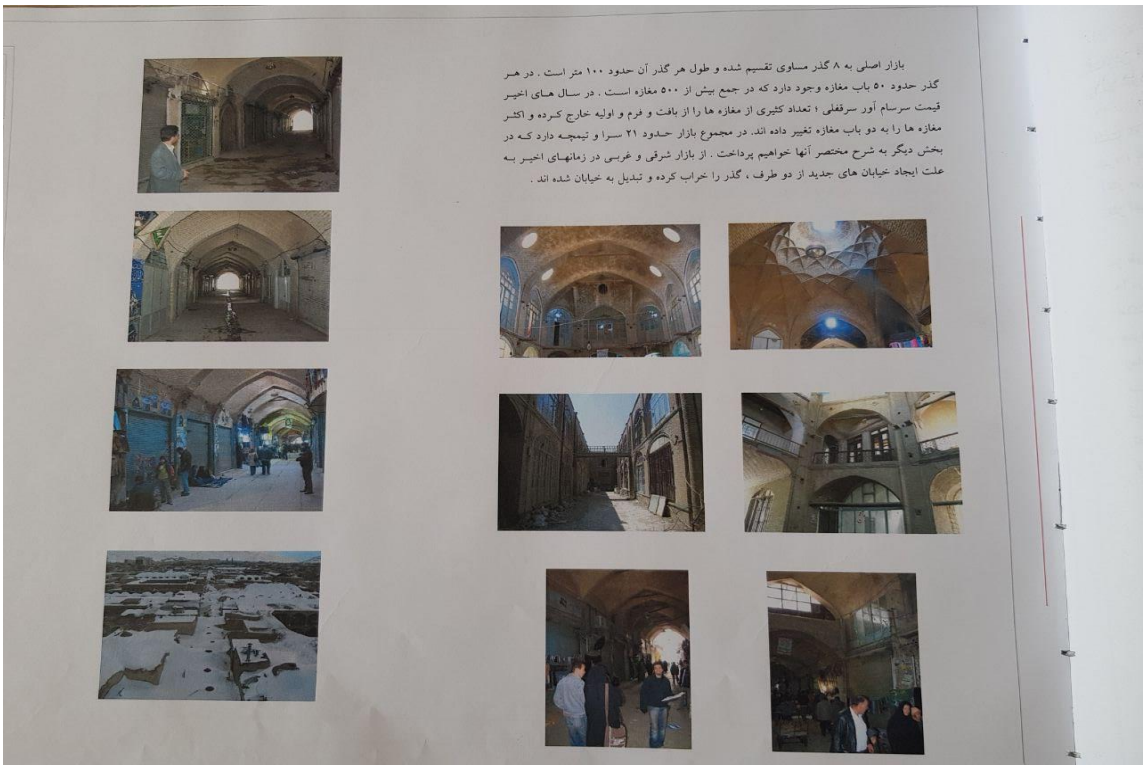
۳- جداره ها

- جداره راسته اصلی

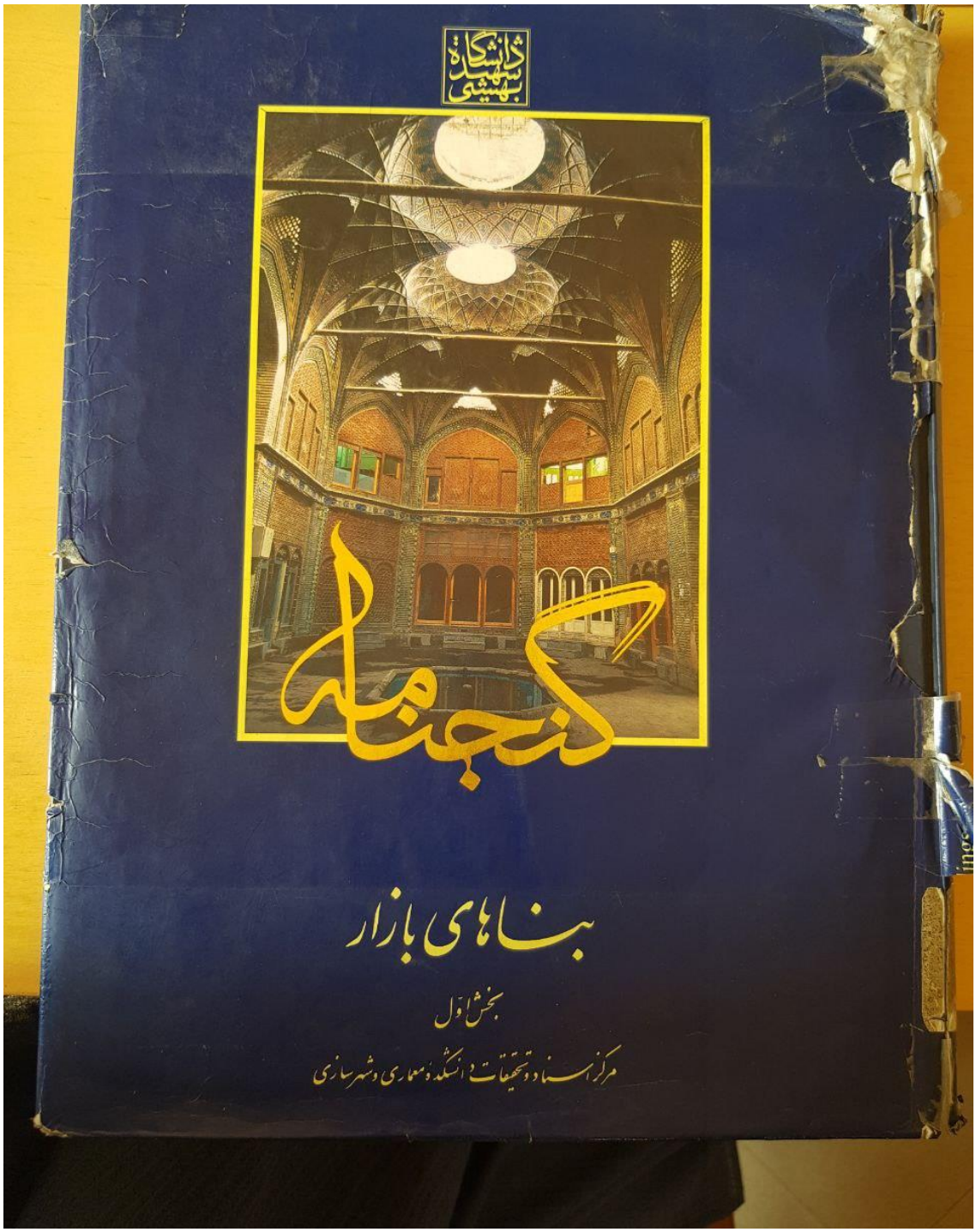
طبق روال موجود در تمامی بازارهای ایران ، بازار اراک نیز از عناصری همچون حجره های متعدد ترکیب شده که طبق نقشه ارائه شده از نمای عمومی راسته در طول و عرض به طور متوالی ابتدا دهانه حجره ها سپس دهانه گذرها و در پی آن ورودی سراها قابل رویت است. طول راسته اصلی بازار که در محور شمال به جنوب امتداد یافته (شروع از میدان ارگ تا خیابان امام) حدود ۷۲۲.۵۲ متر است که حدود ۳۲۰ دهنه حجره و ورودی ۲۲ سرا در بدنه این راسته قرار دارد . راسته اصلی بازار مسقف بوده که به شیوه طاق و تویزه (طاق و چشمه) اجرا شده است

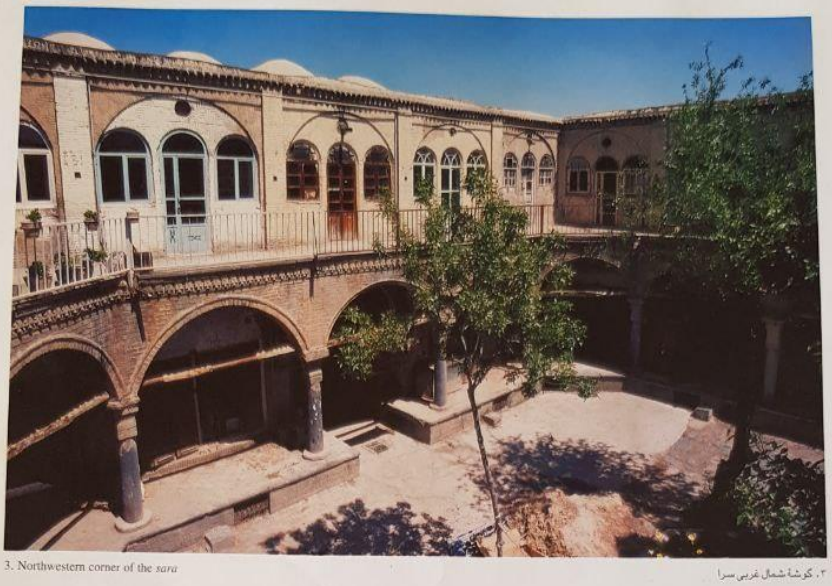
کارفرما سازمان میراث فرهنگی و گردشگری استان مرکزی

	عنوان :		
	نقشه سیویل پارسه		
	شناخت بازار		



بازار اصلی به ۸ گذر مساوی تقسیم شده و طول هر گذر آن حدود ۱۰۰ متر است . در هر گذر حدود ۵۰ باب مغازه وجود دارد که در جمع بیش از ۵۰۰ مغازه است . در سال های اخیر قیمت سرسام آور سرقفلی ؛ تعداد کثیری از مغازه ها را از بافت و فرم و اولیه خارج کرده و اکثر مغازه ها را به دو باب مغازه تغییر داده اند. در مجموع بازار حدود ۲۱ سرا و تیمچه دارد که در بخش دیگر به شرح مختصر آنها خواهیم پرداخت . از بازار شرقی و غربی در زمانهای اخیر به علت ایجاد خیابان های جدید از دو طرف ، گذر را خراب کرده و تبدیل به خیابان شده اند .

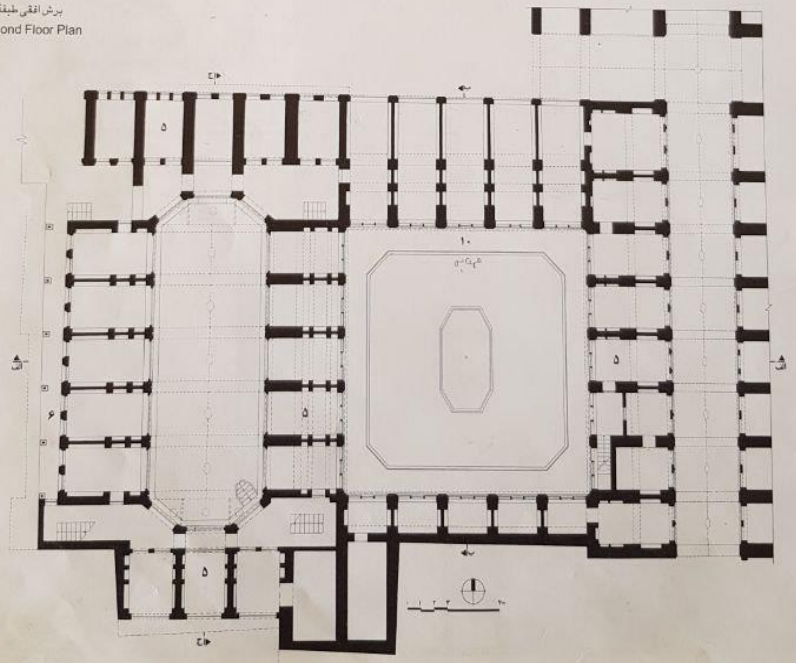

دانشگاه شهید بهشتی
گنجنامه
بناهای بازار
بخش اول
مرکز اسناد و تحقیقات دانشکده معماری و شهرسازی



3. Northwestern corner of the *sara*

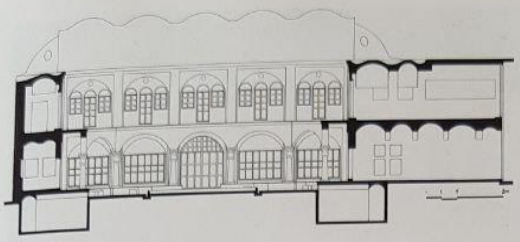
۳. گوشهٔ شمال غربی سرا

پرش افقی طبقهٔ دوم
Second Floor Plan

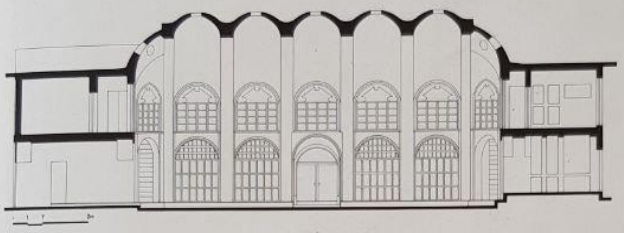


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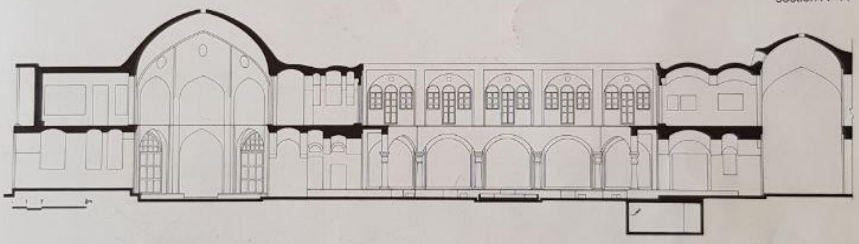
برش عمودی ب ـ ب
section B - B

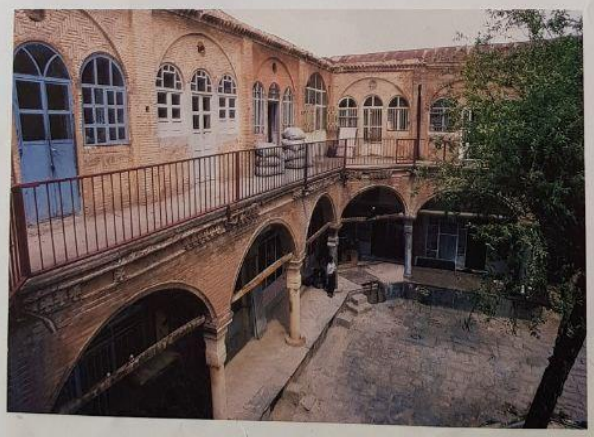


برش عمودی ج ـ ج
section C - C



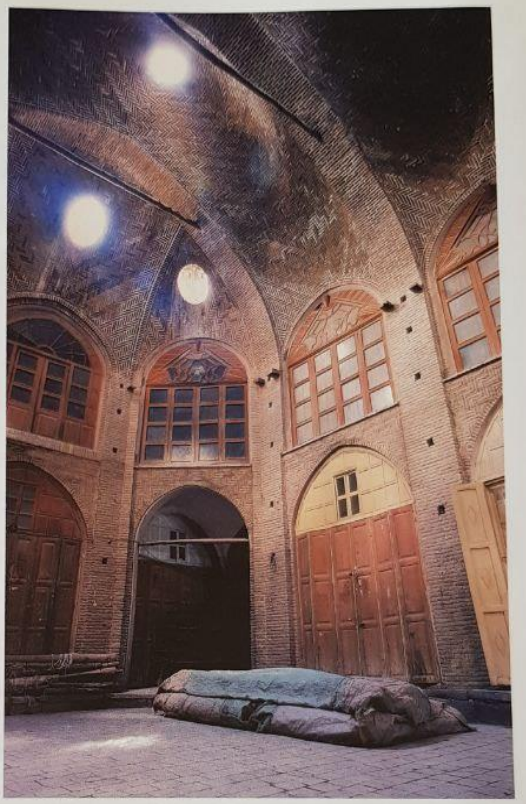
برش عمودی الف ـ الف
section A - A



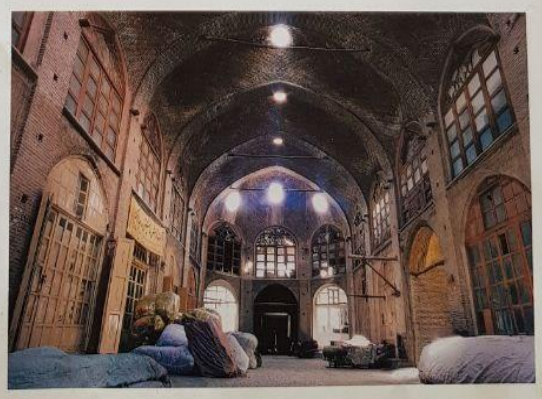


۴. گوشهٔ شمال شرقی سرا
4. Northeastern corner of the *sara*

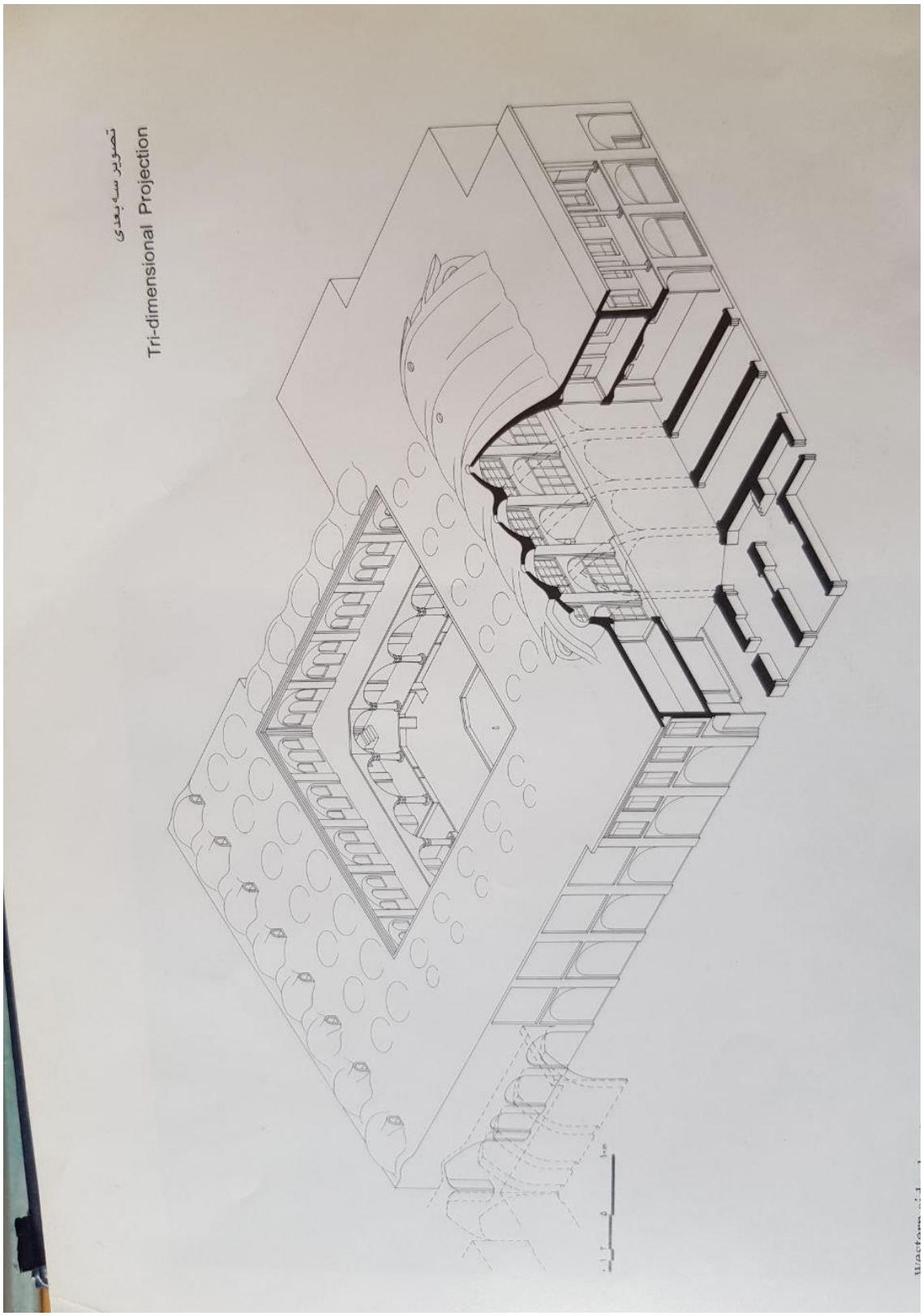
۲۰
187

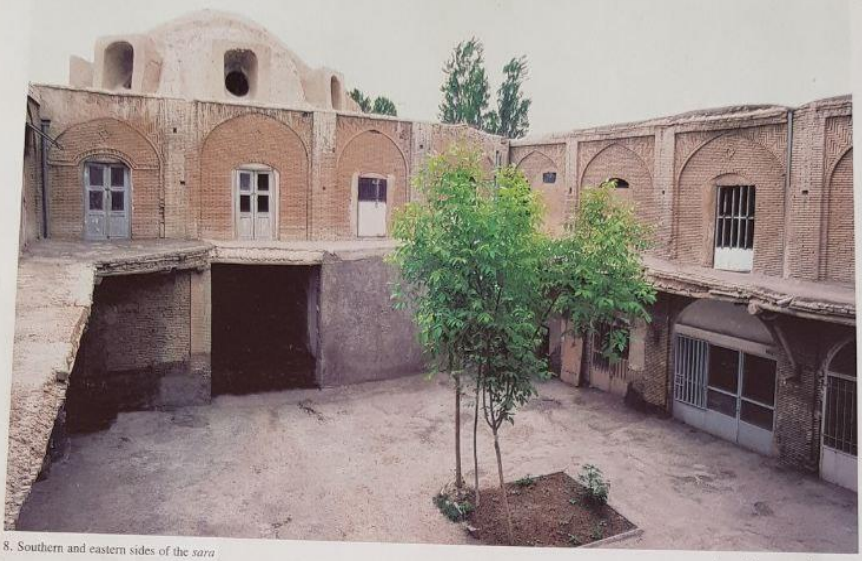


۵. گوشه جنوب غربی فضای میانی تیمچه
5. Southwestern corner of *timcheh*'s central space



۶. فضای میانی تیمچه
6. *Timcheh*'s central space

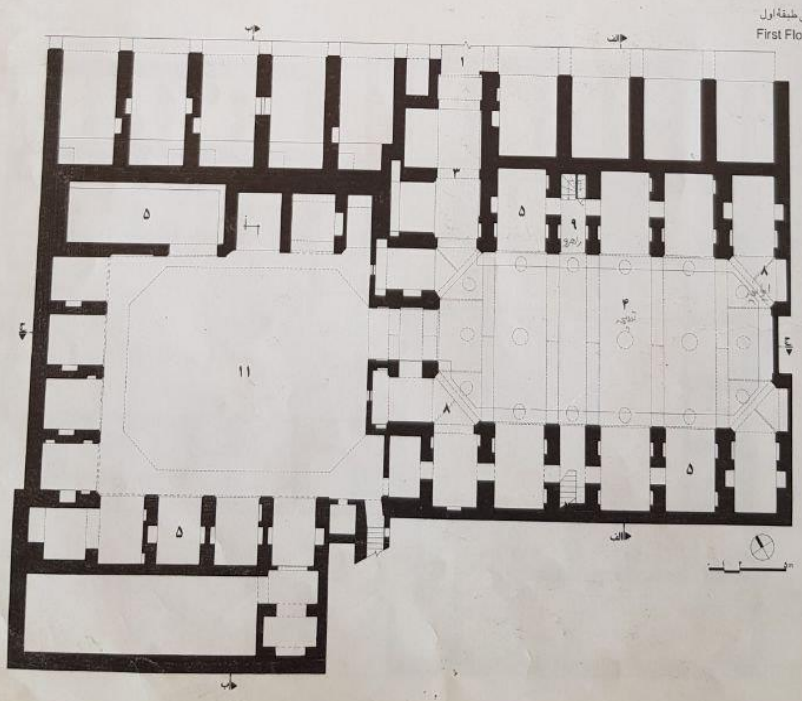

تصویر سه بعدی
Tri-dimensional Projection



8. Southern and eastern sides of the *sara*

۸. جبهه‌های جنوبی و شرقی سرا

برش افقی طبقهٔ اول
First Floor Plan



۲۵
182

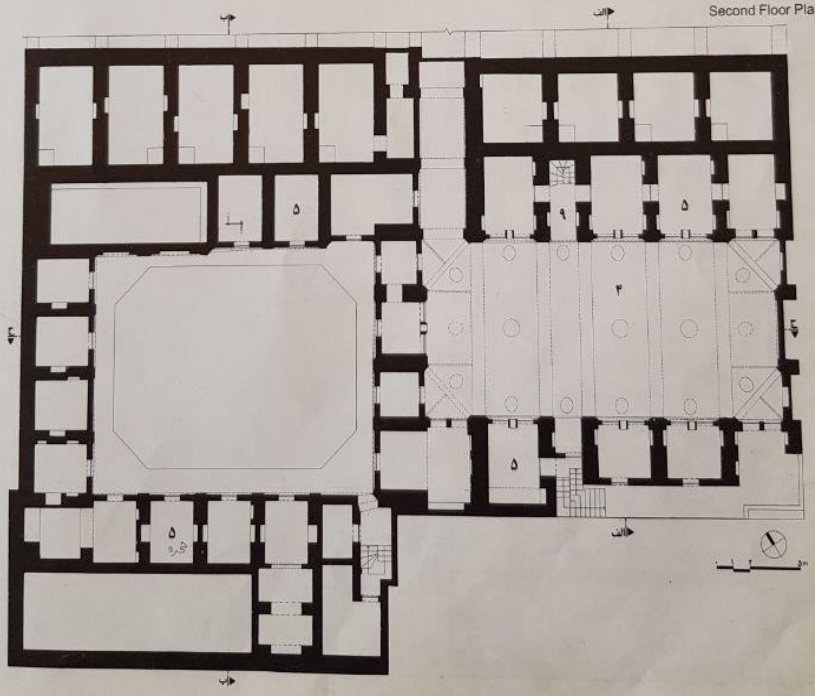


9. Western side of the *sara*

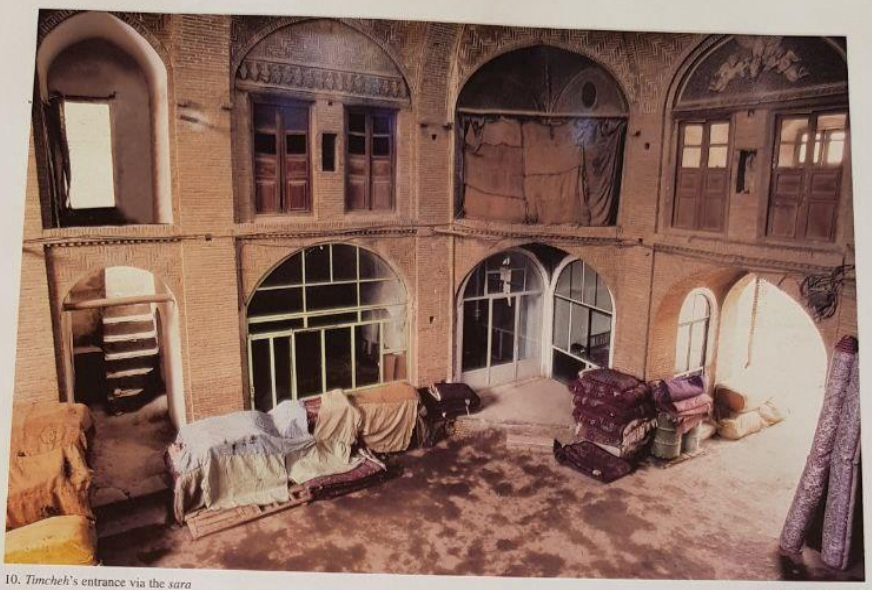
۹. جبههٔ غربی سرا

برش افقی طبقهٔ دوم

Second Floor Plan



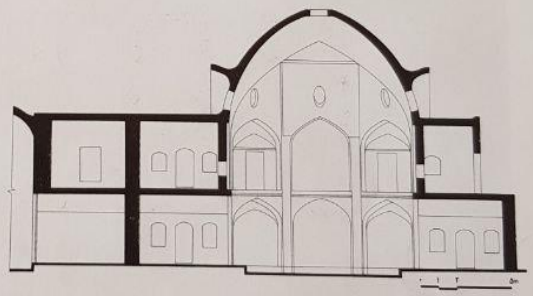
۲۶
181



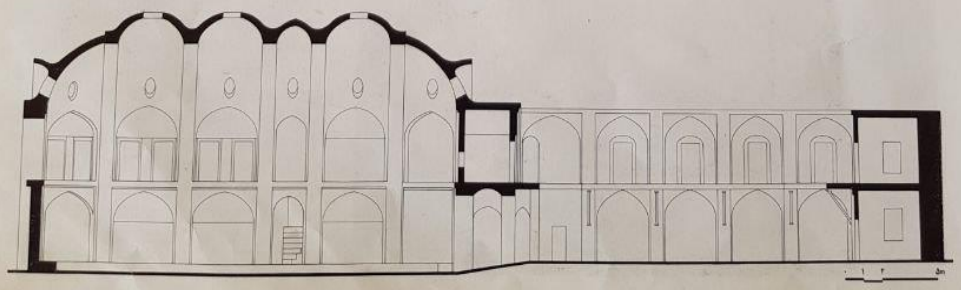
10. *Timcheh*'s entrance via the *sara*

۱۰. ورودی تیمچه از سرا

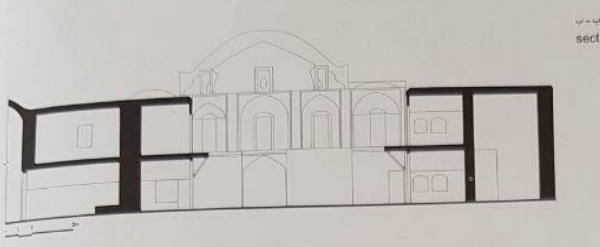
برش عمودی الف ـ الف
section A - A



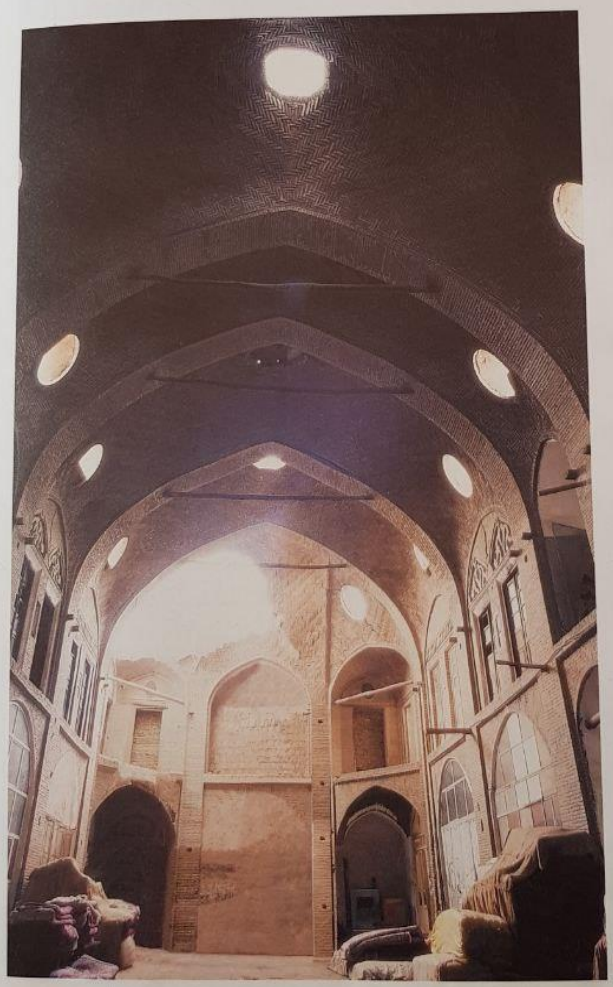
برش عمودی ج ـ ج
section C - C



۲۷
180



پرش عمودی ب ـ ب
section B - B



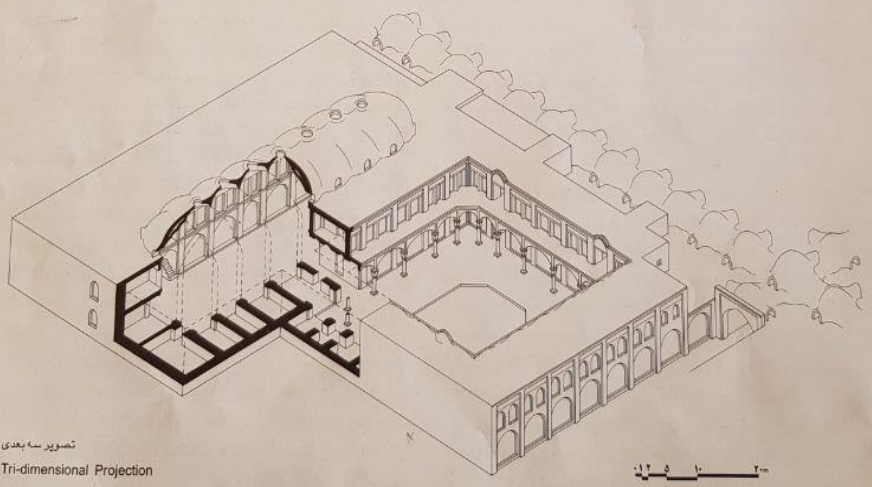
۱۱. فضای میانی تیمچه
11. *Timcheh*'s central space

۲۸
179



13. Eastern and northern sides of the *sara*

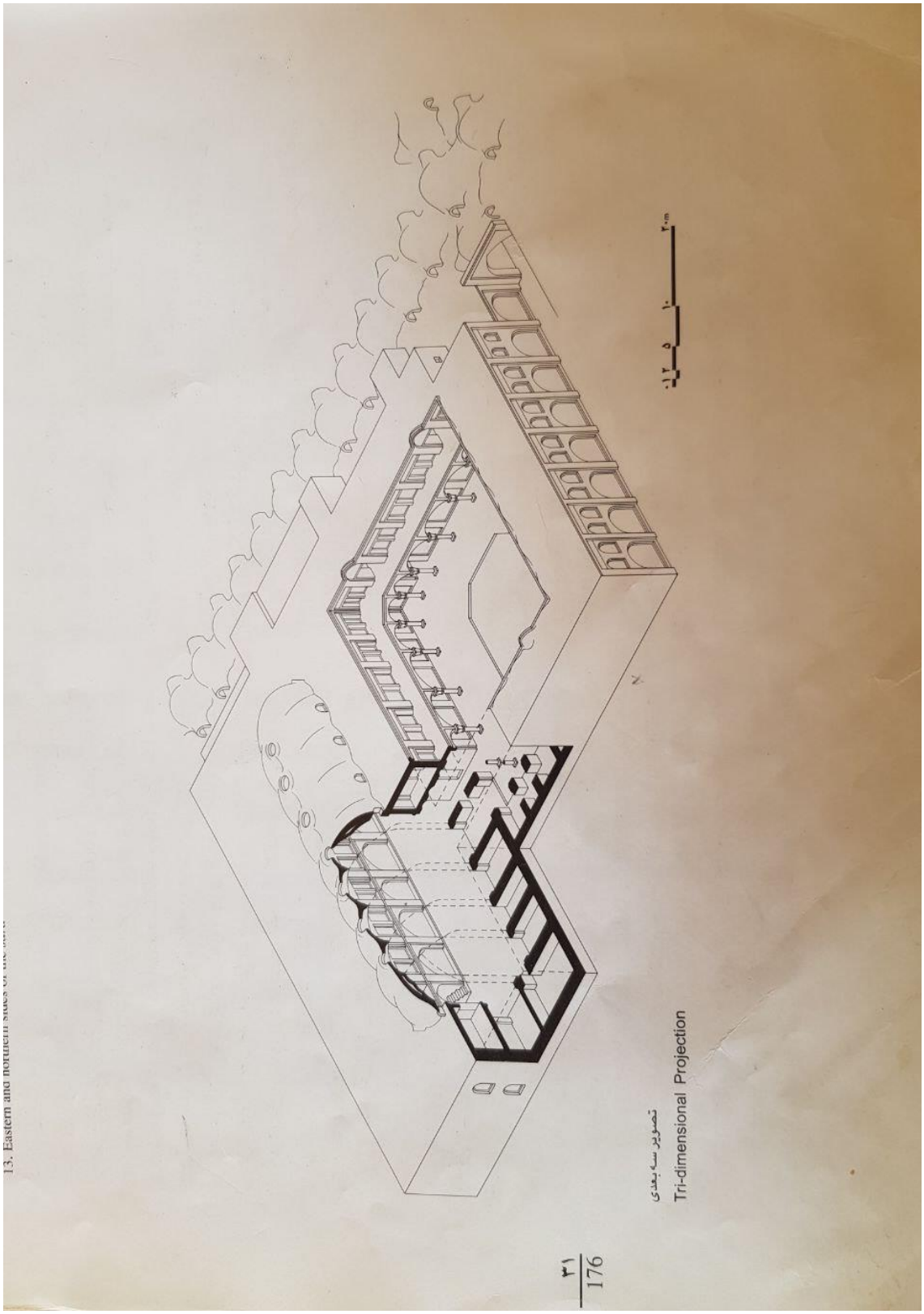
۱۳ـ جبهه‌های شرقی و شمالی سرا

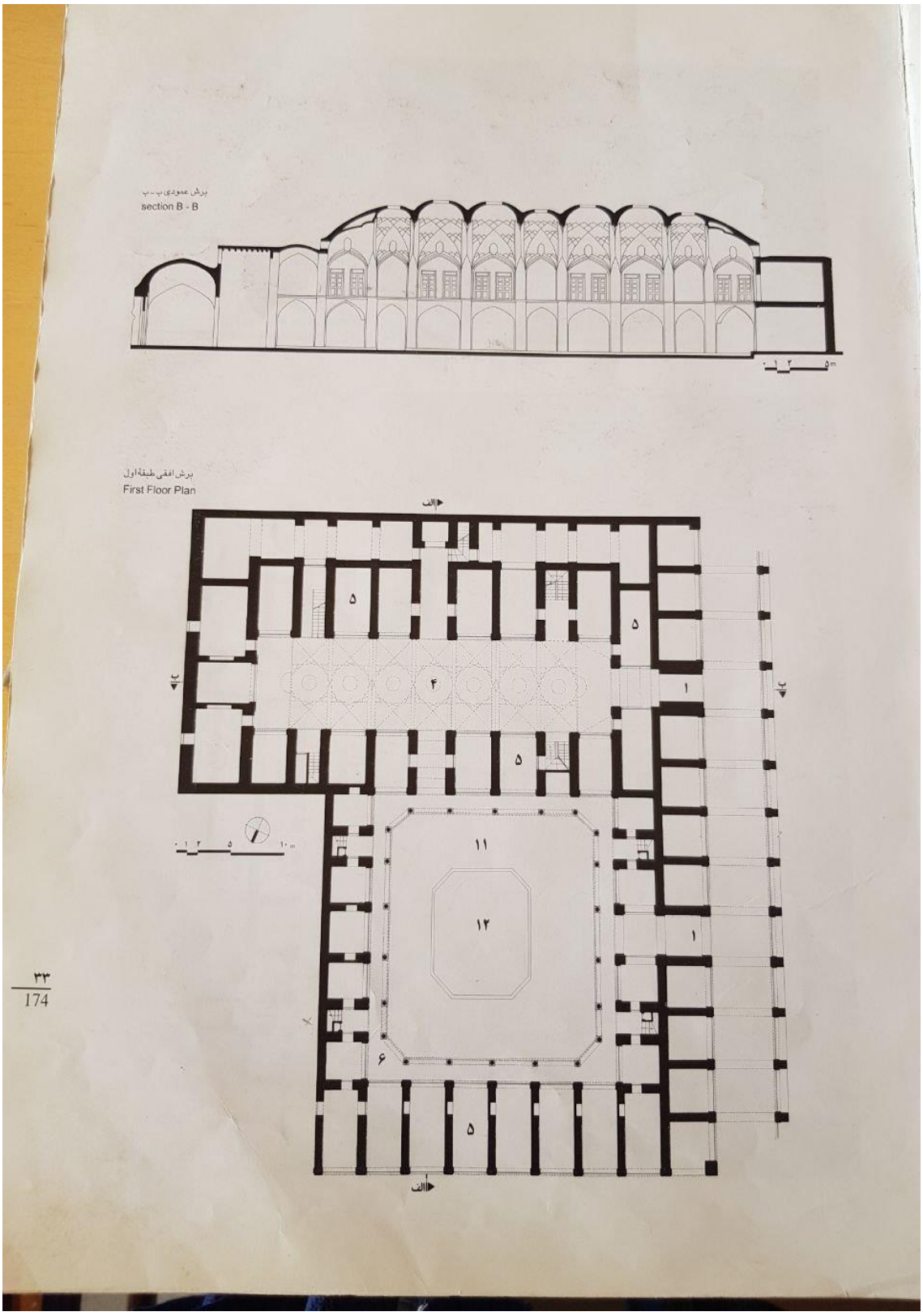


۳۱
176

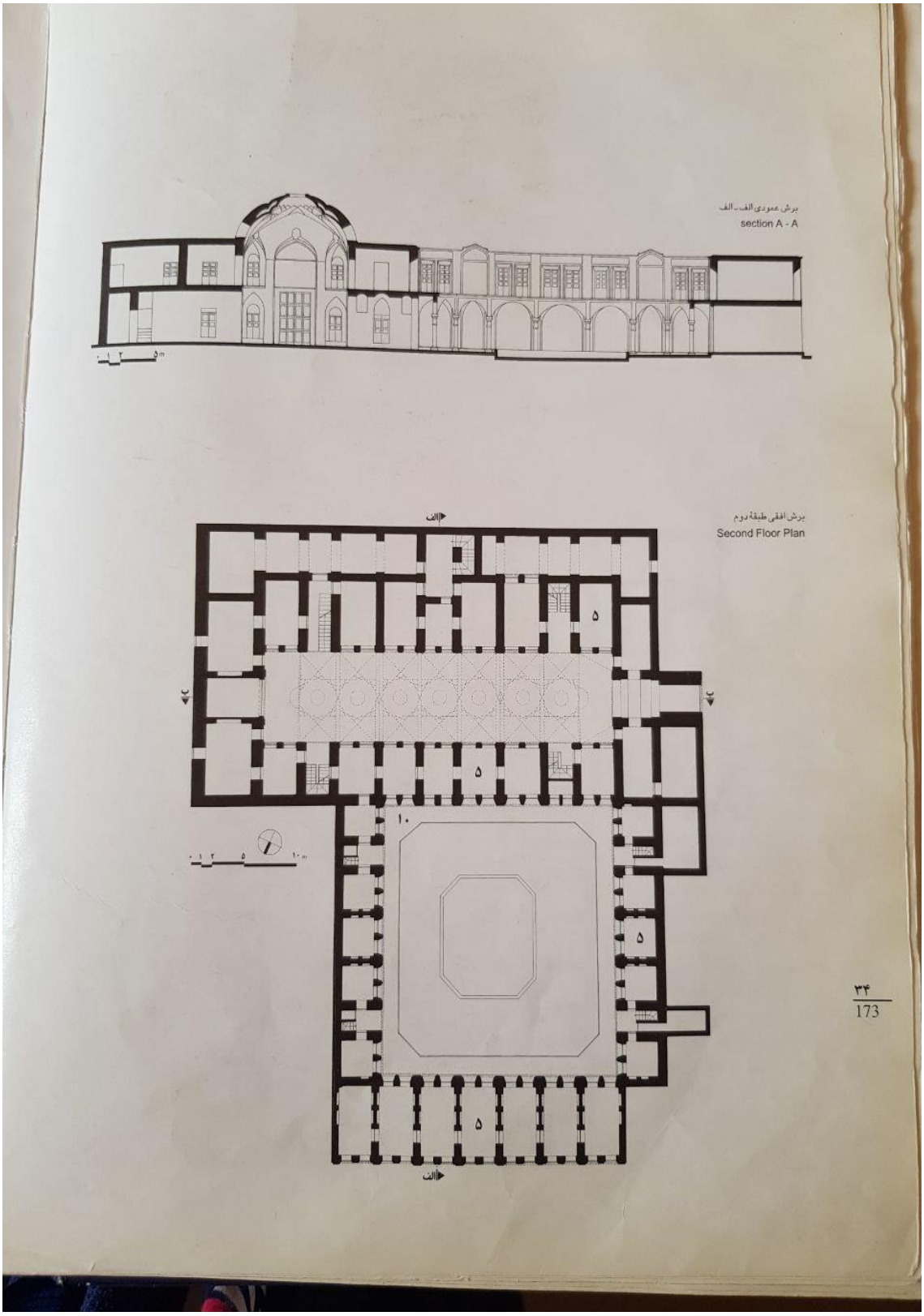
تصویر سه‌بعدی

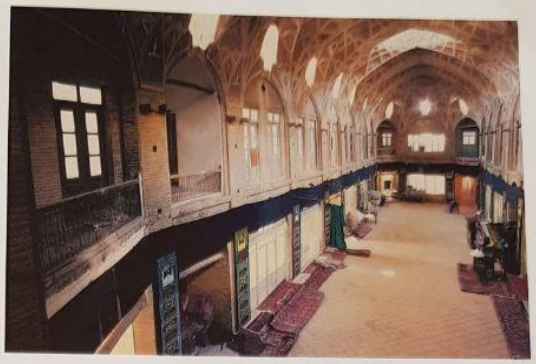
Tri-dimensional Projection


۳۱
176
تصویر سه بعدی
Tri-dimensional Projection
۰ ۵ ۱۰ ۲۰m

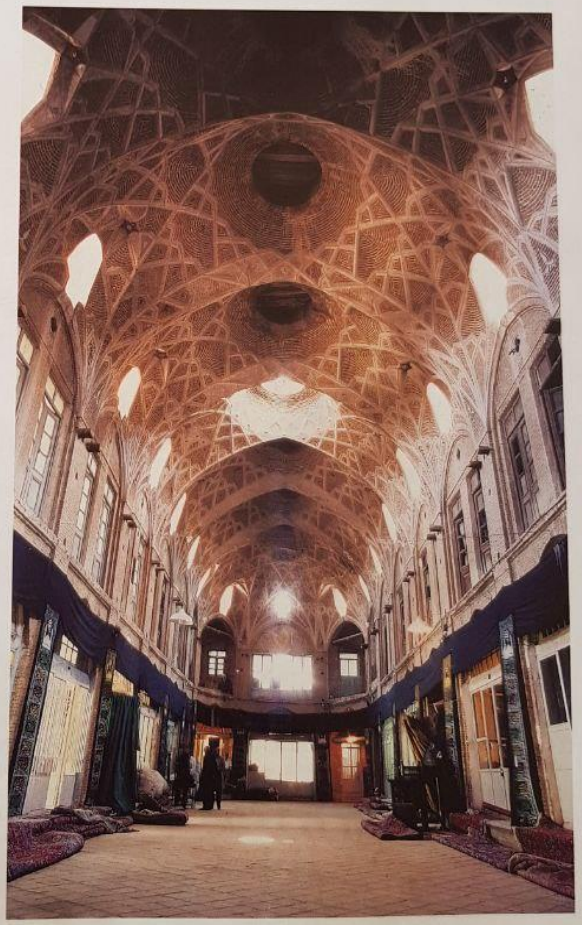

برش عمودی ب ـ ب
section B - B
برش افقی طبقهٔ اول
First Floor Plan
الف
ب
۱
۴
۵
۶
۱۱
۱۲

۳۳
174


برش عمودی الف ـ الف
section A - A
برش افقی طبقهٔ دوم
Second Floor Plan
الف
الف
۳۴
173



۱۵. فضای میانی تیمچه
15. *Timcheh*'s central space



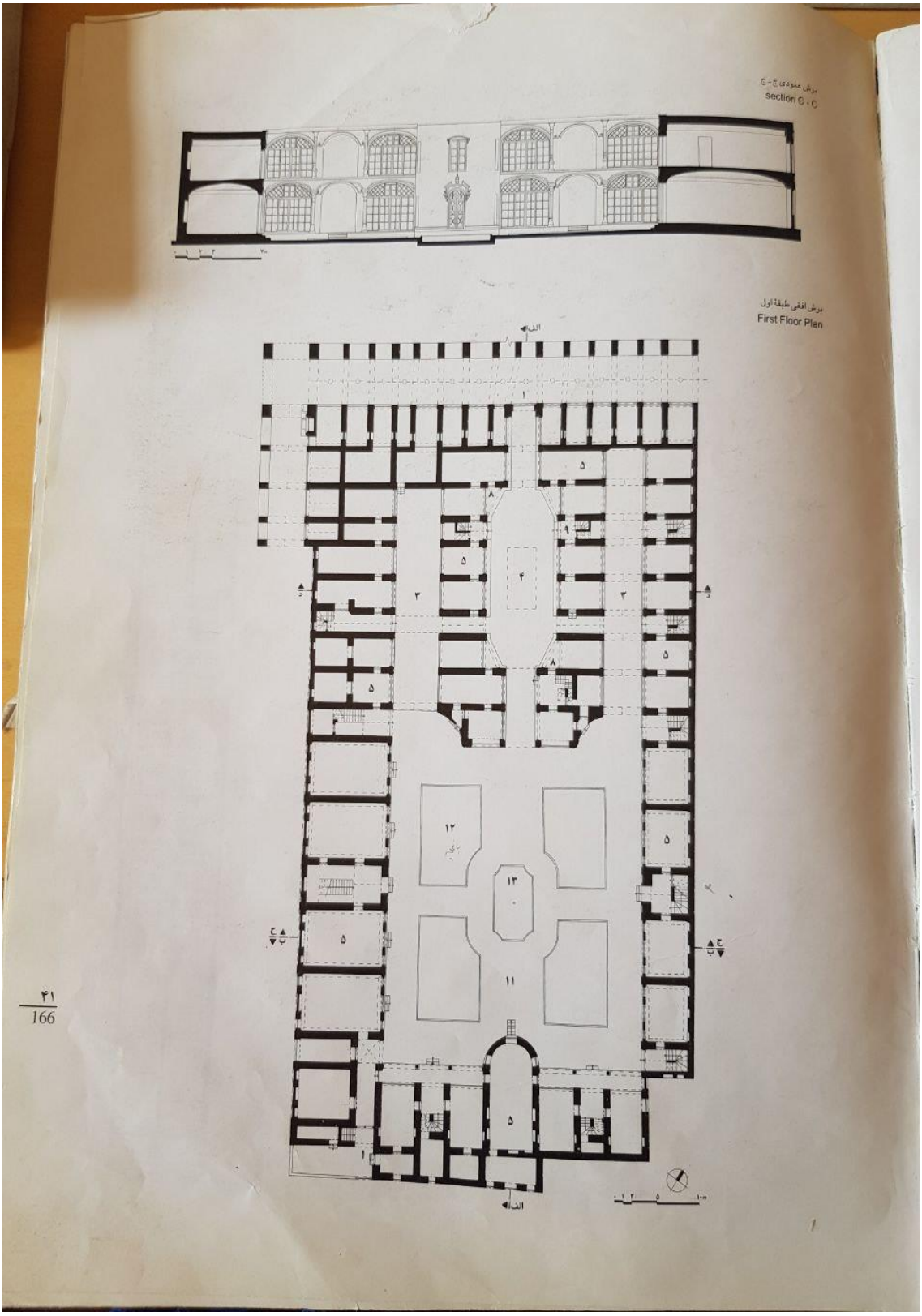
۱۶. فضای میانی تیمچه
16. *Timcheh*'s central space

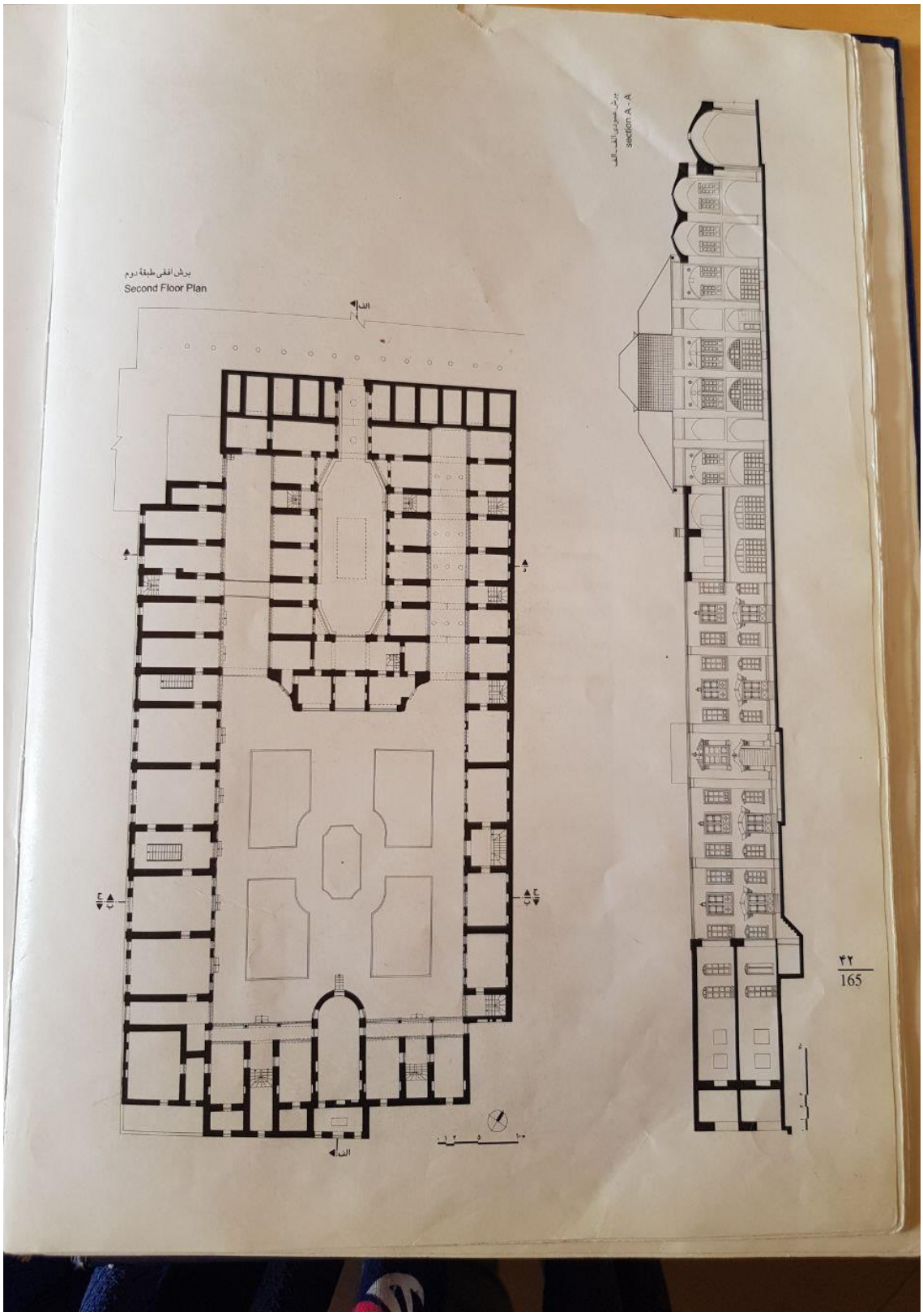
۱۷. قسمتی از سقف فضای میانی تیمچه

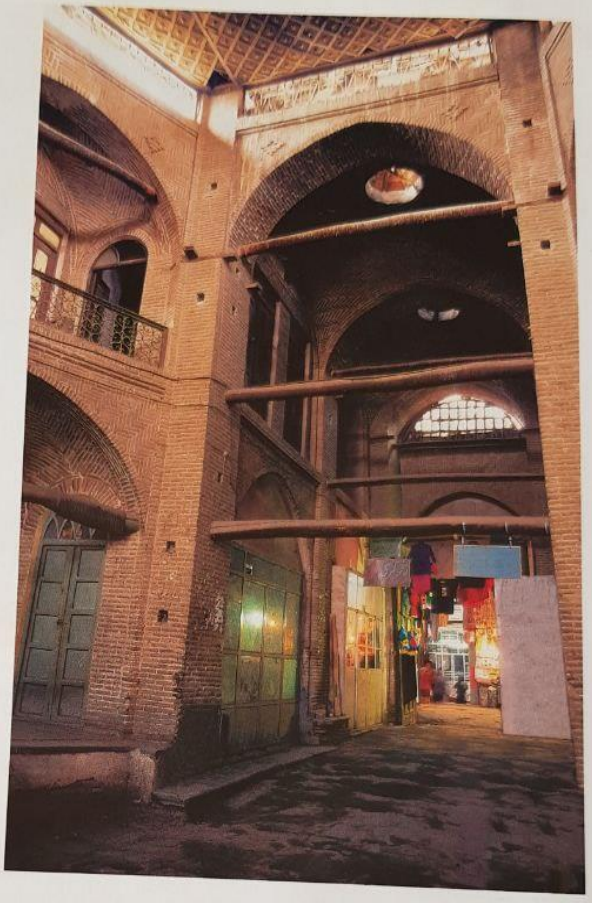
17. Part of the *timcheh*'s central space ceiling

as though it simply replaces the central chamber of this

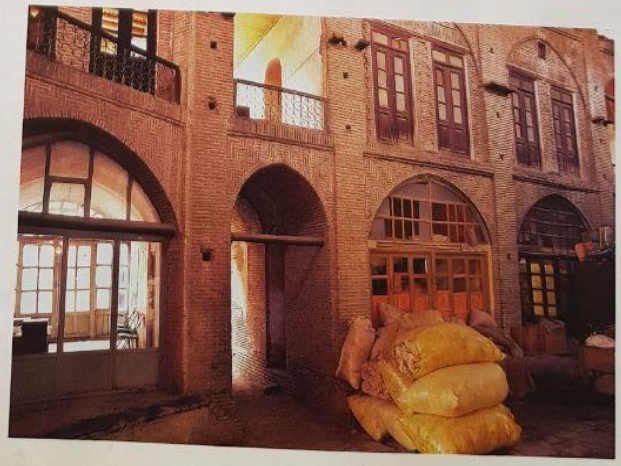
doors are also very similar to those of the windows of the upper floor of the *timcheh*. The arches above them are


برش عمودی C - C
section C - C
برش افقی طبقهٔ اول
First Floor Plan
۴۱
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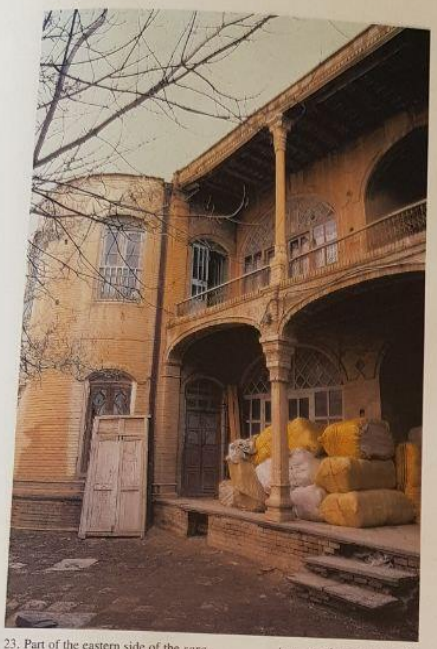

برش افقی طبقة دوم
Second Floor Plan
برش عرضي A - A
section A - A
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۲۰. ورودی تیمچه از راستهٔ بازار
20. *Timcheh*'s entrance from the bazaar's main passage

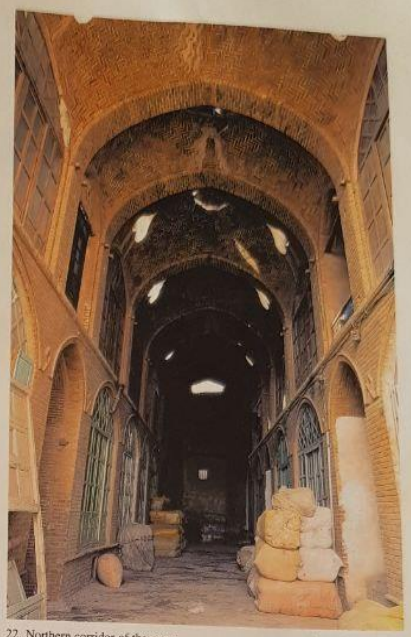


۲۱. قسمتی از بدنهٔ جنوب غربی فضای میانی تیمچه
21. Part of the southwestern facade of the *timcheh*'s central space



23. Part of the eastern side of the *sara*

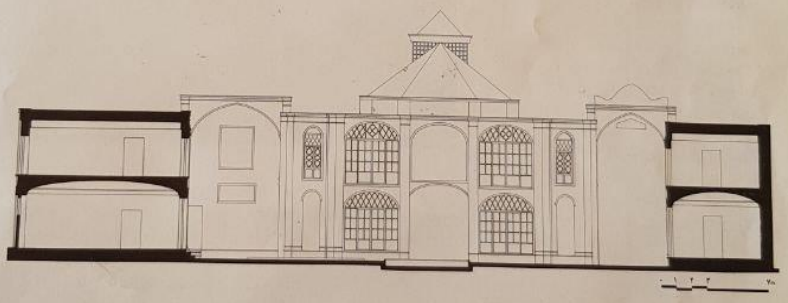
۲۳. قسمتی از جبههٔ شرقی سرا



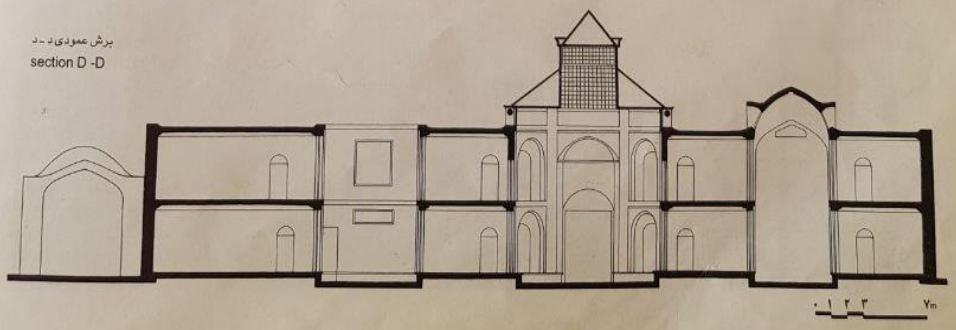
22. Northern corridor of the *sara*

۲۲. دالان شمالی سرا

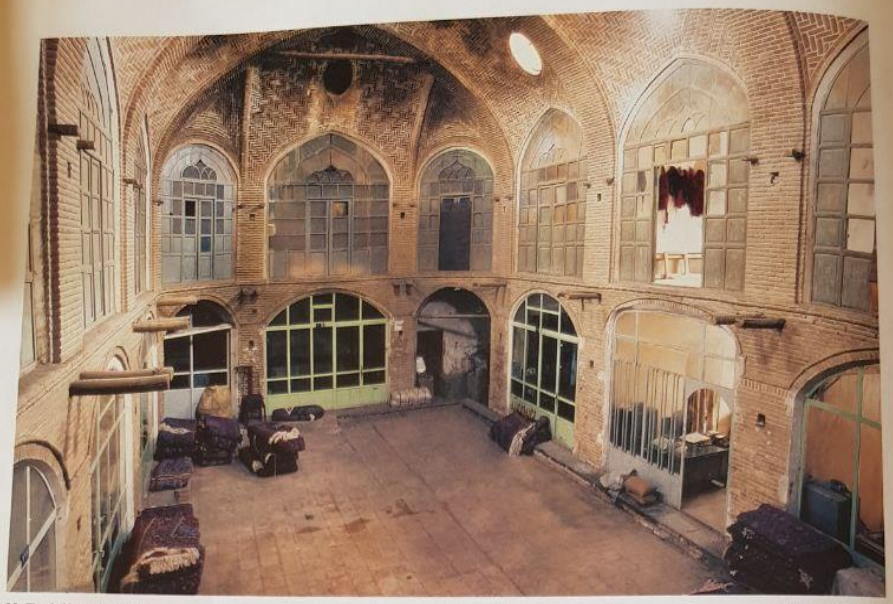
برش عمودی ب-ب
section B - B



برش عمودی د-د
section D -D



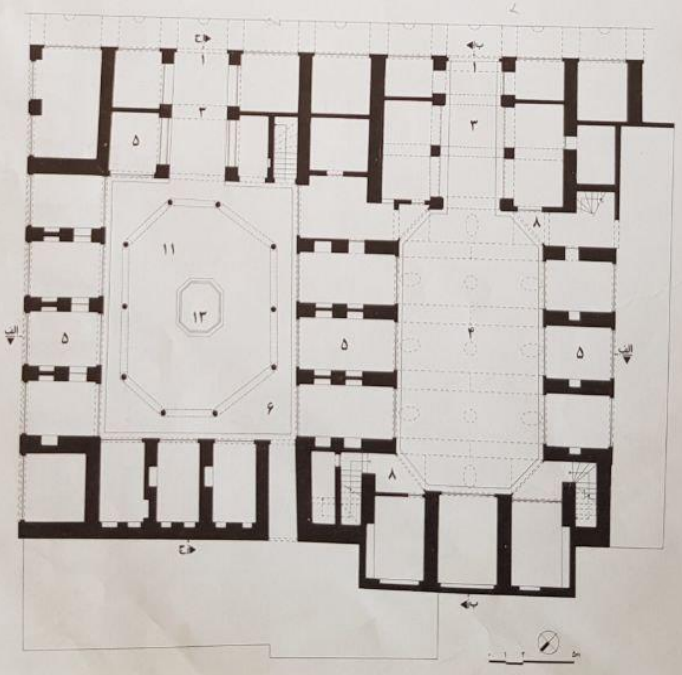
۴۴
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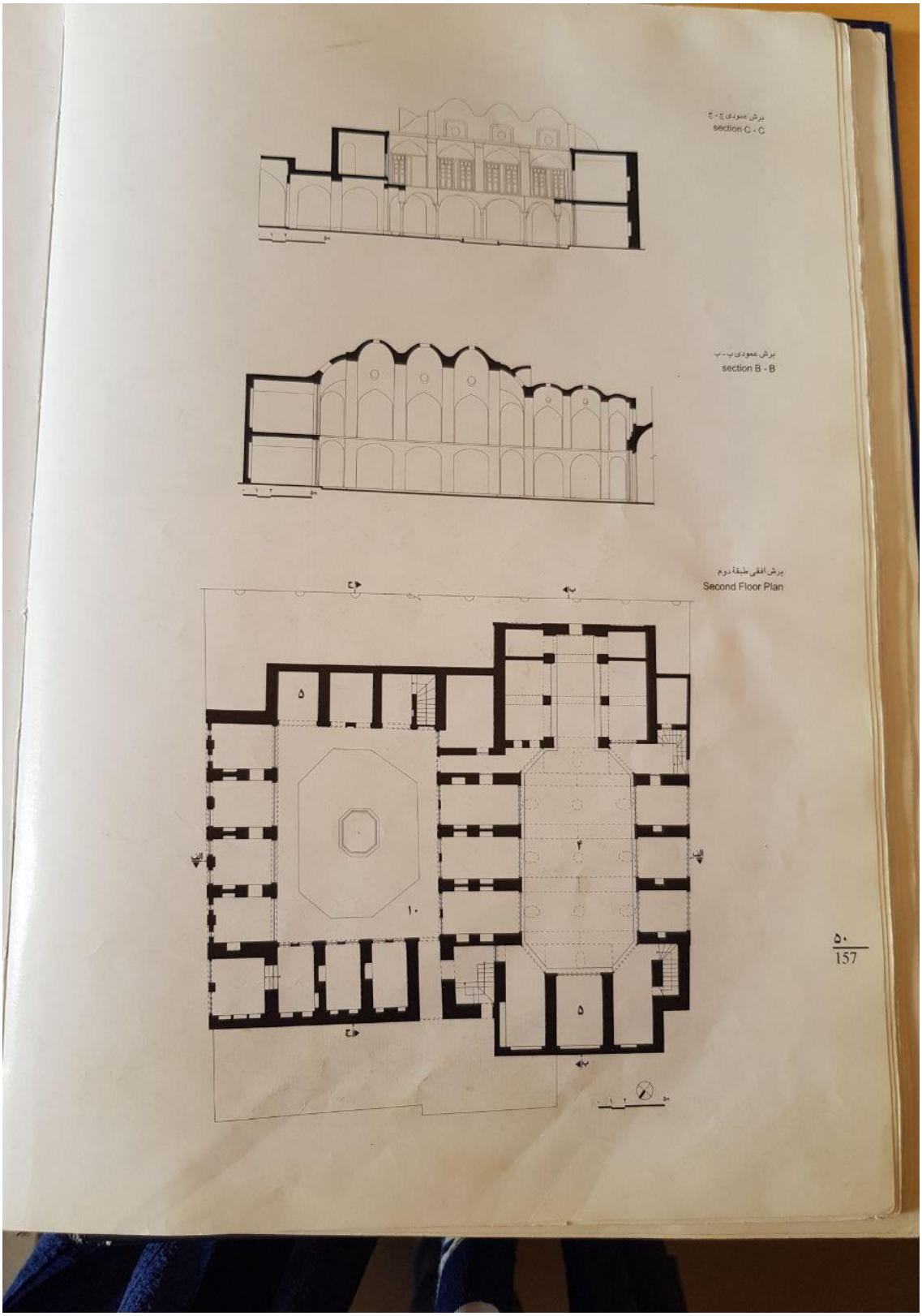
25. *Timcheh*'s central space

۲۵. فضای میانی تیمچه

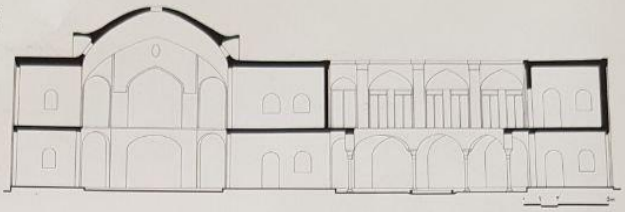
برش افقی طبقهٔ اول
First Floor Plan



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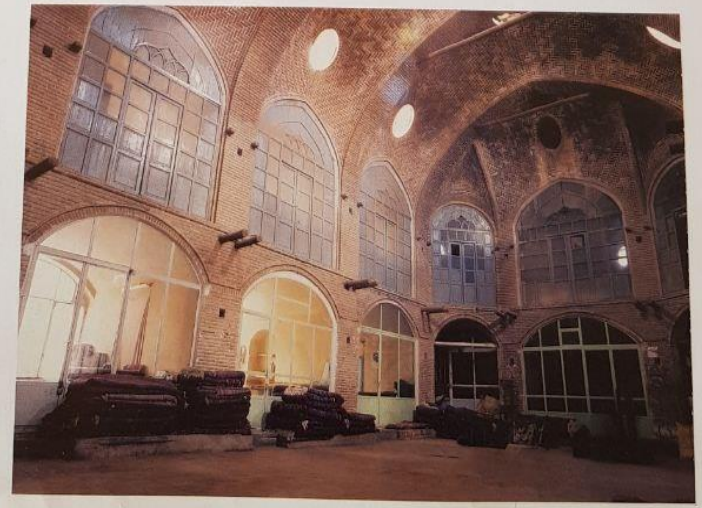

برش عمودی ج - ج
section C - C
برش عمودی ب - ب
section B - B
برش افقی طبقهٔ دوم
Second Floor Plan
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برش عمودی الف ـ الف
section A - A





۲۶. گوشه جنوبی سرا
26. Southern corner of the *sara*

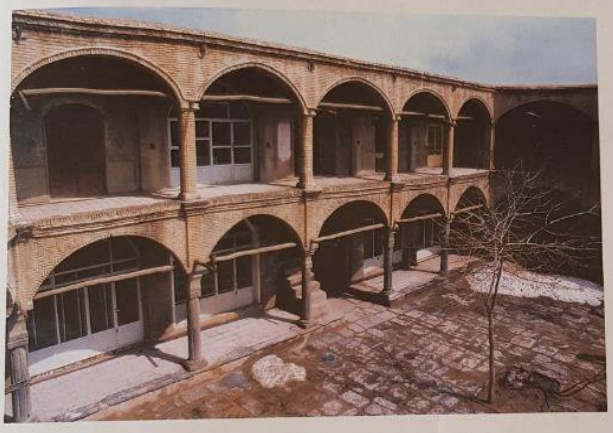


۲۷. فضای میانی تیمچه
27. *Timcheh*'s central space

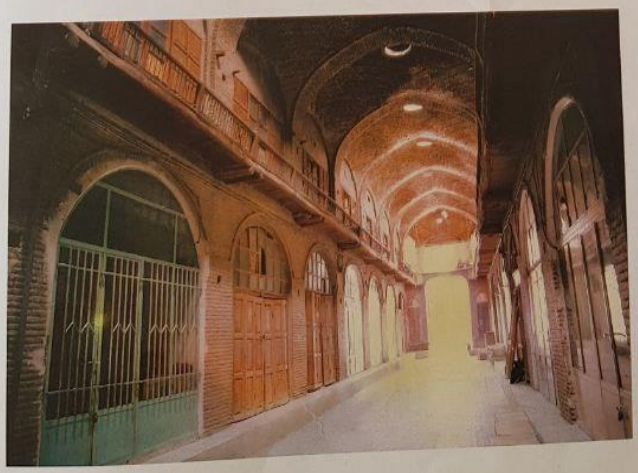
۵m
۲۸. ورودی تیمچه از راسته بازار
28. *Timcheh*'s entrance from the bazaar's main passage
تصویر سه بعدی
Tri-dimensional Projection



۳۰. منظرهٔ عمومی سرا
30. General view of the *sara*

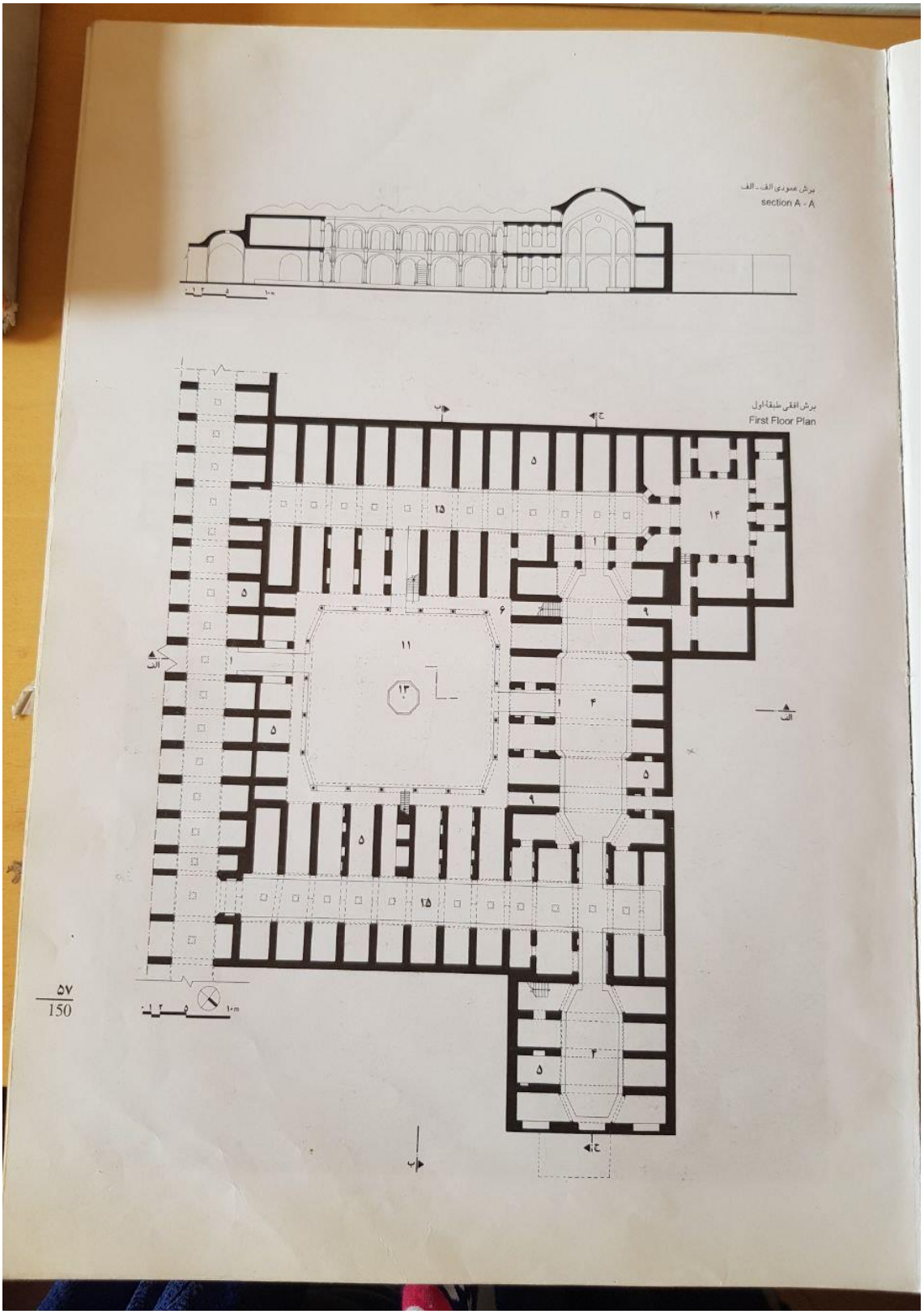


۳۱. جبههٔ شرقی سرا
31. Eastern side of the *sara*

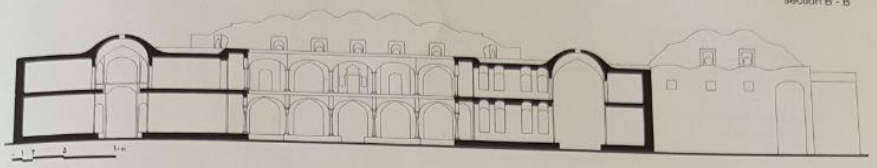


۳۲. راستهٔ بازار غربی
32. Western bazaar's main passage

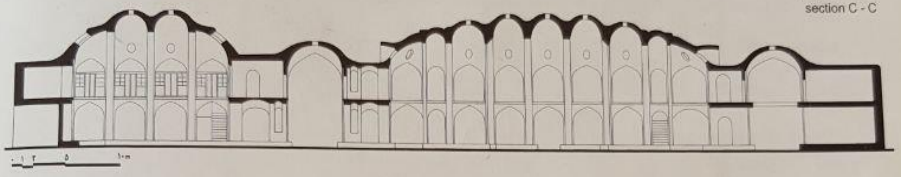
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برش عمودی الف ـ الف
section A - A
برش افقی طبقه اول
First Floor Plan
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برش عمودی ب-ب
section B - B

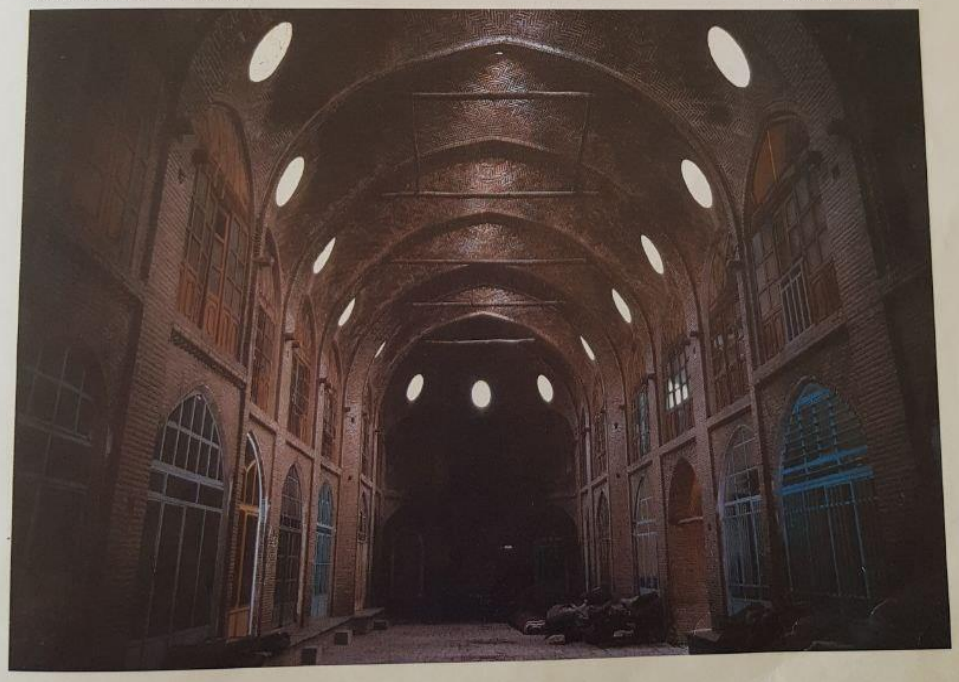


برش عمودی ج-ج
section C - C

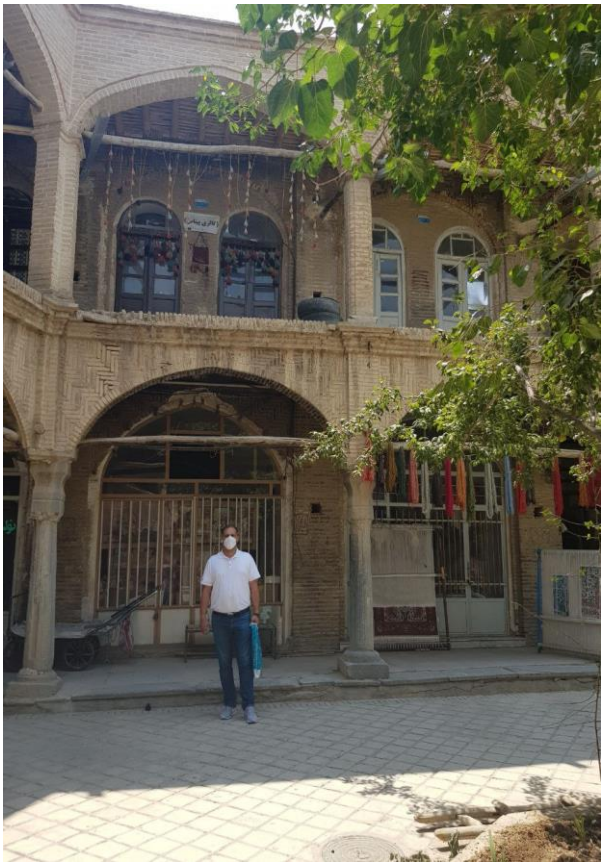


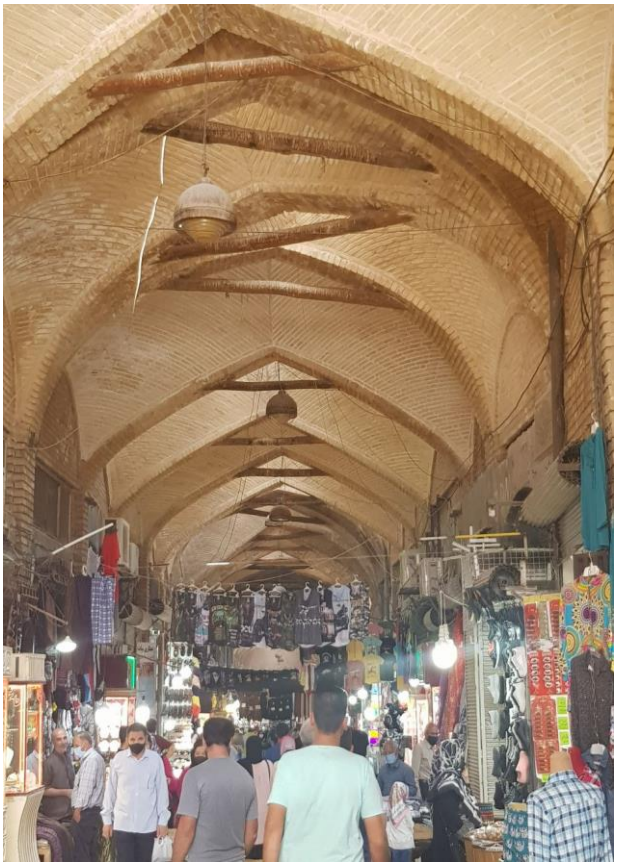
33. Central space of the southern *timcheh*

۳۳. فضای میانی تیمچهٔ جنوبی



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عطاری

Parts of Characters and Dimensions incorporated into the Nowzari Caravanserai Simulation

Excel file of all simulated data is available. Will be available by email if needed.

Keyword	Key	U-Value (incl bridging) (W/m2K)	Km (KJ/K)	Cost per surface area (GBP/m2)
CONSTRUCTION	Project pitched roof	0.16	6.412	105
CONSTRUCTION	Project external floor	0.246	6.294	80
CONSTRUCTION	Project internal floor	2.929	88.2	210
CONSTRUCTION	Project external door	2.823	29.278	40
CONSTRUCTION	Project internal mass	3.017	88.2	210
CONSTRUCTION	Project flat roof	0.25	32.614	75
CONSTRUCTION	Project wall	0.743	100	165
CONSTRUCTION	Project partition	1.639	22.5	64
CONSTRUCTION	Project ground floor	0.25	93.96	339

Keyword	Name	Layers	UValue (W/m2K)	Trans Light (VT)	Trans Total (SHGC)	Trans Direct Solar	Cost per surface area (GBP/m2)
GLAZING	Project roof glazing	3	2.178	0.738	0.682	0.595	170
GLAZING	Project internal glazing	3	2.178	0.738	0.682	0.595	170
GLAZING	Project external glazing	2	1.96	0.744	0.691	0.624	160

Building Data	
Building number of zones:	208
Building heated/cooled floor area (m2)	1293.87
Building volume (m3)	4939.73
Building external area (m2)	3808.11
Building area-weighted average U-value (W/m2K)	0.691
Building external surface area/Volume (m-1)	0.771

Activity Area Summary	
Activity	Area (m2)
Generic Office Area	1293.87
Total	1293.87

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)	Orientation (deg E of N)	Slope (deg)
Infiltration	Outside	N/A	N/A	5.586	N/A	N/A	N/A	N/A
Ground floor	Ground	5.928	0.25	1.4816	93.96	556.9949	0	180
Ceiling	Block 3 - Zone 5	0.722	2.929	2.1146	88.2	63.6804	180	0
Ceiling	Block 3 - Zone 68	1.116	2.929	3.2686	88.2	98.4312	180	0
Ceiling	Block 3 - Zone 70	4.051	2.929	11.8649	88.2	357.2982	180	0
Ceiling	Block 3 - Zone 6	0.038	2.929	0.1113	88.2	3.3516	180	0
Partition	Block 2 - Zone 2	1.721	1.639	2.8213	22.5	38.7225	24.24	90
Partition	Block 2 - Zone 62	6.641	1.639	10.8869	22.5	149.4225	28.7	90
Partition	Block 2 - Zone 63	12.772	1.639	20.9377	22.5	287.37	295.44	90
Partition	Block 2 - Zone 7	8.423	1.639	13.8082	22.5	189.5175	204.27	90
Partition	Block 2 - Zone 6	0.601	1.639	0.9852	22.5	13.5225	159.27	90
Partition	Block 2 - Zone 6	11.836	1.639	19.4033	22.5	266.31	113.09	90

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)	Orientation (deg E of N)	Slope (deg)
Infiltration	Outside	N/A	N/A	19.747	N/A	N/A	N/A	N/A
Ground floor	Ground	19.689	0.25	4.921	93.96	1849.979	0	180
Ceiling	Block 3 - Zone 2	1.275	2.929	3.7343	88.2	112.455	180	0
Partition	Block 2 - Zone 56	8.075	1.639	13.2377	22.5	181.6875	113.7	90
Partition	Block 2 - Zone 57	8.075	1.639	13.2377	22.5	181.6875	113.7	90
Partition	Block 2 - Zone 58	1.488	1.639	2.4393	22.5	33.48	113.7	90
Partition	Block 2 - Zone 58	5.403	1.639	8.8574	22.5	121.5675	79.4	90
Partition	Block 2 - Zone 58	2.203	1.639	3.6115	22.5	49.5675	23.85	90
Partition	Block 2 - Zone 59	6.085	1.639	9.9754	22.5	136.9125	23.85	90
Partition	Block 2 - Zone 59	5.425	1.639	8.8934	22.5	122.0625	328.78	90
Partition	Block 2 - Zone 60	8.033	1.639	13.1689	22.5	180.7425	294.11	90
Partition	Block 2 - Zone 61	8.033	1.639	13.1689	22.5	180.7425	294.11	90
Partition	Block 2 - Zone 62	1.445	1.639	2.3689	22.5	32.5125	294.11	90
Partition	Block 2 - Zone 62	5.419	1.639	8.8836	22.5	121.9275	258.55	90
Partition	Block 2 - Zone 64	1.721	1.639	2.8213	22.5	38.7225	204.24	90
Partition	Block 2 - Zone 6	4.599	1.639	7.5393	22.5	103.4775	204.24	90
Partition	Block 2 - Zone 55	1.917	1.639	3.1426	22.5	43.1325	204.24	90
Partition	Block 2 - Zone 54	5.398	1.639	8.8492	22.5	121.455	150.28	90

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)
Infiltration	Outside	N/A	N/A	5.472	N/A	N/A
Ground floor	Ground	7.089	0.25	1.7718	93.96	666.0825
Ceiling	Block 3 - Zone 78	1.456	2.929	4.2644	88.2	128.4192
Ceiling	Block 3 - Zone 77	5.479	2.929	16.0473	88.2	483.2478
Ceiling	Block 3 - Zone 76	0.154	2.929	0.451	88.2	13.5828
Wall	Outside	7.626	0.743	5.6678	100	762.6
Partition	Block 2 - Zone 57	15.263	1.639	25.0213	22.5	343.4175
Partition	Block 2 - Zone 2	8.075	1.639	13.2377	22.5	181.6875
Partition	Block 2 - Zone 54	15.294	1.639	25.0721	22.5	344.115
Glazing	Outside	1.065	1.96	2.0874	0	0

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)
Infiltration	Outside	N/A	N/A	2.66	N/A
Ground floor	Ground	3.054	0.25	0.7633	93.96
Ceiling	Block 3 - Zone 5	0.337	2.929	0.987	88.2
Ceiling	Block 3 - Zone 68	2.718	2.929	7.9607	88.2
Partition	Block 2 - Zone 2	4.599	1.639	7.5393	22.5
Partition	Block 2 - Zone 64	11.836	1.639	19.4033	22.5
Partition	Block 2 - Zone 64	0.601	1.639	0.9852	22.5
Partition	Block 2 - Zone 7	5.249	1.639	8.6049	22.5
Partition	Block 2 - Zone 55	0.608	1.639	0.9967	22.5
Partition	Block 2 - Zone 55	11.812	1.639	19.3639	22.5

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)
Infiltration	Outside	N/A	N/A	3.745	N/A	N/A
Ground floor	Ground	4.687	0.25	1.1715	93.96	440.3905
Ceiling	Block 3 - Zone 65	0.252	2.929	0.7381	88.2	22.2264
Ceiling	Block 3 - Zone 66	0.193	2.929	0.5653	88.2	17.0226
Ceiling	Block 3 - Zone 67	0.069	2.929	0.2021	88.2	6.0858
Ceiling	Block 3 - Zone 78	4.173	2.929	12.2222	88.2	368.0586
Partition	Block 2 - Zone 56	15.294	1.639	25.0721	22.5	344.115
Partition	Block 2 - Zone 2	5.398	1.639	8.8492	22.5	121.455
Partition	Block 2 - Zone 55	7.955	1.639	13.041	22.5	178.9875
Partition	Block 2 - Zone 53	10.451	1.639	17.1328	22.5	235.1475
Partition	Block 2 - Zone 52	2.15	1.639	3.5246	22.5	48.375
Wall	Outside	3.367	0.743	2.5024	100	336.7

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)
Infiltration	Outside	N/A	N/A	6.297	N/A	N/A
Ground floor	Ground	6.62	0.25	1.6546	93.96	622.0153
Ceiling	Block 3 - Zone 5	0.719	2.929	2.1059	88.2	63.4158
Ceiling	Block 3 - Zone 66	0.122	2.929	0.3573	88.2	10.7604
Ceiling	Block 3 - Zone 67	4.664	2.929	13.6603	88.2	411.3648
Ceiling	Block 3 - Zone 68	1.115	2.929	3.2657	88.2	98.343
Partition	Block 2 - Zone 2	1.917	1.639	3.1426	22.5	43.1325
Partition	Block 2 - Zone 6	11.812	1.639	19.3639	22.5	265.77
Partition	Block 2 - Zone 6	0.608	1.639	0.9967	22.5	13.68
Partition	Block 2 - Zone 7	9.495	1.639	15.5656	22.5	213.6375

Partition	Block 2 - Zone 53	11.874	1.639	19.4656	22.5	267.165
Partition	Block 2 - Zone 54	7.955	1.639	13.041	22.5	178.9875

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)
Infiltration	Outside	N/A	N/A	5.114	N/A	N/A
Ground floor	Ground	6.579	0.25	1.6443	93.96	618.1629
Ceiling	Block 3 - Zone 75	0.189	2.929	0.5536	88.2	16.6698
Ceiling	Block 3 - Zone 76	6.391	2.929	18.7184	88.2	563.6862
Wall	Outside	7.513	0.743	5.5838	100	751.3
Partition	Block 2 - Zone 58	15.238	1.639	24.9803	22.5	342.855
Partition	Block 2 - Zone 2	8.075	1.639	13.2377	22.5	181.6875
Partition	Block 2 - Zone 56	15.263	1.639	25.0213	22.5	343.4175

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)
Infiltration	Outside	N/A	N/A	3.748	N/A	N/A
Ground floor	Ground	8.057	0.25	2.0137	93.96	757.0358
Ceiling	Block 3 - Zone 74	0.624	2.929	1.8276	88.2	55.0368
Ceiling	Block 3 - Zone 75	7.433	2.929	21.7703	88.2	655.5906
Wall	Outside	6.813	0.743	5.0635	100	681.3
Wall	Outside	17.213	0.743	12.793	100	1721.3
Wall	Outside	1.509	0.743	1.1215	100	150.9
Wall	Outside	3.253	0.743	2.4177	100	325.3
Partition	Block 2 - Zone 59	3.883	1.639	6.3656	22.5	87.3675
Partition	Block 2 - Zone 2	2.203	1.639	3.6115	22.5	49.5675
Partition	Block 2 - Zone 2	5.403	1.639	8.8574	22.5	121.5675
Partition	Block 2 - Zone 2	1.488	1.639	2.4393	22.5	33.48
Partition	Block 2 - Zone 57	15.238	1.639	24.9803	22.5	342.855

Glazing	Outside	1.065	1.96	2.0874	0	0

Element	Adjacent condition	Area-Nett (m2)	U-Value (W/K-m2)	U-Value*Area (W/K)	Km (KJ/m2-K)	Km*Area (KJ/K)
Infiltration	Outside	N/A	N/A	2.245	N/A	N/A
Ground floor	Ground	6.692	0.25	1.6726	93.96	628.7803
Roof	Outside	0.659	0.25	0.1648	32.614	21.4929
Ceiling	Block 3 - Zone 74	1.466	2.929	4.2937	88.2	129.3012
Ceiling	Block 3 - Zone 73	4.567	2.929	13.3761	88.2	402.8094
Partition	Block 2 - Zone 58	3.883	1.639	6.3656	22.5	87.3675
Wall	Outside	6.695	0.743	4.9758	100	669.5001
Wall	Outside	1.536	0.743	1.1416	100	153.6
Wall	Outside	13.609	0.743	10.1145	100	1360.9
Wall	Outside	6.877	0.743	5.1111	100	687.7
Partition	Block 2 - Zone 60	11.629	1.639	19.0639	22.5	261.6525
Partition	Block 2 - Zone 2	5.425	1.639	8.8934	22.5	122.0625
Partition	Block 2 - Zone 2	6.085	1.639	9.9754	22.5	136.9125
Partition	Block 2 - Zone 59	7.709	3.017	23.2599	88.2	679.9338

Main Dimensions and sizes of Nowzari Caravanserai (recorded in AutoCAD file)

Every dimension and measurement is documented in the images that follow; however, their visibility is compromised by the low clarity of the images. This image is generated as a result of AutoCAD.

For further review or future research, the AutoCAD file of every component of the Arak Bazaar, but notably the Nowzari Caravanserai, is available and will be sent to you via email if required.

