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# Assessment of Thermal Comfort in Vernacular Buildings in the Cold and Mountainous Region (Case Study: Hamadan, Iran)

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**ABSTRACT:** The vernacular architecture of cities with old civilizations like Hamadan, located in a cold and mountainous area, stems from centuries of optimizing material use, construction techniques, climate considerations, and the least use of fossil fuels to provide residents comfort. This region represents a specific type of dwelling that is a spectacular example of its climate conditions and compatible with its surrounding environment. This study aims to investigate the geometric conformation of Hamedan houses and elicit the proper suggestions to provide comfort conditions. To reach these goals, 15 houses located in the old districts of Hamadan belonging to three different historical eras were selected. Then, according to Mahoney's Table, Evan's index, Pen warden graph, and climate consultant software thermal comfort factors were assessed and calculated to compare elicited design strategies with typology. These attributes to architectural strategies for this region like southeastern orientation, medium-sized windows, thick outdoor and indoor walls, thick insulation with sufficient temporary heating equipment, the high heat capacity of materials, compact urban texture and planning, protection against intensive wind aimed to provide comfort conditions. Then these methods were compared whit three eras' houses to illustrate how much compatibility was there practically, which eventually reduced in each of them.

**Keywords:** *Vernacular architecture, Bioclimatic design, Typology, Cold and mountainous region, Hamadan, Thermal comfort.*

## INTRODUCTION

The indigenous architecture of each region reflects the culture, lifestyle, and image of the past and the region's identity, which is compatible with the current climate, topography, and resources. Assuming that the predecessors before the emergence of fossil energy consumption have provided indoor comfort conditions, the present study has been formed to use their construction techniques to introduce solutions to construct buildings compatible with the climate. Buildings and urban design play an essential and decisive role in thermal comfort. They also affect the shape of optimal and functional spaces in residential buildings. Traditional architectural experiences of old territories like Iran, such as Hamadan, indicate buildings' major success in adapting to local conditions, environments, optimizing construction, and energy consumption. Since all these methods were tried and tested for centuries, they can be considered the right solution in analogous cases. So, suggestions in this article can help other similar regions with similar climates. It can give various ideas about plans, a form of volume, space relationships, material usage. For example, some traditional buildings in Beijing of China, Santa Fe of New Mexico, Srinagar (Kashmir valley) of India, and many regions studying their climate situation indicate many homogeneous similarities to Hamadan's climate, urban, and structure.

Furthermore, what makes Hamadan unique from the other regions is its historical value and residents' experiences in vernacular construction that went back more than centuries. Also, its urban evaluation structure, which is circular, makes it spectacular to be a sample for this type of climate. All these can help collate information about cold and mountainous regions that can have more compatible buildings with our nature,

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leading to less devastation on the earth.

Climatic design is a way to reduce the multilateral expenditures of a building. In all climates, vernacular buildings are constructed on climate principles to minimize the mechanical heating and cooling requirements and, as a result, use the natural energy available around the building. Long-term savings will make climate design techniques the best investment for building owners. Buildings erected on climatic methods work well against adverse climate factors and provide a healthy and beautiful human ambiance. Many studies examined different perspectives and situations regarding indigenous architecture. To reach the survey's aim, this study considers previous related research about vernacular building, bioclimatic design, and thermal comfort.

Many studies examined different perspectives and situations in table 1. It can conclude that vernacular architecture studies reached appropriate construction techniques that respond to climate factors like rain, wind, humidity, and sunlight, eliciting design strategies related to walls, roofs, interior, and exterior buildings. Studies on building typology analyzed vernacular houses according to their materials, way of construction, and attention to their historical eras to use those strategies in today's buildings. Moreover, bioclimatic design research claimed that climate-responsive solutions could lead to energy consumption and sustainability in contemporary dwellings. Sustainable architecture surveys helped find proper design strategies from historical places to make buildings more efficient and functional to surmount today's dilemmas.

Furthermore, several recent studies have been carried out on climate-oriented building design to assess thermal comfort conditions in living spaces and present a presumable solution to reduce embodied and operational energy consumption. Most of them evaluate thermal comfort in vernacular buildings to improve indoor and outdoor comfort as much as possible. Overall, their goals and strategies can help identical climate-building improvements and contribute to a better understanding of the people's comfort and the progression of rural living conditions. Regarding studies on similar articles, Hamadan, with its multi-millennial indigenous architecture, dwellings, and textures, can be an appropriate area to assess traditional buildings' typology in cold and mountainous climates.

**Bioclimatic Concept**

Climate design is a method used for minimizing the costs of energy consumption in a building. Design is the first "defense line" against climate factors outside the structure. Similar ideas and strategies can be efficacy in cities with the same climate and formation. Many cities with similar climates, form evaluations, and similar surroundings generate analogous building acquisitions. For example, some traditional buildings are there in Beijing of China, which are known as cave-dwelling. They also used their vernacular materials and made their houses as possible to be compatible with their cold climate (Sun, 2013). It has a similar condition to Hamadan, so it can be seen that their strategies are almost identical. In all types of weather, buildings constructed based on climate design principles minimize the cooling and heating requirements by properly using natural energy surrounding the structure (Watson et al., 1993). The ultimate goal of climate design is to satisfy residents and to meet their needs such as heat, light, and acoustics. In this case, these items are selected based on the local materials and techniques implemented later on while erecting the buildings.

Table 1: Previous related research from various surveys

| Crucial achievement | Synopsis | Indexes |
|---|---|---|
| Vernacular Architecture | Ecological design clues in local examples are explored by drawing attention to natural materials, traditional construction techniques, ingenious design, and spatial organization .strategies | (Kırbaş & Hızlı, 2016) |
| | The effects of climatic factors, such as rain, wind, humidity, and sunlight, on vernacular .houses are explained as plan, external walls, roof, and exterior of buildings | (Engin et al., 2007) |
| | Explore the five different climatic regions in China; analysis of each region covers the climate and its vernacular architecture. Finally, analysis data from Meteonorm V6.1. | (Sun, 2013) |
| | It intends to create a knowledge base of vernacular building traditions that will include information about the energy performance of traditional building techniques and address .areas of cost, material availability, and cultural traditions | (Zhai & Previtali, 2010) |
| | Review examples of vernacular architecture and its building elements in Nepal and analyze .qualitatively how bioclimatic design strategies were applied | (Bodach et al., 2014) |
| | The findings reveal that vernacular architecture incorporates bioclimatic strategies to meet .under heating and overheating needs differently | (Desogus et al., 2016) |
| | It shows that vernacular architecture successfully addresses specific adaptation challenges imposed by local conditions. Moreover, it indicates that vernacular architecture presents .itself as a model for a sustainable design approach | (Philokyprou et al., 2021) |
| | It revealed that the efficacy of traditional passive design techniques would not be sufficient to achieve thermal comfort in the predicted future climate scenario. So, the passive design .techniques of Myanmar vernacular housing need to be improved | (Zune et al., 2020) |

Continiue of Table 1: Previous related research from various surveys

| | | |
|---|---|---|
| Building Typology | Analysis of a vernacular housing according to, taking into account the complexity of the historical area, selecting the representative building typologies; and, defining information .sheets | (Pozas & González, 2018) |
| | It provides efficient methodological support for the classification and retrofit of many .existing buildings in the hot summer and cold winter zone in China | (Gui et al., 2018) |
| | It shows that the island's vernacular architecture has focused on developing an orientation .between the climate of the region and a good understanding of the construction | (Mazraeh & Pazhouhanfar, 2018) |
| | It provides an excellent argument to realize the benefits of vernacular buildings by reducing .the dependency on powered cooling | (Homod et al., 2021) |
| Bioclimatic Design | Bioclimatic strategies in a particular location must be re-evaluated to design new and retrofit existing energy-efficient contemporary buildings with comfortable indoor thermal .conditions | (Pajek & Košir, 2018) |
| | climate action is mainstreamed in development planning and especially in the economically and socially vulnerable sectors of the economy | (Agency, 2016) |
| | It showed that residents in the Turpan basin exhibited better adaptability to the hot climate than the cold climate | (Yang et al., 2020) |
| | It shows that the integrated climate-responsive solutions used in these dwellings have well-responded to the local climate characteristics in this city and have contributed to the forma-.tion of climate-responsive buildings in the severe climate conditions of this region | (Mohammadi et al., 2018) |
| | It investigates climatic solutions and their advantages as an idea to develop and use in con-.temporary architecture to reach sustainability | (Motealleh et al., 2018) |
| | Certain bioclimatic design strategies that have been adopted in specific cities and countries .could be exported to other zones with similar climates | (Daemei et al., 2019) |
| Sustainable Architecture | The architectural values of the historical center of Oporto are analyzed regarding the inter-.actions of both its main generative topics and inherent sustainable values | (Alves, 2017) |
| | Attempt to bring awareness to some common practical issues and provide simple solutions .to make the buildings more efficient, functional, and comfortable | (Zebari & Ibrahim, 2016) |
| | It focuses on Portugal's sustainable building and urban design to evolution, the most .striking aspects, present needs, and future trends | (Guedes et al., 2009) |
| Thermal Comfort | It shows that YaoDong had excellent characteristics regarding the thermal environment in .the summer | (Zhou et al., 2018) |
| | The space heating, cooling, mechanical ventilation loads, and total annual energy consump-.tion are reduced due to passive solar design features in the building | (Chandel & Sarkar, 2015) |
| | The study is relevant for utilizing vernacular materials and architectural features to improve .thermal comfort in modern buildings worldwide | (Chandel et al., 2016) |
| | It constrains the concrete skeletal structure system and tests the efficiency of using different outer-wall construction materials to achieve thermal comfort in three different climatic .zones | (Felix & Elsamahy, 2017) |
| | Thermal comfort of eight vernacular buildings that use modern construction materials to improve structural durability. Buildings were comfortable most of the time, with a slight .discomfort during late night and morning hours | (Samuel et al., 2017) |
| | It contributes to a better understanding of rural people's thermal comfort and the improve-.ment of rural living conditions | (Zhang et al., 2018) |
| | The study provided positive results confirming that responsive climate strategies employed in underground cave dwellings were effective in providing methods and implications to .create more comfortable indoor environments for rural residences | (Zhu et al., 2020) |
| | It has been found that these vernacular dwellings perform quite satisfactorily except in .the winter months and the occupants feel comfortable in a broader range of temperature | (Singh et al., 2010) |
| | It presents quantitative data on the effectiveness of each parameter on outdoor thermal .comfort in the streets and courtyards | (Sözen & Oral, 2019) |
| | It indicates that the diverse spaces of vernacular buildings in Turpan can create different thermal environmental conditions for buildings and stimulate residents' thermal adaptation .behaviors | (Chang et al., 2021) |
| | It establishes the baselines for a sustainable, bioclimatic, affordable housing model for .western sub-Saharan Africa | (Widera, 2021) |
| | It shows that Myanmar's vernacular buildings with multistage roofs offer an opportunity to improve indoor comfort in tropical climates. Therefore its ability to moderate indoor tem-.peratures through simple building physics and geometry should be honored | (Zune et al., 2020) |

Moreover, climate design depends heavily on a building's position to receive light, natural heat, and adequate airflow during other months of the year. Based on what was mentioned above, the local architecture of Hamedan is considered a fruit of proper knowledge about the climate because the houses were built based on a solid understanding of the local climate alongside genius choices, which resulted in the interrelation of site, climate, and building.

## MATERIALS AND METHODS

Traditional dwellings are reliable sources for examining indigenous design in different areas. It requires the exploration of buildings from different historical eras. Due to the extended mass of houses, the variety of relevant samples, the degradation of remaining over time, and individual studies' difficulty, their analysis is complex. Hamedan was selected as one of the oldest historic cities with a cold and mountainous climate. To study the environment of the vernacular houses of Hamedan, among the 20 indigenous houses that existed in Hamedan, 15 were selected that have the ability of library and field studies. Also, represent and demonstrate all types of houses in different periods. According to the classification of vernacular houses (Zarei et al., 2018), they were divided into Qajar-Qajar / Pahlavi and Pahlavi categories based on the time of construction. Each class includes five houses.

Then (shape of plan, orientation, area of the different part of the plan and ratio of them, openings, their scale, thickness of walls and floors, height of floor to ceiling) in all 15 houses were examined. The Mahoney table was then used for initial design suggestions. Since this Table has limitations, the Evans index was used to consider the impact of airflow, clothing, and human activity. Due to the importance of the effects of building walls in determining comfort conditions and human climatic needs, the bio-climatic criterion of the Givoni building was studied. Also, the Penn Warden diagram was evaluated under sunlight and shade due to the importance of outdoor comfort. Finally, the findings of the characteristics were compared with each other and with the characteristics of the vernacular houses of Hamedan. The present study is descriptive-analytical and is a cluster sampling method.

### Location and History

Hamedan falls at latitude lines of 45-34 N, 50 to 34 minutes, and longitude lines of 24-48 E, 33 to 48 minutes, and is 1870 meters above sea level. For years, it had connecting roads from western to central Iran (Zarei, 2011). The area is mountainous in most parts and contains minor central mountains from the Zagros mountain range. With a height of 3574 meters above sea level, Alvand is a mountain facing the city from the eastern branches of central Zagros and extends from west to south (Azkai, 2001, 1). Only villages and small towns can flourish in a mountain outskirt due to the steep slope and rough surface (Ghobadian, 2011, 98). Being 1747 meters above sea level, Hamedan has always had the chance to develop on a vast plain in the outskirts of a great mountain. Hamedan province is home to more than 1752 cultural and historical monuments and natural resorts, giving the city prominence among neighboring provinces. More than 1004 items are registered in the national heritage list and have given the city the exact name of "cradle of civilization." (Jahanpour, 2008, 13).

It is supposed that Diako, the Median king, established the city, and that is how the town was named: Ekbatan, Higmatana, Anadana, or Hamadana. Nebuchadnezzar destroyed the city, and it was not rebuilt until the time of Darius the Great. Excavations and studies around Gian hill revealed that the residents had a relatively advanced culture, and the civilization goes back to approximately 6000 years ago. Moreover, diggings in Goodin and Sagavi hills in Kangavar and Nooshijan around Malayer have provided considerable evidence about the primary scripture and fundamental forms of the coin and early manifestations of Iranian religion and architecture. About 2500 years ago, when the Achaemenids dynasty reigned over half of the ancient world, Higmatana (Hamedan) glowed like a pearl as one of the empire's two capitals. The Assyrian King, Tiglath Pilesere I, mentioned Amadana or Hamadana's first time in his inscription. However, the city was constantly referred to as Hegmatan in the Achaemenid inscription and Ekbatan by the Greek Herodotus in his book. In 345 Hijra, the whole town was demolished by a massive earthquake. Historical evidence, exposed through excavations, indicates that the city was raided three times during its turbulent history, first by Alexander the Great, second by the Arabs, and finally by the Mongolians (Azkai, 2001 81).

Located both on the Silk Road and significant roads of western Iran, Hamedan has always been a center of attention from a commercial point of view during the past centuries. The city was rebuilt from 1309 to 1312 based on an arch-shaped plan designed by Carl Frisch, a German architect, and civil engineer. This is evident in the surrounding developments whose architecture is still in a 19th and 20th-century European baroque style. Six thirty-meter, regular streets branch off from the city's central square, each having an angle of 60' with the adjacent street. The city has expanded around one central square with concentric circles (Gharegozloo, 1994, 22).

### Climatic Data

Climatic conditions in the alpine and cold parts of Hamedan are as follows. It is cold in winter and moderates during summer. It has low humidity. It has a radical difference in temperature day and night. There are cold western winds in winter and long-term precipitation of snow and frosty weather. It has small and enclosed urban and rural areas. It has dense urban and rural textures with adjacent buildings. The direction of sunlight and topography are the main elements that determine urban and suburban life development. The

Table 2: Hamadan climatic data 2013-2018 (meteorological site of Iran)

| Season | | Winter | | | Spring | | | Summer | | | Autumn | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Avg. Temperature (C°) | 0.9 | 0.6 | 3.5 | 9 | 13.4 | 19.4 | 23.3 | 23.6 | 18.7 | 13.5 | 8.4 | 1.6 |
| Min Temperature (C°) | -10.5 | -8.2 | -2.1 | 2.7 | 6.4 | 9.8 | 13.9 | 12.8 | 7 | 2.5 | -2.1 | -6.6 |
| Max Temperature (C°) | 2 | 4.3 | 11.5 | 18.1 | 23.9 | 30.9 | 34.9 | 34.2 | 29.8 | 21.9 | 13.7 | 5.9 |
| Amount of Rainfall (mm) | 58 | 50 | 58 | 76 | 56 | 6 | 1 | 1 | 1 | 6 | 36 | 35 |
| Relative Humidity (%) | 76 | 73 | 64 | 56 | 50 | 36 | 31 | 31 | 34 | 48 | 61 | 73 |
| Days of Rainfall | 11.6 | 11.1 | 12.4 | 12.1 | 9.5 | 2 | 1.3 | 1.6 | 1 | 5.6 | 6.8 | 10.1 |
| Average wind speed (m/s) | 1 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| Prevailing wind direction (degrees) | 120 | 120 | 120 | 210 | 180 | 140 | 120 | 0 | 240 | 120 | 330 | 120 |

Fig. 1: Specify houses by number on the Google Earth map

main passageways and alleys are generally narrowly aligned with the contour line (Ghobadian, 2011). It is noteworthy that Hamedan is ranked as BSK (Cold, Semi-arid climate) in Koppen Climate Classification. As far as human welfare is concerned, the climate results from interconnected factors such as sunshine, temperature, humidity, wind blow, and rain precipitation (Kasmai, 2003, 3). Table 2 presents a weather report of the area.

### Typological Analysis

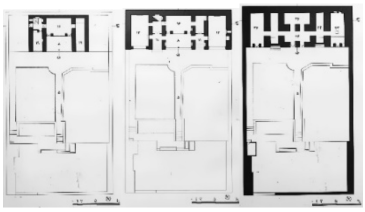
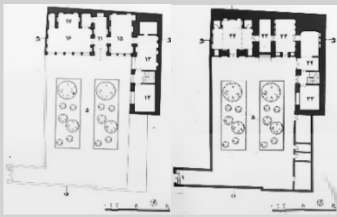
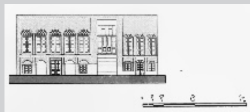
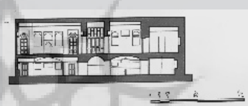
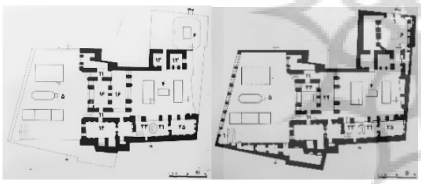
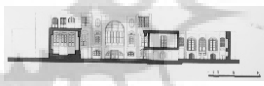
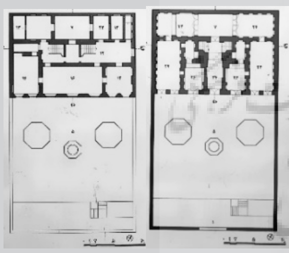
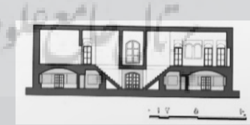
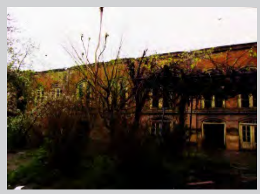
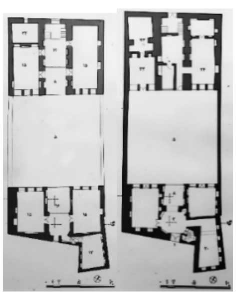
Traditional dwellings of Hamadan have been evaluated in three eras. In Fig.1, the location of the houses in Hamedan is specified. In Table 3, the plans and geometric characteristics of each house are introduced.

## Evaluation

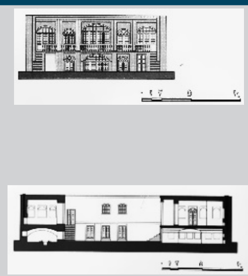
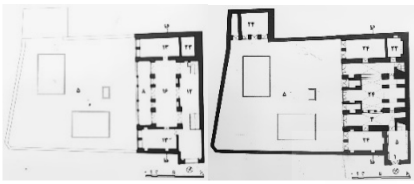
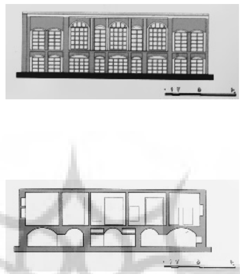
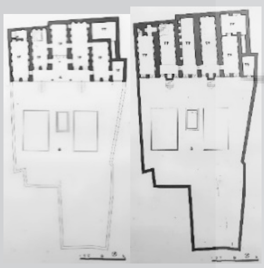
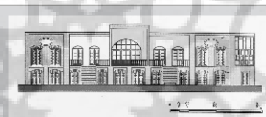
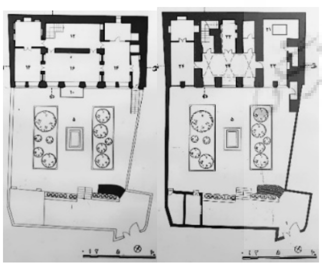
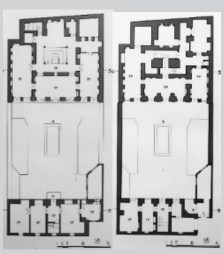
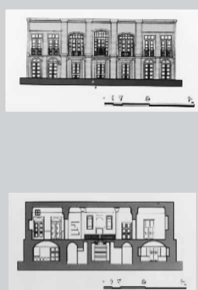
### Site Plan

Traditional Hamedan dwellings were formed to respond efficiently to sunlight, disturbing winds, and topography. Area of houses or the so-called area of the site plan varied from 334 to 1604 square meters depending on the families' living conditions. Dimensions of plans were different from this proportion, too (118 m² to 872 m²). However, what stands out is the ratio of the site plan, which changes from 18 to 62 percent. Except for three case studies, the others were under 50 percent,

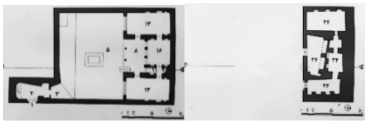
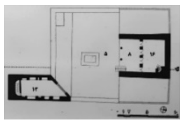
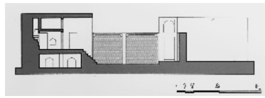
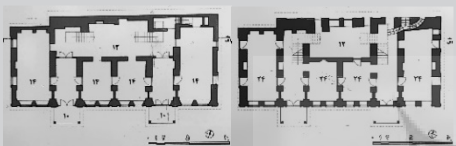
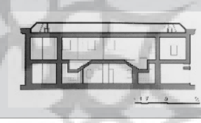
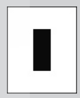
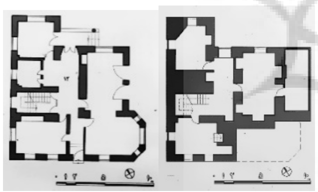
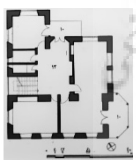
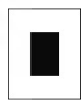
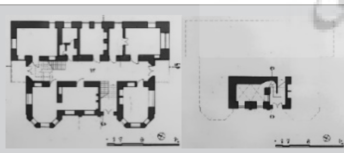
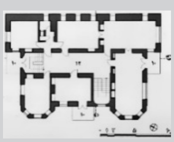
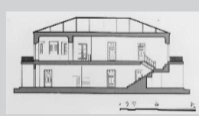
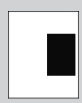
Table 3: Typology of Hamadan Houses (Source: Zarei et al., 2018)

| | Typological Analysis | | | |
|---|---|---|---|---|
| | **Plan** | **Section & Elevation** | **Building Configuration** | **Photo** |
| Ghazanfari House .1 |  |   |  |  |
| Entezaam House .2 |  |   |  |  |
| Naraghi House .3 |  |  |  |  |
| Sharafi House .4 |  |   |  |  |
| Samadian House .5 |  |   |  |  |

Continiue of Table 3: Typology of Hamadan Houses (Source: Zarei et al., 2018)

| Typological Analysis | | | | |
|---|---|---|---|---|
| | Plan | Section & Elevation | Building Configura-tion | Photo |
| Khalabani House .6 |  |  |  |  |
| Seyfi House .7 |  |  |  |  |
| Sharifi House .8 |  |  |  |  |
| Samavat House .9 |  |  |  |  |
| Zarabi House .10 |  |  |  |  |

Continiue of Table 3: Typology of Hamadan Houses (Source: Zarei et al., 2018)

| | Typological Analysis | | | |
|---|---|---|---|---|
| | Plan | Section & Elevation | Building Configura-tion | Photo |
| 11. Tajbakhshian House |   |  |  |  |
| 12. Poustizadeh House |  |   |  |  |
| 13. Ebadi House |   |  |  |  |
| 14. Mazouchi House |   |   |  |  |

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Continiue of Table 3: Typology of Hamadan Houses (Source: Zarei et al., 2018)

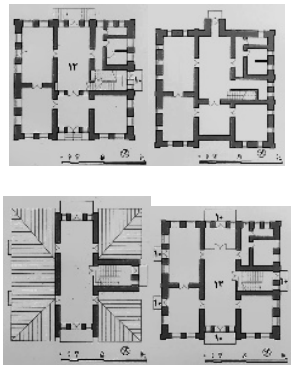
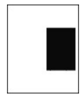
| Typological Analysis | | | | |
|---|---|---|---|---|
| | Plan | Section & Elevation | Building Configura-tion | Photo |
| 15. Aslani House |  |  |  |  |

Table 4: Evaluation of houses

| Name of House | Type | Shape of Plan | Orientation | Area of Site Plan (m²) | Area of Plan or Close Spaces (m²) | Open and Semi-opened Areas (m²) | Ratio of Plan to Site plan | Number of Facades | The ratio of Opening to Surface of South Facade | The ratio of Width to Length of the site plan | Number of Floors | Height of Floors (m) | Height of Ceiling (m) | The thickness of the Outer Wall (m) | The thickness of the Inner Wall (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.Ghazanfari House | 1 | One Sided | 42° | 859.33 | 153.73 | 705.6 | 0.18 | 1 | 0.37 | ⅗ | Ground Floor | 1.8 | 0.6 | 1.7 | 1.5 |
| | | | | | | | | | | | First Floor | 2 | 0.7 | 1.4 | 0.9 |
| | | | | | | | | | | | Second Floor | 2 | 0.5 | 0.7 | 0.9 |
| 2.Entezam House | 1 | L-Shaped | 23° | 522 | 213.96 | 308.04 | 0.4 | 2 | 0.32 | ⅗ | Ground Floor | 2 | 0.4 | 1.4 | 1.1 |
| | | | | | | | | | | | First Floor | 3.5 | 0.5 | 1.1 | 0.7 |
| 3.Naraghi House | 1 | Four Sided | 36° | 1443.66 | 872.1 | 571.56 | 0.6 | 4 | 0.44 | ⅖ | Ground Floor | 2.1 | 0.4 | 1.3 | 1.1 |
| | | | | | | | | | | | First Floor | 2.9 | 0.5 | 1.33 | 0.88 |
| 4.A.Sharafi House | 1 | One Sided | 31° | 734.2 | 308.63 | 425.57 | 0.42 | 1 | 0.25 | ⅗ | Ground Floor | 1.83 | 0.44 | 0.9 | 0.75 |
| | | | | | | | | | | | First Floor | 3.52 | 0.51 | 0.64 | 0.51 |
| 5.Samadian House | 1 | Two Sided | 28° | 496.72 | 321.25 | 175.47 | 0.64 | 2 | 0.49 | ⅖ | Ground Floor | 2.22 | 0.22 | 0.8 | 1.2 |
| | | | | | | | | | | | First Floor | 2.33 | 0.44 | 0.67 | 0.89 |
| 6.Khalabani House | 2 | U-Shaped | 33° | 404.31 | 251.71 | 152.56 | 0.62 | 3 | 0.43 | ⅗ | Ground Floor | 1.82 | 0.32 | 0.79 | 0.95 |
| | | | | | | | | | | | First Floor | 3.11 | 0.53 | 0.93 | 0.62 |
| 7.Seyfi House | 2 | One Sided | 55° | 715.89 | 342.29 | 373.6 | 0.47 | 1 | 0.45 | ⅗ | Ground Floor | 2.5 | 0.35 | 0.92 | 0.74 |
| | | | | | | | | | | | First Floor | 4.64 | 0.44 | 0.86 | 0.43 |
| 8.Sharifi House | 2 | One Sided | 33° | 1004.72 | 322.06 | 682.66 | 0.32 | 1 | 0.31 | ⅖ | Ground Floor | 1.9 | 0.41 | 0.6 | 1.23 |
| | | | | | | | | | | | First Floor | 3.4 | 0.45 | 0.6 | 1 |
| 9.Samavat House | 2 | One Sided | 28° | 554 | 215.93 | 338.07 | 0.38 | 1 | 0.37 | ⅗ | Ground Floor | 2.31 | 0.33 | 0.75 | 1.25 |
| | | | | | | | | | | | First Floor | 3.71 | 0.66 | 1.22 | 0.61 |
| 10.Zarabi House | 2 | Two Sided | 28° | 709.64 | 402.4 | 307.24 | 0.56 | 2 | 0.38 | ⅖ | Ground Floor | 2.83 | 0.25 | 1.02 | 0.76 |
| | | | | | | | | | | | First Floor | 2.9 | 0.85 | 0.74 | 0.44 |
| 11.Tajbakhshian House | 3 | One Sided | 9° | 333.47 | 117.81 | 215.66 | 0.35 | 1 | 0.18 | ⅘ | Basement | 1.66 | 0.44 | 1.38 | 1.11 |
| | | | | | | | | | | | Ground Floor | 1.77 | 0.55 | 0.83 | 0.55 |
| | | | | | | | | | | | First Floor | 2.61 | 0.61 | 0.83 | 0.55 |
| 12.Poustizadeh House | 3 | Center | 17° | 1371.52 | 233.35 | 1138.17 | 0.17 | 4 | 0.24 | ⅘ | Ground Floor | 3.05 | 0.42 | 1.08 | 0.86 |
| | | | | | | | | | | | First Floor | 3.47 | 0.63 | 0.43 | 0.86 |
| 13.Ebadi House | 3 | Center | 60° | 564.57 | 171.82 | 392.75 | 0.3 | 4 | 0.22 | 1 | Basement | 2.9 | 0.41 | 0.86 | 0.65 |
| | | | | | | | | | | | Ground Floor | 3.04 | 0.52 | 0.65 | 0.65 |
| | | | | | | | | | | | First Floor | 4.78 | 0.6 | 0.56 | 0.65 |
| 14.Mazouchi House | 3 | Center | 61° | 1603.47 | 280.57 | 1322.9 | 0.17 | 4 | 0.19 | ⅘ | Ground Floor | 3.08 | 0.46 | 0.96 | 0.64 |
| | | | | | | | | | | | First Floor | 3.27 | 0.56 | 0.96 | 0.48 |
| 15.S.aslani House | 3 | Center | 61° | 689.15 | 211.41 | 477.74 | 0.3 | 4 | 0.2 | ⅘ | Basement | 2.05 | 0.31 | 0.86 | 0.43 |
| | | | | | | | | | | | Ground Floor | 4.37 | 0.41 | 0.65 | 0.43 |
| | | | | | | | | | | | First Floor | 4.27 | 0.41 | 0.65 | 0.43 |

compact at a part of the courtyard in the first and the second eras but in the third one as they were located in the middle of the yard with less compression in plan and site plan.

**Orientation**

Due to the city's geographical position, topography, and environmental factors such as wind direction (disturbing wind of west and southwest), sun radiation, and urban texture, the orientation of dwellings in all three eras are towards the southeast. In the first era, houses were constructed between 36 degrees of the southeast and 42 degrees of the southwest, with one house toward the southwest. In the second era, the degrees are between 33 of the southeast and 55 of the southwest, with one house toward the southwest. Finally, in the third era, they are altered between 60 degrees of the southeast and 61 degrees southwest with two houses toward the southwest.

**Opening**

Façade of the south or southeast has been considered to evaluate openings. Besides, in one-side houses, the main façade is toward the south or southeast, and it is the only façade with openings. The south and southeast façade is the main one to receive the most solar radiation in two-side houses, L-shaped and U-shaped. In these four types, houses related to the first and second era have openings toward the yard, unlike the houses of the third era located in the middle of the yard. Therefore, we can see four façades toward the yard or sometimes streets with openings, and, in this case, the south façade is considered the main one for evaluation. According to an assessment, 19 to 49 percent of the façade is openings.

**Thickness of Walls**

In traditional houses of Hamadan, the thickness of walls depends on different factors such as the number of floors and the load which walls should bear. The reason is that they are load-bearing partitions that should bear the roof's weight, and as a result, they are thicker on lower floors.

**Height of Floor**

The height of the stores in buildings depends on the rooms and their locations. The height of two-door and three-door rooms was usually 2 to 2.5 meters. The kitchen and Cezan (storeroom in Hamadan), usually located in the basement or ground floor, had a height of 1.8 to 2.5 meters in the third era; this number sometimes reached 3 meters. Halls and terraces were higher than other rooms. They were 2 to 3 meters high, and even in some cases, their height equaled two floors.

**The Ratio of Width to Length**

Studies show that the width ratio to houses' length in the first and second eras follows the golden rectangle. But in the third era, the houses are located in the center of a square courtyard.

**Shape of Plan**

In different books, Hamadan dwellings are divided into five categories: one-sided, two-sided, L-shaped, U-shaped, and ultimately, houses located in the center of the yard. Most of the third era's dwellings were central in type, unlike those in the first and the second eras.

All of the items listed above are presented in table 4, with an assessment of each home that shows the trend of home changes over time depending on the period in which they were built.

**Construction Materials**

Generally, materials used in traditional dwellings of Hamadan were stone, brick, adobe, and wood. About Hamadan, in the first and second eras, most of the walls were constructed by adobe and brick. Furthermore, all of them were load-bearing. Major and minor wooden beams held vault roofs from bough or logs. Beams and columns were tied together to counter earthquakes. The space between beams was covered by matting, and the final layer was made by gypsum plaster and paint or wooden boards, as shown in Fig. 2. In the meantime, the roof's multilayers and the free space between the side beams acted like the insulation layer (Etemad Sheykholeslami, 2011). In the third era, the steel frame was used as a block joist.

**Architectural Thermal Comfort Strategies based on the Mahoney Tables**

The Mahoney table is a weather assessment tool that provides the architect with simple and crystal-clear design instructions. To better understand the initial proposals of climatic architecture design, it is discussed. It contains six tables related to entering weather information to explicit two final result tables. They cite rudimentary suggestions for vernacular architecture. According to Mahoney's table calculation, the weather of different months is shown in table 5. It can be understood that during the nine months of the year - March to December - the temperature difference between day and night, which fluctuates around the clock is more than 10 degrees, makes an uncomfortable situation. Specifically, thermal storage is needed.

Moreover, seven months of the year - December to May - are considered cold months when the day temperature is less than the minimum comfort temperature of 10 degrees in the Mahoney table. These considered the region in cold and arid temperatures. Therefore, the architectural suggestions of this climate based on the Mahoney tables are as follows. Building orientation should be on the east to the west axis to reduce exposure to the sun. Compact planning is needed. No air movement is required. Openings should be medium-sized (20 to 40%), heavy external and internal walls are suggested. Finally, heavy roofs with over eight hours' time lag are required.

Thermal Comfort Strategies based on Evan's Index

The Evan's Index measures the relationship between dry air temperature and relative humidity, tangible and intangible airflow, activity, and clothing. The summary of the Hamadan

Fig. 2: Material of roof, Details (left), Upper layer (right)/ (Etemad Sheykholeslami, 2011)

climate is indicated in table 6, according to Evan's tables. It is considered to surmount flaws or scarce of Mahoney tables. Also, combined with the Mahoney tables, it renders the human comfort inside the building as much as possible to provide architectural strategies for thermal and human comfort in harmony with the climate, if necessary.

Since fluctuation around the clock is high in this region, we need to consider architectural strategies to reach comfortability in most months of the year. So that, days of June and July are considered above the comfort limit, requiring constructing the buildings with heat capacity and time lag. Days of August and September in most hours resemble two previous months. Just in some hours, they are in the comfort zone according to Evan's index, which describes the thermal condition as "comfortable airflow per area of 1 meter per second." So, we need to protect the building against strong wind and sun radiation. Days of May are a bit different from other months, divided into three parts; two of them are above and below the comfort zone, requiring architectural strategies. So that, a building with heat accumulation capability would be sufficient. Some other hours of its place in "comfort zones per summer dress or subtle style in the night airflow (0.1 meters per second)." Days of April and October in most hours are below the comfort limit. Just in some hours, they categorized in "Per ordinary clothes and warm and comfortable area of thick blankets at night." So, it does not require thick insulation, and only temporary heating equipment is needed. All days and nights of other months are considered below the comfort zone, so they need vernacular strategies such as appropriate insulation coincidence with permanent heating equipment in buildings to reach comfortability.

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Table 5: Diagnosis of Hamadan climatic data according to Mahoney table

| Thermal Stress | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | C | C | C | C | N | H | H | H | H | N | N | C |
| Night | C | C | C | C | C | C | N | N | C | C | C | C |

H: above comfort limit; N: within comfort limit; C: below comfort limit

Table 6: Hamadan situation in Evan's scales

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | a | C | C | C | C | C | H | H | N | N | C | C | C |
| | b | C | C | C | C | N | H | H | H | H | C | C | C |
| | c | C | C | C | N | H | H | H | H | H | N | C | C |
| Night | a,b,c | C | C | C | C | C | C | C | C | C | C | C | C |

H: above comfort limit; N: within comfort limit; C: below comfort limit

a: Group comfortable airflow per area of 1 meter per second

b: Area rugs comfort zones per summer dress or subtle style in the night air flow (0/1 meters per second)

c: Per ordinary clothes and warm and comfortable area of thick blankets at night

By deliberating the climatic conditions of Hamedan in Tables 5 and 6 then comparing them with each other, it shows accurately they complete each other's as Evans considers the situation in a, b, and c conditions. So all nights are cold, and days of most months of the year are cold too. Hence, buildings in this region should be constructed with high or medium heat capacity, protection against strong winds, and the ability to accumulate heat, which controls temporary or permanent equipment usage.

**Comfort Conditions according to Climate Consultant App**

According to each city's weather information extracted from valid meteorological sites in the EPW (Energy plus Weather file) format, different graphs and charts can help consider suitable strategies for the mentioned region. They relate to the thermal comfort of Hamadan. The graph in Fig. 3 shows the design strategies according to a monthly calculation. It shows that buildings are in the comfort zone in some hours from May to October also simultaneously in these months need sun shading of windows. In other months of the year, wind protection of outdoor spaces is required. The graph in Fig.7 indicates the situation in an hourly type. So that, in most hours of the year, heating and Humidification are needed (41.5%). In 21.2% and 19.2% of year's hours, passive solar direct gain high mass and internal heat gain is required, respectively. Direct evaporate cooling and sun shading of windows are two following strategies we should consider in this region as they allocate 18.9 and 16.1 percentage of hours of the year to themselves, in turn. This region is in its comfort zone, just 7.4% of the hours. Finally, humidification and wind protection of outdoor spaces with 1.7 and 0.7% are less critical items to be considered.

**Comfort Conditions, according to Penwarden Graph**

One of the pioneers who prepared a graph to predict pedestrians' outdoor comfort zone is Penwarden. Indeed, there are two kinds of graphs (Fig. 4). One of them is related to human comfort in shadow. The other assesses it in sunshine according to the type of clothes, the vertical axis's dry temperature, and

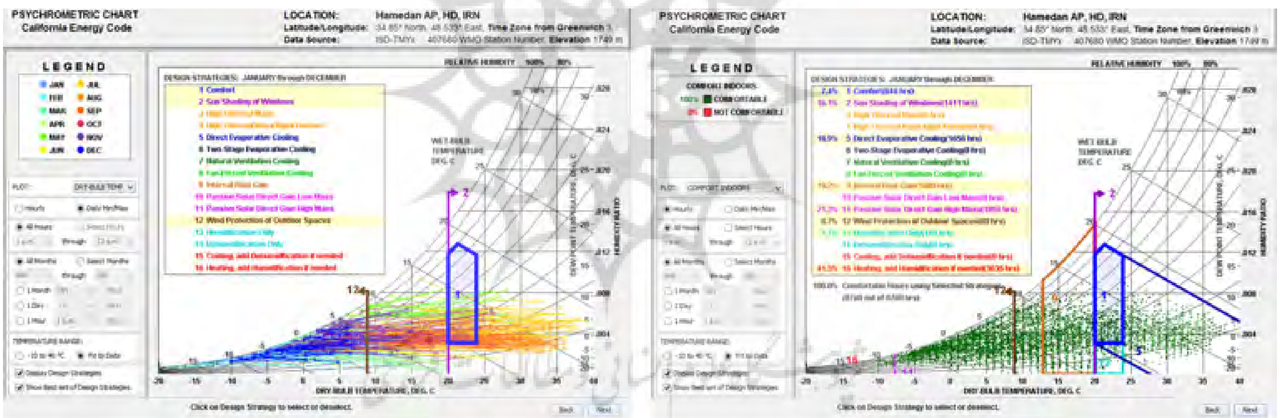


Fig. 3: Hourly comfort condition, meteorological sites in the EPW (climate consultant)

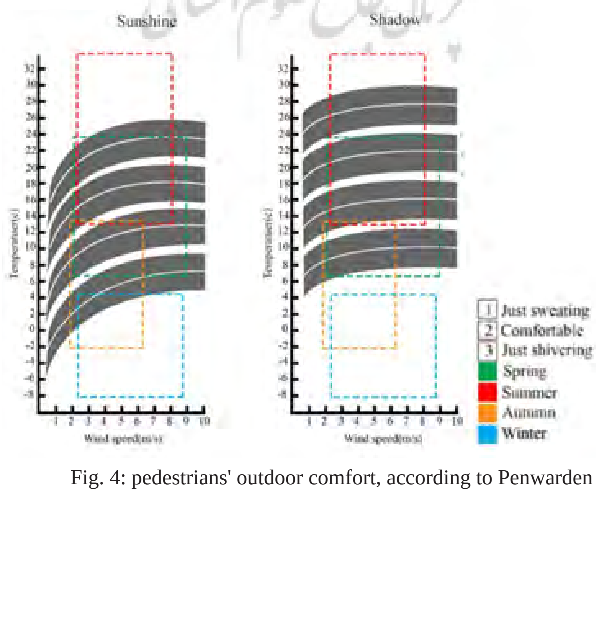


Fig. 4: pedestrians' outdoor comfort, according to Penwarden


Fig. 5: Evaluation of Hamedan alleys

wind speed on the horizontal axis. The wind speed and average temperature of each season are considered in Table 2, drawn for different seasons of the year; we can conclude that it is always cold regarding graph morning weather except in summer. Also, the midday weather is pleasant in spring and autumn, but it is cold the other times of the day. And in the winter, the weather is always cold unless in sunny middays when the weather is pleasant. Hence, streets and alleys in urban texture should be designed to prevent wind and receive sun radiation in winter. Since the vernacular houses are located in old neighborhoods and alleys (Fig.5), and because of the critical impact of the external heat condition of the building on the comfort conditions inside the building, the Joulan neighborhood is analyzed as a part of the old texture that life is still going on today. By examining the thermal condition of these alleys, it is possible to explore the proper shape of the walls outside the building and how they are arranged side by side.

## RESULT AND DISCUSSION

With taking into account the surveys of Hamadan houses and comparing them with the calculated climatic indicators and also with considering the strategies presented in each section, it can be concluded that: According to Mahoney tables, Evan's index, Climate consultant app, and Penwarden graph, assessments show similar strategies for this specific region or any other with this climate. To follow these architectural strategies, we should consider these items. Southern orientation, attention to heat capacity (wall thickness, heavy roofs, appropriate materials, temporary or permanent indoor equipment), protection against the strong wind, openings, compatible use of active and passive solar energy. Comparing them with the three mentioned eras indicate the following:

1) First-era houses had thick walls with appropriate heat capacity, heavy roofs. Except for one of our specimens, they were building-oriented on the southeast to acquire sun radiation and prevention against the intensive wind. Furthermore, openings were small or medium-sized.

2) In the second era's dwellings, floor-to-ceiling height increased by 10 percent, making it hard to keep the indoor heat. This era's buildings also had thick walls, heavy roofs, and orientation was the same as the first era. In comparison, the size of openings increased by 3.6 percent compared to the previous period. Likewise, openings are still in the category of small or medium-sized.

3) Third-era dwellings, like the two predecessors, had thick walls and heavy roofs with the same orientation. But most of them are located at the central yard, so the number of their openings increased in four façades. In other words, the ratio of the first and second eras has risen by 47.76 % and 45.81%, respectively. Also, floor-to-ceiling heights dramatically increased 31 percent in this era. So that, they also lost their accordance with our mentioned tables and indexes strategies.

In all three eras, the compact plan and urban texture were considered by constructors. Dwellings were constructed with appropriate heat capacity and insulation materials. Also, traditional heating equipment in Iran, chimney and Corsi, was used temporarily or permanently according to seasons. These design strategies completely match with explicit architectural strategies. To evaluate better, all strategies are placed in table 7. It illustrates that the first and second eras were more compatible with their surroundings and more congruent with elicit strategies, unlike the third era, which had less similarity with the two previous ones.

## CONCLUSION

Hamadan indigenous housing, which is based on the region's climate, was designed to utilize the formal elements of construction and provided the appropriate physics for the buildings to save energy, and created comfortable heating conditions and has been quite successful in these areas. Evaluating all these factors indicates a particular type of indigenous building that responds to climate according to accurate design strategies derived from appropriate region architecture to provide effective relations between site, building, and climate. These indigenous dwellings indicate the correct use of what climate and material offer us. Also, by studying them, their evolution can be addressed. Moreover, they are a perfect example of how traditional sustainable buildings should look like. There are many settlements in different parts of the world as this region which these strategies can help them be more compatible with their nature. Also, many megacities or small towns have this similar climate and analogous surroundings in other parts of the world. These strategies or even part of them can help approach more sustainable buildings and urban forms in the future.

Hamadan vernacular houses illustrate appropriate design strategies such as considering thick walls and roofs with proper insulation and attention to the heat capacity of materials. They can also use small or medium-sized openings, southeast-northwest orientation to sun radiation acquisition, prevention

Table 7: Comparison of results

| | Design strategies | Mahoney table | Evan's index | Climate consultant | Penwarden graph | Houses<br>First era | <br>Second era | <br>Third era |
|---|---|---|---|---|---|---|---|---|
| Mahoney Table Result | Building oriented on the east to the west axis to reduce exposure to the sun | ● | | | | ● | ● | ● |
| | Compact planning | ~ | | ● | ~ | ~ | ● | |
| | No air movement required | ● | | | | ● | ● | |
| | Medium openings, 20-40% | ● | | | | ● | ● | |
| | Heavy external and internal walls | ● | ● | ~ | | ● | ● | ~ |
| | Heavy roofs; over 8 hours' time lag | ● | | | | ~ | ● | |
| Evan's Index Result | Heat capacity and latency components | | July & August | | | | | |
| | Protecting the building from intense radiation and wind | | May & June & Sep & Oct | | | Just from wind | Just from wind | |
| | Adequacy of heat-accumulating building components | ● | April | ● | | ~ | ● | ● |
| | Unnecessary thick insulation and insufficient temporary heating equipment | | Mar & Nov | | | | | |
| | The need for proper insulation and permanent heating | proper insulation | Jan & Feb & Dec | proper insulation | | proper insulation | proper insulation | proper insulation |
| | Appropriate insulation for buildings with medium or high heat capacity | ● | ● | ● | | ● | ● | ● |
| Climate Consultant | Comfort Zone (7.4%) | | | ● | | | | |
| | Sun Shading of Windows (16.1%) | | | ● | ● | | | |
| | Direct Evaporative cooling (18.9%) | | | ~ | | | | |
| | Internal Heat Gain (19.8%) | ● | ● | ● | | ● | ● | ● |
| | Passive Solar Direct Gain High Mass (21.2%) | ● | | ● | ● | ● | ● | |
| | Wind protection of outdoor spaces (0.7%) | | ● | ~ | | ● | ● | |
| | Humidification only (1.7%) | | | ● | | | | |
| | Heat and Humidification is needed (41.5%) | | ● | ● | | ● | ● | ● |
| Penwarden Graph | Compact urban texture | ● | | | ● | ● | ● | |
| | Protecting passages and alleys from intense wind | | | ● | ● | ● | ● | |

● : All year round

of intensive wind, use of the earth's heat, considering capable height between stores, and compact urban texture. Also, internal heat is regarded in most months of the year. Passive solar energy helps them to provide comfort conditions.

These design strategies match our tables and findings entirely. However, the best compatibility among these three eras goes back to the first era, particularly compact planning and compact urban texture. Although building orientation was against the elicit strategies in one case, all other factors were matched. The second era was precisely like the first one incompatibility with strategies and like the previous one. However, the height of floor to roofs increased in this era, making it hard to keep sufficient heat in buildings. But, in the third era, most one-sided yards turn into central yards, which help to have too much air movement that is not required for this climate, according to our tables. In this era, the percentage of openings ratios to façades increased dramatically, another reason for air movement that reduces comfort conditions based on assessment criteria. Also, because alleys in the traditional urban texture were breezeway that connected the houses and finally to the main street to prevent wind and precipitation, the third era has the least compatibility with its surroundings and nature.

Energy consumption assessment in vernacular buildings and current housing can be studied using related software to survey other aspects of future articles. Furthermore, comparing them or making a model of urban texture and assessing their advantages and disadvantages in different eras according to cold and mountainous climates can also be the aims. Finally, according to their buildings' efficacy issues, these acquisitions can be updated gradually in similar parts of the world with similar climates.

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