Assessing the Bioclimatic Architecture of Well-reserved Vernacular Houses in Assilah, Morocco: Insights for Sustainable Modern Architecture

Evaluación de la Arquitectura Bioclimatica de Casas Vernaculas bien conservadas en Asilah, Marruecos: perspectivas para una arquitectura moderna sostenible

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Abstract

The world is expected to construct the equivalent of New York City each month until 2030. Meanwhile, with the urgent need to reduce greenhouse gas emissions, these buildings must be energy-efficient and minimize active energy use to maintain indoor thermal comfort. Vernacular houses, as well-preserved traditional homes, offer valuable insights into climate-adaptive and flexible architectural solutions for thermal comfort, passed down to us from our ancestors. Hence, in this study taking advantage of the well reserved vernacular houses in the northern city of Morocco, Assilah, we identified and evaluated the effectiveness of bioclimatic architectural features adopted in the region under the Mediterranean climate. The methodology includes a detailed field survey of identified bioclimatic houses, focusing on their architectural characteristics, bioclimatic features, and residents' satisfaction with internal thermal comfort. The main results indicate that these houses, with features such as interior patios (with centrally (60%) or rear-located (40%)), skylights present in 70% of the homes, and strategic solar protection used 50% of the houses, achieve quite comfortable indoor thermal performance and occupant satisfaction, with better performance observed in hotter months than in colder ones. These findings aim to inspire energy-efficient building practices by identifying and assessing the suitability of climate-responsive design strategies. It is suggested to rediscover and draw inspiration from Moroccan bioclimatic and vernacular architecture to guide contemporary architectural practices.pproach.

Keywords: Vernacular House, bioclimatic architecture, thermal comfort, Archicad, Passive design strategies, solar protection.

Resumen

Se espera que el mundo construya el equivalente a la ciudad de Nueva York cada mes hasta 2030. Mientras tanto, con la urgente necesidad de reducir las emisiones de gases de efecto invernadero, estos edificios deben ser energéticamente eficientes y minimizar el uso de energía activa para mantener el confort térmico interior. Las casas vernáculas, como hogares tradicionales bien conservados, ofrecen valiosas ideas sobre soluciones arquitectónicas adaptadas al clima y flexibles para el confort térmico, transmitidas por nuestros antepasados. Por lo tanto, en este estudio, aprovechando las casas vernáculas bien preservadas en la ciudad norteña de Marruecos, Asilah, identificamos y evaluamos la efectividad de las características arquitectónicas bioclimáticas adoptadas en la región bajo el clima mediterráneo. La metodología incluye una encuesta de campo detallada de las casas bioclimáticas identificadas, centrada en sus características arquitectónicas, elementos bioclimáticos y la satisfacción de los residentes con el confort térmico interior. Los principales resultados indican que estas casas, con elementos como patios interiores (centrales en un 60% o ubicados en la parte trasera en un 40%), claraboyas presentes en el 70% de los hogares, y protección solar estratégica utilizada en el 50% de las casas, logran un rendimiento térmico interior bastante cómodo y satisfacción de los ocupantes, con un mejor desempeño observado en los meses más cálidos que en los más fríos. Estos hallazgos buscan inspirar prácticas de construcción energéticamente eficientes al identificar y evaluar la idoneidad de las estrategias de diseño adaptadas al clima. Se sugiere redescubrir e inspirarse en la arquitectura bioclimática y vernácula marroquí para guiar las prácticas arquitectónicas contemporáneas.

Palabras clave: Casa Vernácula, arquitectura bioclimática, confort térmico, Archicad, estrategias de diseño pasivo, protección solar.

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1. Introduction

The operation of the building sector is responsible of 34% of the energy consumed worldwide, and with that its accounts of 37% of the GHG emissions (Programme & Construction, n.d.). As of the latter is the main cause of climate change and the increase of earth average temperature, high energy consuming sectors-as the building sector- are called to decrease their energy consumption and increase the energy use efficiency (Moisio et al., 2024). However, if business as usual scenario is followed (Kuramochi et al., 2020), the energy consumption of the building sector is expected to be increasing, due to several reasons, namely, population growth, increased life quality, and more importantly climate change consequences (DIALLO et al., n.d.).

The latter is of the main causes, since a big part of the energy needs of the buildings are the ones related to the insurance of internal thermal comfort. The climate change consequences (Normandin, 2021), precisely the increase of earth temperature-20 to 40 % of population are currently living in area where the increase on temperature has already attained 2°C-is causing higher demands, especially for cooling demand (Couzin, 2019).

Understanding the seriousness of the matter, several countries have defined GHG emissions mitigation goals for their building sector (Baker et al., 2021). And as one of the means possible to achieve this goal is to increase the energy efficiency (Skillington et al., 2022). Morocco is one of the countries that have defined an ambitious goal for their building sector, defined as the decrease of the GHG of the sector by 11.6% by 2030 (CONTRIBUTION DÉTERMINÉE AU NIVEAU NATIONAL DANS LE CADRE DE LA CCNUCC, 2016). Of the nationally determined contributions defined for that is “The Thermal Construction Regulation in Morocco (RTCM)” a regulation that aims to improve energy efficiency in the building sector. Implemented in 2015, RTCM sets technical specifications for thermal performance across different climatic zones and building types (residential and tertiary) (Merini et al., 2020). The regulation emphasizes the use of energy-efficient materials and designs to reduce energy consumption and greenhouse gas emissions.

It has been continually proven (Toishiyeva et al., 2022), that modern urbanization, and the tendency of adopting similar type of architecture without taking into consideration the sites environment, and the weather characteristics, or taking advantage of natural resources, such as solar and wind, results in less efficient buildings and higher need for active controlling to achieve internal thermal comfort (Akyildiz, 2020). On another hand, when the mentioned features are considered, which what bioclimatic architecture stands for (Pan et al., 2024), researchers have shown that the indoor environment tends to be more comfortable and the energy needs of the house tends to be lower- relying on less active strategies for indoor environment regulation (Aghimien et al., 2022).

In China, Huang et al. have conducted a detailed survey of vernacular houses in three different rural zones of the country, characterized by different weather conditions (Huang et al., 2024). The aim of the study was to identify and evaluate the region-specific bioclimatic features adopted by the houses to inspire energy-efficient and sustainable building practices. Some of the bioclimatic features studied include the use of high thermal mass materials for increased thermal inertia, compact settlement patterns to enhance protection from strong winds, and the integration of semi-open spaces like balconies and courtyards for improved ventilation and natural cooling. Through their results, the authors have shown that these bioclimatic features for passive cooling and heating are correlated with optimal thermal performance.

In India, more specifical under the subtropical climate of Himachal Pradesh, Sarkar et al. have conducted a comparative study of indoor thermal comfort of two type of houses, traditional and modern (Sarkar & Bose, 2015). They have conducted a field survey to evaluate the perception of the occupants, and in parallel have measured indoor thermal parameters. The traditional house with higher thermal mass materials, compact settlement patterns, thick walls and small openings, and semi-open spaces, have been found to have higher indoor temperature in winter, stays above the required minimum, benefit of good humidity, and overall achieve higher occupants' satisfaction compared to the modern one. For the latter, similar result was found by Alabid et al. in desert climate of Lybia. The authors followed a similar approach- field survey and measurements- found that in terms of indoor thermal comfort and energy efficiency, occupants found traditional houses with bioclimatic architecture more satisfying (Alabid & Taki, 2014).

In cold climate conditions, under the weather of Bingol in Turkey, Varolgünes took advantage of the rebuilding of the city that took place after the 2003 earthquake to assess the traditional houses effectiveness in terms of thermal comfort against the new modern houses(Kürüm Varolgüneş, 2020). The results have emphasized that the new houses are designed independently to the climate conditions, which made them highly sensitive to the external environmental conditions over the whole year period. On the other and, the traditional houses with bioclimatic features were perceived as more satisfying in terms of indoor temperature, air quality, and visual comfort, a alongside their energy consumption.

In Algeria, and under the desert climate of Ouargla, Khechiba et al., using simulation and measurements, compared a traditional house, with a compact architecture, a courtyard, thick walls, natural ventilation, and long and narrow windows, against a modern house that adopt standardized architecture (Khechiba et al., 2023). The thermal comfort results showed a huge advantage to the traditional house, and very low efficiency and suitability of the modern design. On another hand, Nugroho et al. have conducted a suitability evaluation of bioclimatic architecture under the tropical humid climate of Budaggan in Indonesia (Nugroho et al., 2023). Taking into consideration a vernacular house, the authors have adopted observation and measurements techniques. The house adopted twenty-two bioclimatic features. Overall, the house benefited from a sufficient comfortable environment, in some rooms more than others, however, in terms of humidity, it exceeded 80%, which is considered uncomfortable. From the twenty-two features, the authors found that only eleven of them are suitable in the case studied, while the remaining others are responsible for downgraded thermal performance. Another suitability evaluation was conducted by Khambadkone et al. (Naveen Kishore & Rekha, 2018). This time the authors have used a calibrated simulation model for a typical house to evaluate bioclimatic features for passive cooling and heating, while considering 21 locations of a climate zone in India. The authors have concluded that even inside the same climate zone the optimum bioclimatic strategies are different, therefore, architects should optimize their designs and tailor their strategies to the specific location to achieve the highest bioclimatic potential and minimize reliance on active energy use for thermal comfort. Pajek et al. stressed out the need of re-evaluation of bioclimatic features and the avoidance of the replication of the ones used in old vernacular traditional buildings (Pajek & Košir, 2018). Hence, the fact that they have worked efficiently in the past does not imply that they are efficient in the current conditions and with the fast shift expected in climate conditions in the future. The authors using the example of two houses under the moderate-Mediterranean climate of Slovenia, have demonstrated that for a period of 1966-2050, the needs have been shifting towards higher needs on cooling and lower on heating. Consequently, the optimum bioclimatic features are shifting. With that the bioclimatic building studied which are usually designed in favour to heating gains, in such climate, perform worse and worse with the passage of time compared to the non-bioclimatic one. Therefore, as suggested by the authors renovation actions should be practiced, and that has been supported by other researchers (Berger et al., 2014; Cao et al., 2017; Pierangioli et al., n.d.).

To conclude, even with the well documented efficiency of bioclimatic architecture, especially the one passed from historical building traditions in vernacular buildings, several authors are stressing that with the current and future expected deviation of climate conditions, more identification, re-evaluation, and suitability assessment studies of location dependent bioclimatic features are needed. Therefore, in this study we took advantage of the well reserved bioclimatic houses in the old city of Assilah, Morocco, to identify and asses the thermal performance of the houses under the Mediterranean weather of the region. For that potential houses have been identified and thorough survey was conducted to identify the characteristics of the houses, namely, general information, envelope characteristics, bioclimatic features characteristics, internal comfort perception, and residents' strategies for internal comfort enhancement.

2. Research methodology

2.1. City's Characteristics and Climate type

Asilah is a city in the northwest of Morocco at Lambert coordinates 35.47° N latitude–6.03° W longitude. As displayed in Figure 1, it faces the Atlantic Ocean at an altitude of 17 meters above sea level, and protected from Atlantic influences by the surrounding mid-altitude mountains. With approximately 31,000 inhabitants at present, its old Medina extends over an area of 7 hectares, is surrounded by ramparts and walls in the shape of a parallelogram as it can be seen in Figure 2. The city's history dates back to 1500 B.C and over the centuries, it has seen the influence of various civilizations including the Romans, Portuguese, and Spanish, each leaving a distinct mark on its architectural landscape. Remarkably, the old city of Asilah has been able to preserve the traditional architecture of its houses, making it an excellent resource for evaluating the efficiency of bioclimatic architecture. The architecture of Asilah's houses incorporates traditional bioclimatic elements, features such as interior patios, skylights, Moucharabieh, and exterior shutters.

The city experiences a warm Mediterranean climate, characterized by a dry summer with varying temperatures between 17°C and 32°C, and a cold to mild winter with varying temperatures between 6°C and 11°C. The average wind speeds oscillate between 13.6 km/h and 17.3 Km/h, while the East and West directions are the most dominant during the year. The hot season lasts for 3 months, from June 22 to September 22, with an average daily high temperature above 27°C. The hottest day of the year is July 27, with an average maximum temperature of 30°C and a minimum of 20°C. The cool season lasts for 3.9 months, from November 24 to March 21, with an average daily high temperature of 17°C. The coldest day of the year is January 19, with an average minimum temperature of 8°C and maximum of 16°C.

Figure 1: Geographical Location and Urban Layout of Asilah

Figure 2: The old city of Asilah

2.2. Method

Conducting occupant surveys is a key method broadly adopted by researchers for evaluating indoor thermal environments, as it helps provide insights into occupants' thermal comfort, highlight adaptive behaviours, and help identify specific factors affecting satisfaction (Majewski et al., 2020). Firstly, an initial scan of the old city of Asilah- where most vernacular houses are located- was conducted to identify potential houses that can be considered for the study. The choice was taken based on the number of traditional bioclimatic features present in the houses. Hence, the good orientation of the building, the compactness of the envelope, the good sizing of the openings and windows, the presence of louvered and breeze shutters, as well as the presence of the skylight and the central interior patio, were key features considered. With that ten houses in the old city were identified for the study as represented in Figure 3. Secondly, a field survey was conducted to identify the characteristics of the houses, namely, general information, envelope characteristics, bioclimatic features characteristics, internal comfort perception, and residents' strategies for internal comfort enhancement. The bioclimatic features were categorized into five aspects: Layout of the building, spacing, openings, building envelope, and architectural elements-patio and skylight. While the internal comfort evaluation was based on summer temperature, winter temperature, air quality, and temperature control ease. And residents' strategies for internal comfort were evaluated based on strategies for temperature control, and air quality enhancement.

Figure 3: Location map of the houses studied.

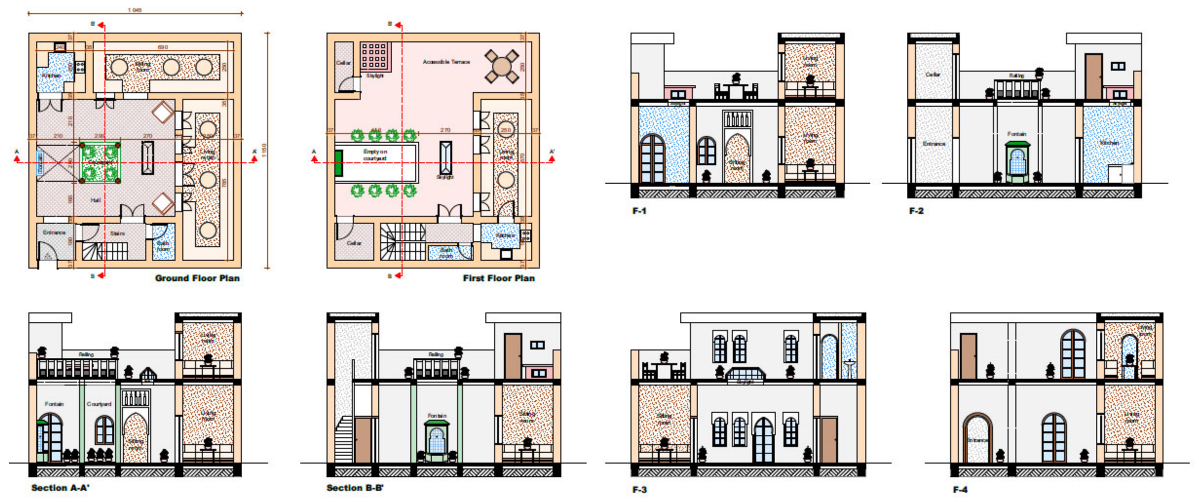
3. Results and discussions

2.3. Reserved bioclimatic features in the buildings' architecture of Asilah

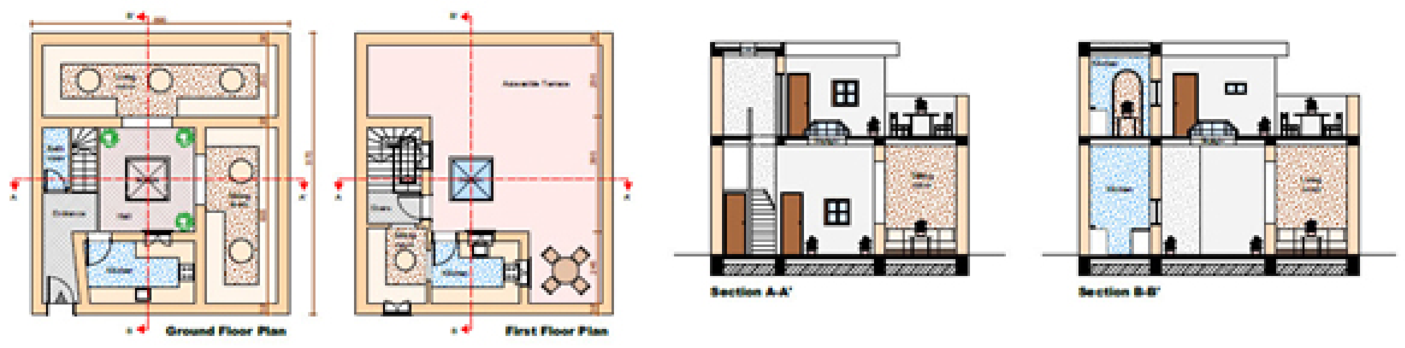
After the identification of the potential houses to contribute to the study, agreements with the owners were made and technical visits were scheduled. Through observation and measurements, the architectural plans and sections of the houses were drawn, and they are represented in Table 1. As it can be seen, the elevation of the houses varies between ground plus one, and ground plus two, as houses were back then designed to suit and provide privacy and dependence to families with higher number of members compared to modern houses. All the houses are built in a compact form either in a square shape or a rectangular shape. Meanwhile, the total surface of the houses varied between 64 m^2 and 410 m^2, as depicted in Table 2, where general construction details of the houses are represented. The walls of the houses are constructed with the local material brick, specifically, brick type B12. The higher dimension of the latter, as the modern houses are built with B6 brick (El Asri et al., 2023), gives the walls a higher thickness that varies between 35 cm and 40 cm, depending on the coating used. And it varies usually between white plaster or Moroccan zellige for exterior/ interior walls, and for roofs between coated concrete or Moroccan zellige. 80% of the considered houses are built with a patio, as it can be seen in Table 3. The patio designates an archetype of open-air interior space, having a functional role and a symbolic representation in traditional Moroccan houses. For the latter, the space has a central place in the social life of the occupants, reserved for pleasurable activities, as family gathering and relaxation, especially in hotter period. The latter is one of the main functional roles of the space if well designed and optimised (Meir & Pearlmutter, 1992), hence, it known that the patio act as buffer spaces that moderate outdoor climate conditions, significantly improving the thermal comfort by providing passive cooling in summer and increasing sunlight in winter (El Asri et al., 2023). This is achieved through the strategic use of shade, natural ventilation, and evapotranspiration assured by the use of fountains in the canter of its area. Through Table 1, it can be shown, that the placement of the patio in the houses is either at the centre of the house (60%) or at the back of the plot (40%). The area of the patios varies between 9 m^2 and 42 m^2, as depicted in Table 2. And they are usually decorated with different type of green plants and a fountain, as it can be seen through the images in Table 4. The second most adopted bioclimatic features on the houses are the integration of skylight. 70% of the houses possess a one, with a surface area that varies between 0.61 m^2 and 5.60 m^2. As it can be seen in Table 4, the skylight is an opening in the roof or the ceiling covered by thick glass that allows the penetration of sunlight to the interior of the houses. The skylight is known to enhance daylighting, reducing the need for artificial lighting, create a more pleasant indoor environment for the occupants (Laksmiyanti & Salisnanda, 2018), and if well designed contribute to the thermal comfort of the house, especially in terms of passive heating in colder weather.

Another bioclimatic element identified is the use of moucharabieh-present in 50% of the houses, which is projecting, enclosed balconies or windows with carved latticework, as it can be seen in Figure 4 (El Jaouhari et al., 2019). Socially it provides privacy and visual screening from the outside, while thermally the design takes advantage of the local climate by allowing air to flow through the latticework while blocking direct sunlight, providing shade, natural ventilation, and sun protection (Amraoui et al., 2021). The other two features identified for sun protection are used for external windows, and are horizontal shading, and shutters. In Figure 5, the two types of protection are depicted. And from Table 3, it can be seen that 50% of the houses adopt shutters, and 50% adopt horizontal shading, while some of them adopt both as seen in image (b), Figure 5. The horizontal shading is designed to block high-angle summer sun, in order to reduce the overheating, while it allow lower-angle winter sun to enter, to allow the house to benefit from the sun heat gain (Xu et al., 2022). Shutters on another hand block the direct sunlight penetration while allowing diffused light to enter.

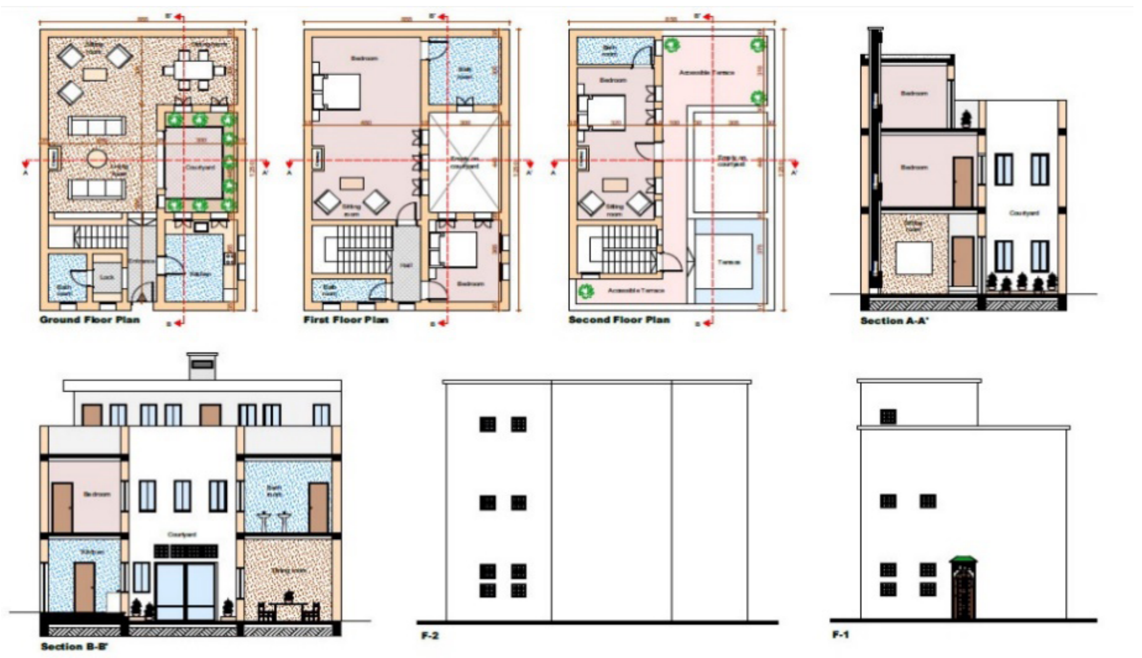
Table 1: *The architectural plans and sections of the ten bioclimatic houses.*



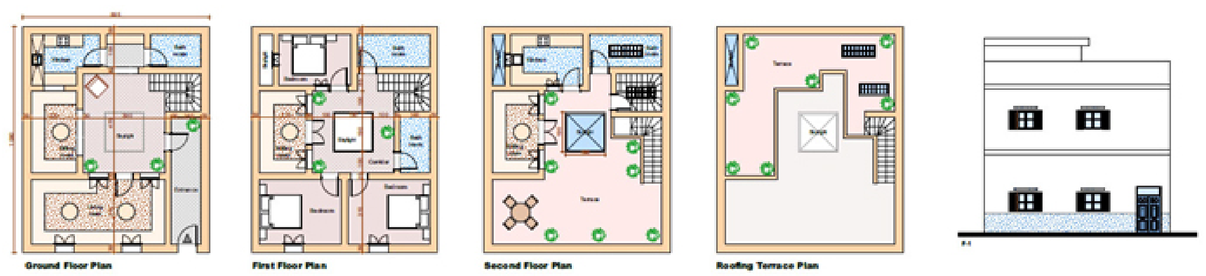
House 1



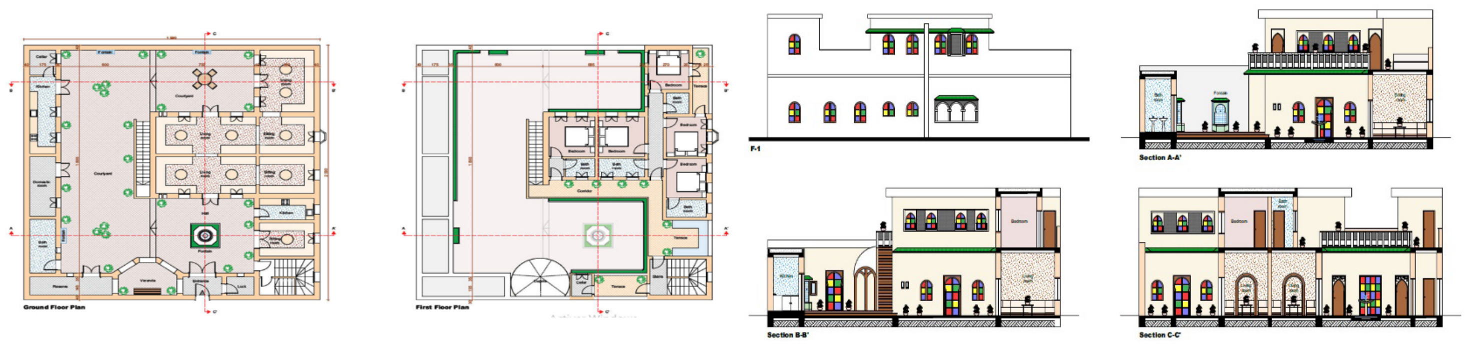
House 2



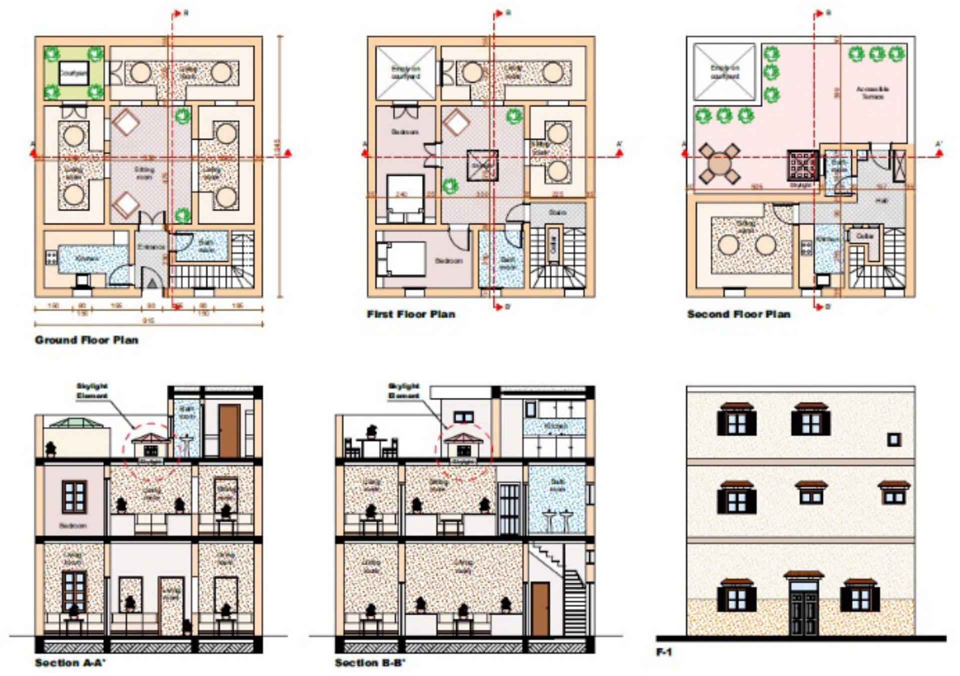
House 3



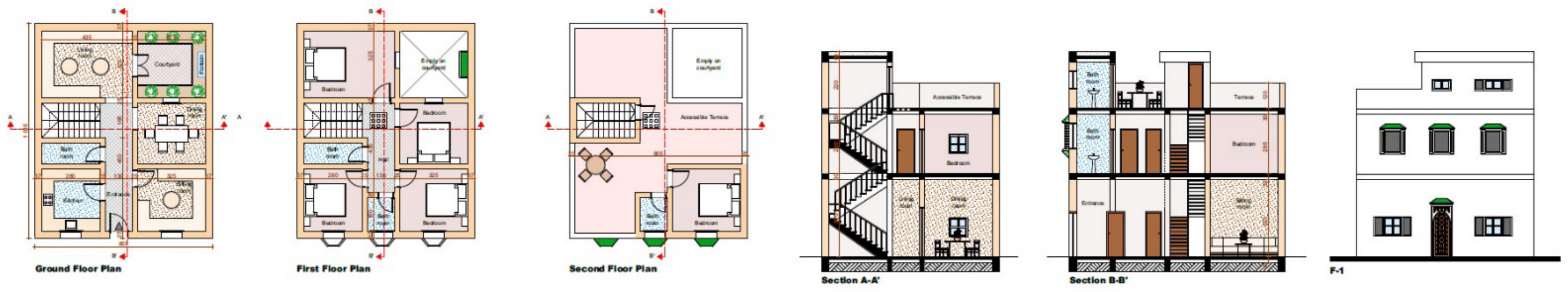
House 4



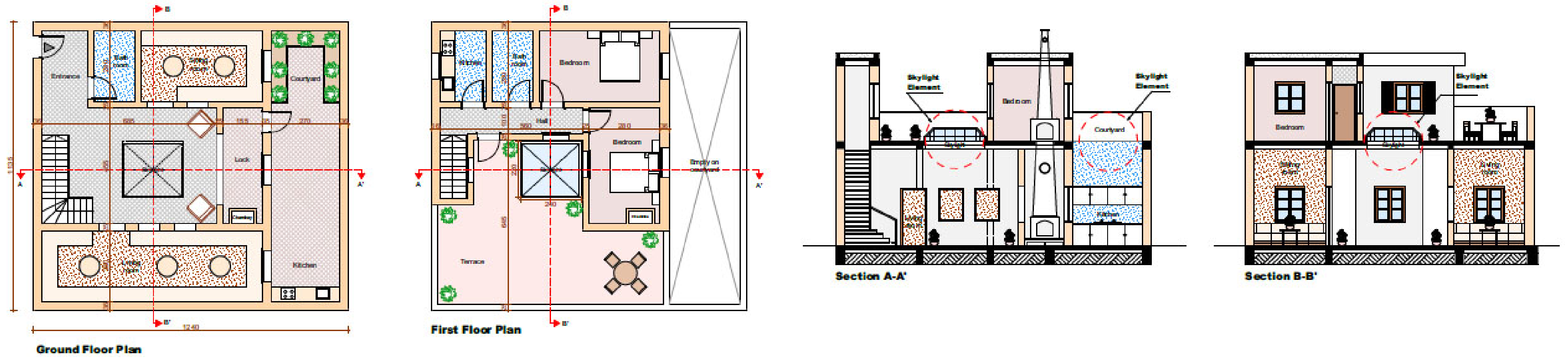
House 5



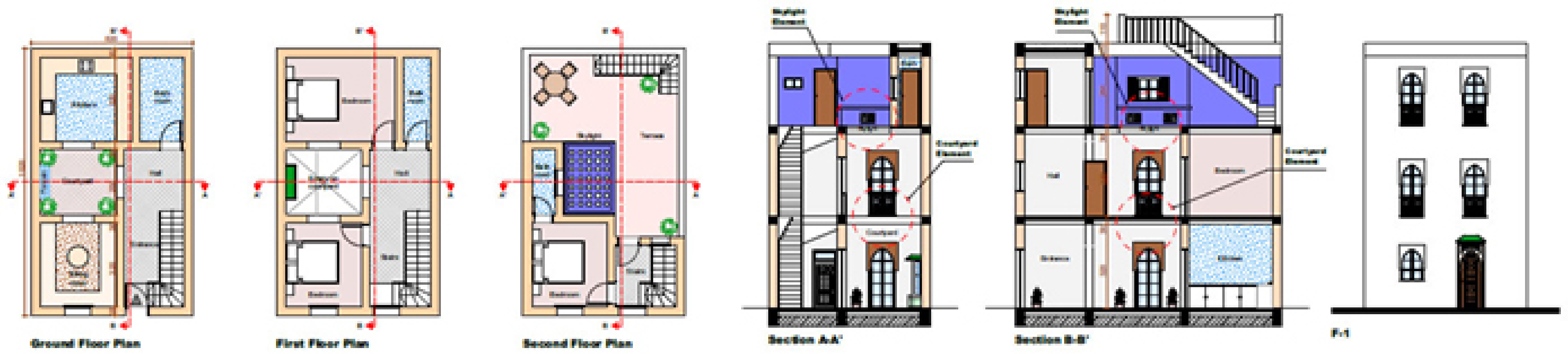
House 6



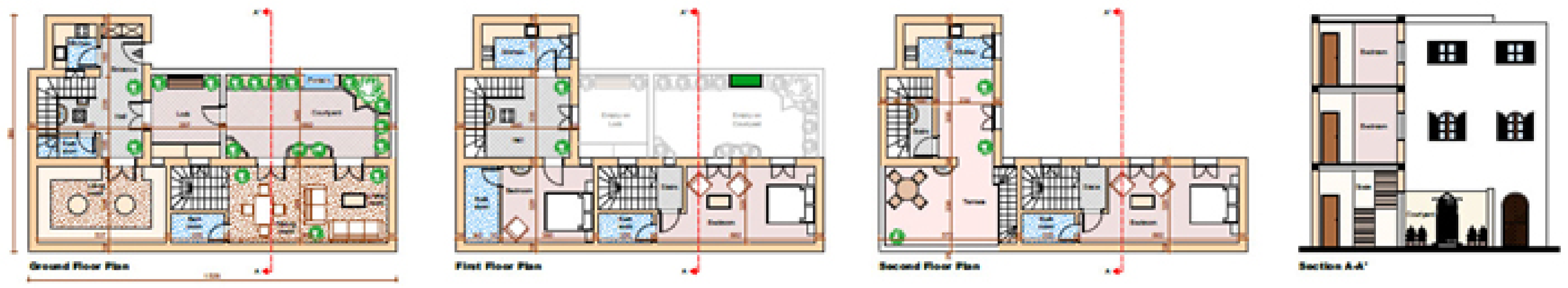
House 7



House 8



House 9



House 10

Table 2: *General construction details of the houses studied.*

House number	Surfaces	Courtyard / Skylight area	Exterior Wall thickness	Finishing walls and roofs	Years of construction /Renovation
1	120 m²	9 m² / 0.96 m²	37 cm	Roof: Moroccan zellige Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1965 Reno: 1998
2	87 m²	— / 2.25 m²	38 cm	Roof: Grey coated concrete cement Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1976 Reno: 2003
3	107 m²	18.43 m² / —	35 cm	Roof: Moroccan zellige Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1964 Reno: 2010
4	97 m²	— / 3.70 m²	39 cm	Roof: Red zellige Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1969 Reno: 2002
5	410 m²	42 m² / —	40 cm	Roof: Yellow zellige Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1961 Reno: 2007
6	96 m²	8.40 m² /1.56 m²	35 cm	Roof: Red zellige Wall: Ext – Yellow coated paint Int – Zellige	Const: 1965 Reno: 2001
7	89 m²	11.38 m² /0.61 m²	37 cm	Roof: Red zellige Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1974 Reno: 2013
8	141 m²	37.45 m² /5.30 m²	36 cm	Roof: Red coated concrete cement Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1963 Reno: 2009
9	64 m²	11 m² / 5.60 m²	35 cm	Roof: Brown zellige Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1978 Reno: 2012
10	126 m²	37.75 m² / —	39 cm	Roof: Blue coated concrete cement Wall: Ext – White plaster coated paint Int – White plaster coated paint	Const: 1964 Reno: 2008

Table 3: *Presence of bioclimatic features in the studied houses.*

House No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Patio	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Skylight	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No
Horizontal Shading	Yes	No	No	Yes	Yes	Yes	No	No	Yes	No
Moucharabieh	No	No	Yes	No	Yes	No	Yes	No	Yes	Yes
Shutters	No	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes

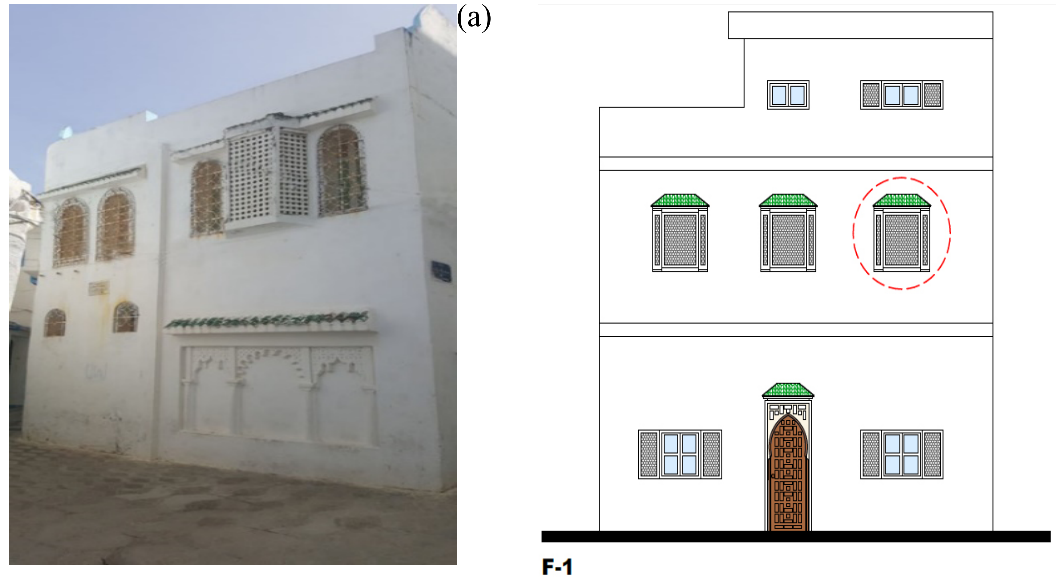
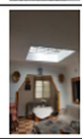
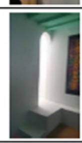


Figure 4: *Integration of Moucharabieh in the exterior walls of the studied houses.*

Figure 5: *Types of horizontal shading and shutters used in the traditional houses.*

Table 4: *Pictures of the different architectural elements studied in the houses.*

House number	Interior Wall finishing	Exterior wall finishing	Courtyard / Skylight	Roofs finishing
House n° 1				
House n° 2				
House n° 3				
House n° 4				
House n° 5				
House n° 6				
House n° 7				
House n° 8				
House n° 9				
House n° 10				

2.1. Indoor thermal comfort evaluation of the bioclimatic houses of Asilah

Of the well documented approaches to evaluate thermal comfort and satisfaction of buildings' occupants is the conductance of survey (Kurnaz & Aniktar, 2024; Wise et al., 2021). Accordingly, a detailed questionnaire has been developed. The survey consisted of a series of detailed questions aimed at understanding the thermal comfort experiences and behaviors of the occupants in their homes. The questions covered various aspects of indoor thermal conditions, such as perceptions of temperature during different seasons, ease of temperature control, and adaptive strategies employed to manage indoor climate. For instance, the survey asked participants to rate their satisfaction with summer and winter indoor temperatures, with options ranging from "Unbearable temperatures" to "Perfect." It also inquired about the methods used for temperature control, such as opening windows or using shutters, and the types of heating used during winter. Additionally, the survey explored the effectiveness of natural ventilation and the presence of architectural devices aiding air renewal, as well as the use of solar protection elements and additional ventilation devices during summer. In Table 5, a detailed overview of the survey results, highlighting the occupants' experiences with temperature comfort during summer and winter, the ease of controlling indoor temperatures, and the quality of natural ventilation are represented. For summer temperature comfort, four houses (1, 3, 8, 10) reported finding the ambient temperatures during summer to be quite comfortable, indicating a high level of satisfaction with the thermal conditions in these homes during the hotter months. Five houses (2, 4, 5, 6, 7) reported normal temperature comfort during summer, suggesting that the majority of houses find the summer temperatures to be within a comfortable range, neither too hot nor too cold. While, one house (9) found the summer temperatures to be moderately acceptable, indicating a slight discomfort but still within a tolerable range. On another hand, for winter temperature comfort, the majority of houses (1, 2, 4, 5, 6, 7, 8, 9, 10) reported the winter temperatures as moderately acceptable, which indicates a general sense of mild discomfort, suggesting that these houses may require additional heating measures or better insulation. While the remaining house (3) reported normal comfort during winter, suggesting adequate thermal performance and effective heating strategies in place. Regarding temperature control ease, six houses (3, 5, 6, 7, 8, 10) found it easy to manage their indoor temperatures, indicating that these houses have effective climate control systems or strategies in place. Two houses (2, 9) found temperature control to be moderately easy, suggesting some effort is required but overall manageable. One house (4) reported a normal level of ease in controlling temperatures, indicating an average level of effort needed. And finally, one house (1) found it difficult to manage temperatures, suggesting potential issues with the house's climate control systems or insulation. Concerning natural ventilation quality, five houses (1, 3, 5, 8, 10) reported very good natural ventilation, indicating that these houses benefit from effective natural air circulation, which contributes to thermal comfort. And the other five houses (2, 4, 6, 7, 9) reported sufficient natural ventilation, indicating that while ventilation is adequate, there may still be room for improvement in air circulation. Consequently, the survey results highlight that most houses find summer temperatures to be comfortable or normal, while winter temperatures are generally seen as moderately acceptable. The ease of temperature control varies, with many finding it easy or moderately easy to manage. While, natural ventilation quality is predominantly very good or sufficient. For insights into the methods and devices used by the occupants to manage their indoor environment across various parameters, the results of the survey are represented in Table 6. Regarding additional ventilation in summer, it was found that six houses (1, 3, 4, 7, 8, 10) do not use any additional ventilation during summer, indicating that natural ventilation is sufficient for these occupants. While other four houses (2, 5, 6, 9) use additional ventilation devices occasionally, when natural ventilation is not enough, and extra measures are needed to maintain comfort. For temperature control in summer, most houses rely on opening windows and taking advantage of solar protection as primary methods, indicating a strategy to control both ventilation and solar gain. While for winter heating, eight houses (2, 3, 4, 5, 7, 8, 9, 10) indicated the use of heaters during winter, either an electrical devise or a fireplace, while instead two houses (1, 6) rely only on increased clothing.

Table 5: *Survey results concerning temperature comfort in summer/winter, temperature control ease, and natural ventilation quality.*

House No.	Summer Temp Comfort	Winter Temp Comfort	Temp Control Ease	Natural Ventilation
1	Quite Comfortable	Moderately Acceptable	Difficult	Very good
2	Normal	Moderately Acceptable	Moderately Easy	Sufficient
3	Quite Comfortable	Normal	Easy to manage	Very good
4	Normal	Moderately Acceptable	Normal	Sufficient
5	Normal	Moderately Acceptable	Easy to manage	Very good
6	Normal	Moderately Acceptable	Easy to manage	Sufficient
7	Normal	Moderately Acceptable	Easy to manage	Sufficient
8	Quite Comfortable	Moderately Acceptable	Easy to manage	Very good
9	Moderately acceptable	Moderately Acceptable	Moderately Easy	Sufficient
10	Quite Comfortable	Moderately Acceptable	Easy to manage	Very good

Table 6: *Survey results concerning methods and devices used by the occupants to manage their indoor environment across various parameters.*

House No.	Additional Ventilation Summer	Heater Usage	Air Renewal Devices	Heating Device Type	Temp Control Method Summer	Solar Protection Elements
1	No	No	Central patio, Interior & Exterior windows, Skylight	Increase clothing	Opening windows	none
2	Occasionally	Yes	Interior & Exterior windows, Skylight	Electric	Opening windows	none
3	No	Yes	Central patio, Interior & Exterior windows	Electric, Fireplace	Opening windows	Moucharabieh, Sun blocker
4	No	Yes	Interior & Exterior windows, Skylight	Electric	Opening windows, Closing shutters	Shutters, Sun blocker
5	Occasionally	Yes	Central patio, Interior & Exterior windows, Skylight	Fireplace	Opening windows, Closing shutters	Shutters
6	Occasionally	No	Central patio, Interior & Exterior windows, Skylight	Increase clothing	Opening windows, Closing shutters	Shutters, Sun blocker, Canopy
7	No	Yes	Central patio, Interior & Exterior windows	Increase clothing	Opening windows, Closing shutters	Shutters, Moucharabieh, Sun blocker
8	No	Yes	Interior & Exterior windows	Fireplace	Opening windows	Moucharabieh, Sun blocker
9	Occasionally	Yes	Central patio, Interior & Exterior windows, Skylight	Electric	Opening windows, Closing shutters	Shutters, Moucharabieh, Wooden pergola
10	No	Yes	Central patio, Interior & Exterior windows, Skylight	Electric	Opening windows, Closing shutters	Shutters, Moucharabieh, Sun blocker, Wooden pergola

Conclusion

With the urgent need to transition towards a sustainable operation of the building sector, with a lower reliance on active energy use for indoor thermal comfort, adopting bioclimatic architecture offers a promising solution by utilizing passive design strategies that enhance energy efficiency and occupant comfort through climate-responsive features. Traditional bioclimatic houses present a valuable resource to evaluate the suitability of different bioclimatic features for their potential adoption on modern houses. The bioclimatic houses of Assilah, Morocco, were the focus of this research. A detailed survey was conducted to identify the bioclimatic features of these houses and assess their indoor thermal comfort. The results indicated that most houses maintain comfortable or normal temperatures in summer and moderately acceptable temperatures in winter. Temperature control was found to be easy or moderately easy for many residents. Additionally, the quality of natural ventilation was predominantly rated as very good or sufficient. Overall, the passive strategies employed in these buildings were sufficient for maintaining comfortable summer temperatures and good air quality. The thermal comfort in these traditional buildings can be attributed to several passive bioclimatic strategies. Patios, positioned either centrally (60%) or at the back (40%) of the house, act as climate buffers, providing passive cooling in summer and enhancing sunlight exposure in winter. Skylights, found in 70% of the homes, improve natural lighting and contribute to heating during colder seasons by reducing the need for artificial lighting. Half of the homes use moucharabiehs, which offer privacy while promoting airflow and providing shade and natural ventilation by blocking direct sunlight. Additionally, 50% of the houses use shutters or horizontal shading devices to reduce direct sunlight and allow for diffused light. However, there is still a greater reliance on active heating during winter months. These findings suggest that contemporary architecture could benefit from incorporating bioclimatic elements from traditional Moroccan designs.

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