THERMAL PERFORMANCE OF PASSIVE ENVELOPE SYSTEMS IN LIWAN TYPOLOGY: CASE OF MID-MOUNTAINOUS REGION IN LEBANON

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ABSTRACT

Vernacular architecture (VA) can be a model for sustainable architecture (Mirahmadi and Altan, 2017), while maintaining harmony with the context, environment, climatic conditions, and uses local available materials. Vernacular practices vary by the use of techniques, materials, and methods of construction in order to minimize the negative impact on the environment (Al Tawayha et al., 2019). It bears a cultural identity that is often lost in some rural areas and has developed strategies that are considered as climatic responsive, minimize the energy consumption, and assure the indoor thermal comfort and quality. In Lebanon, different architectural typologies exist starting with the Rectangle House, Gallery House, Liwan, to Central Hall Houses. This thesis will focus on the Liwan House Typology. This typology mainly exists in coastal and mid-mountain regions. The study emphasizes on building envelope construction with respect to climatic conditions and investigates the thermal performance of the envelope system; i.e. heating/cooling performance and thermal indoor comfort values. The system evolution of walls, roofs, and floors play a marginal role when studying the building's envelope. Finally, this thesis aims to study the adaptability of the Liwan typology to the needs of contemporary housing and operational energy consumption within an environmental sustainable viewpoint, and proposes guidelines for contemporary housing that are applicable within the rules and regulations in the studied location.

Keywords: *Liwan - Envelope - Thermal Comfort - Environmental Dimension*

Chapter One

1.1 INTRODUCTION

Mount Lebanon has an impact on the development of Lebanon through the cultural exposure to Europe (Traboulsi, 2012, p. 1) within two economic arenas as the industrial manufacture of silk thread in Mount Lebanon and the export of silk cocoons to Europe (Khater, 1996). In Mount Lebanon, the Ottoman practice of employing local masons as masters of construction prevailed (Haddad, 2007). In one of the countless terraces in the mountains of Lebanon, a simplest form of Vernacular Houses is found as a singular unit known as the Liwan typology (Ragette, 1974). In Persian, Iwan means portico or an open gallery, though Liwan in Arabic covers the Persian concept (Kalantari, Singeri and Jourshari, 2015). Liwan House is a Lebanese Vernacular Architecture typology (Soleymani, et.al, 2011) of which many houses are still standing and inhabited. Salgın et al. (2017, p. 1) indicates, "When the world seeks for more sustainable buildings, it is acceptable to revisit the past in order to understand sustainable features of vernacular architecture". It has a rectangular-shaped plan (Kalantari, Singeri, and Jourshari, 2015) that is a part of the evolution of the Lebanese Central Hall House, which is a traditional house found in Lebanon (Abou Jaoude, 2016).

1.2 Historical Background on the Liwan Vernacular Envelope Systems

Iwan, or what is known, as Liwan is an architectural form, refers to a part of a building that is enclosed on the three sides, creating an empty vaulted space and opening to an open or closed centralized space (Tuncel, 2019; Peker, 1992). A different term of Liwan has been addressed according to needs and depends on the building that it serves. For Tuncel (2019), Liwan in Persian means open portico, gallery or palace, and this Persian word was adopted from Arabic, Turkish, and Kurdish languages (Abdulrahman et al., 2019). However, the Liwan space in the Sassanid period was used as an audience hall for the kings (Thessaloniki and Arakadaki, 2016). It is a traditional intermediate space (Feroz, 2014), a raised part of a floor (Abdulrahman et al., 2019), and considered as a large alcove opening onto the courtyard (Levant, 2004). Various definitions exist to describe and analyze houses within the Liwan features. Although, Rouhi et al. (2017) describes Liwan as a rectangular space or a tripartite structure (refer to Figure 1.1(a)), usually vaulted, walled on three sides (refer to Figure 1.1(b)), with one end either semi or entirely open on to a central courtyard (refer to Figure 1.1(c)). This space was mostly used in large houses and rich owners, as in the Sassanid period. The fountain feature was added in front of Liwan (Hadid, 2002). From a spatial viewpoint, Liwan may cause hierarchy, variety, readability, and coherence from the outside and inside (Nejadriahi, 2016). There is a spatial extension of the semi-open gallery towards the house interior (Turgut, 2019). AlZubaidi (2007) suggests that the movement between the public, semi-public, and private zones occurs through a transitional space known as a Liwan. This space holds important qualities, as it is a transition space from outside to inside, from glare to dark, from public to private (Ragette, 2012). It acts as a covered outdoor space between the fully open sunny courtyard and the closed dim internal space, softening the transition from very bright to dark (AlZubaidi, 2007). It also connects two living sections acting as a distributional space (Levant, 2004) for there are usually two rooms with doors placed on the frontal part of the Liwan side walls

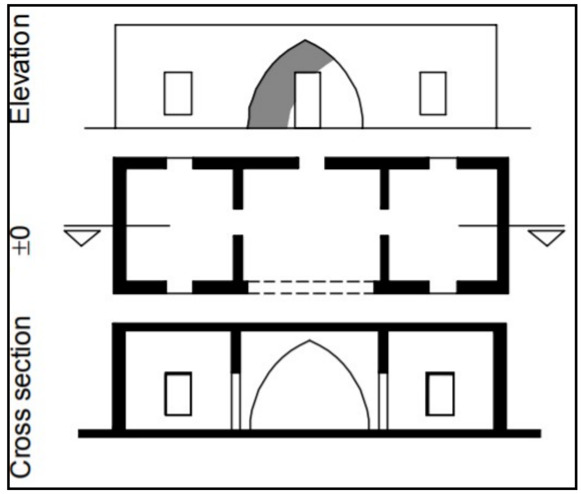


Figure 1.1: (a) Standard Plan, (b) Cross-Section and (c) Elevation of Liwan as Tripartite Structure. Source: (Corpus and Euromed, 2003) Accessed 10-1-2021

(Suzdaltseva, 2019). Liwan can be considered as a whole designation that sets a stream between the garden or yard of the soul and the room as a physical state from a metaphysical point of view (Kalantari et al., 2015, p. 2). At times, the city architectural elements are also applied to rural housing, such as the Liwan, but in a much simpler version with the use of cheaper materials such as wooden roofs covered with plants or mud and brick walls (Levant, 2004). In a typical multipurpose rural house, Liwan was used for living, a local workshop, a warehouse, or a shelter for domestic animals in the central space Liwan (Levant, 2004). It can also serve as the principal reception area of a house with continuous seating on all three walls (Ragette, 2012). As a composition, Liwan is designed of three aligned units where two are used for living and the central unit that is open on the exterior (Levant, 2004). It is located facing a courtyard which is open and without any ceiling. Rooms such as the living room, bedrooms, guest rooms, or other rooms with various functionalities that are located around and faced the courtyard as well (Safarkhani, 2016).

It is important to understand the history overview of Liwan as it was used in different cultures, reflected different terminologies, and depends on different climatic conditions. Some researchers thought that the Liwan was probably developed in Mesopotamia in 3000 B.C (Peker, 1993; Downey, 1988). Tuncel (2019) considers that the trajectory of the Liwan opened up in Roman Empire, effloresced in analogous forms, and was manifested in the Roman period in different forms such as Canopus, Baldachin, Exedra, Apse, Banquet Hall, Pedimented Shrine, Arched Canopy, Aedicula, Audience Chamber, and Tablinum. Among the hypothesis is the conception of Peker (1993) who advanced the notion that Liwan emerged from the tradition of a people accustomed to moving in open air, viewing the blue sky, and living in tents or reed huts as shelters against sun and wind. Those consider Liwan as a rock tent for people used to living in the desert and they reflected the contact with nature, making it common to use rooms with triple walls

(Kakizadeh, 2014). However, Ruether (1967) argues that the Liwan had an archetype created by a nomadic culture that did not only have need for social space but also for physical shelter (Tuncel, 2019). Among the hypotheses of the genesis of Liwan, the viewpoint of Colledge (1967, 120) found it to be at home in Persia, for it is the standard feature of late Iranian architecture. Kakizadeh, (2014) discusses this hypothesis thinking that some people consider Liwan to have emerged from Iranian houses and palaces, though others think that it was formed during the Era of Parthia. Other viewpoints link the prototypes of the later Liwans to the rooms of the late Hittite Palaces, at the beginning of the first millennium B.C., at Zinjirli and the barrel vaulted matted straw covered rush huts of the dwellers of the Babylonian marshes (Kalantari, 2015).

Liwan comes with various sizes and applications, depending on the culture, and purpose of its creation (Tuncel, 2019; Reuther, 1967, 428). Liwan has been used in various buildings such as mosques and palaces (Nejadriahi, 2016). The Anatolian Seljuk Age comprises the nucleus of the palaces of the period with an architectural composition made up of a courtyard and Liwan along with the construction techniques of local building materials and local masonry (Erarslan, 2020). After the Seljuk Sultanate, during the end of the fifteenth and sixteenth century, Ottoman architecture began to develop a different mode of architectural expression of basic characteristics modularity and centrality. The dome represented openness and central structure making it possible to construct higher domes (Thessaloniki and Arakadaki, 2016). The Ottoman Architecture was one of the preferences of Liwan elements for gathering places. Those gathering spaces are called *Divanhane*. Erarslan (2020) defines the Three-Liwan Ottoman Divanhanes, considering it as a place where council meetings are held, ambassadors are received, and other important ceremonies took place as it is considered a reception area, guest room, location for official meetings, or even large spaces of the palaces, pavilions, mansions, and kiosks. The *Divanhanne* is a Turko-Islamic terminology that means Liwan. It is an important Islamic design feature located within the courtyard to define openness in residential buildings, but also for public buildings (Malik and Mujahid, 2016). Erarslan (2020) discusses the evolution of the Divanhane/Liwan in different periods and shows its cultural importance especially in Islamic regions. The first Divanhanes in the Islamic architecture was seen in the time of the Umayyads. One of the first spaces that can be identified as a Divanhane is in the palace of the Umayyad Period and connects the Umayyad Mosque of Damascus (refer to Figure 1.2) which is the earliest surviving stone mosque. The Liwan space of this mosque is the central location of the state administration with a monumental dome-covered Divanhane (Erarslan, 2020).

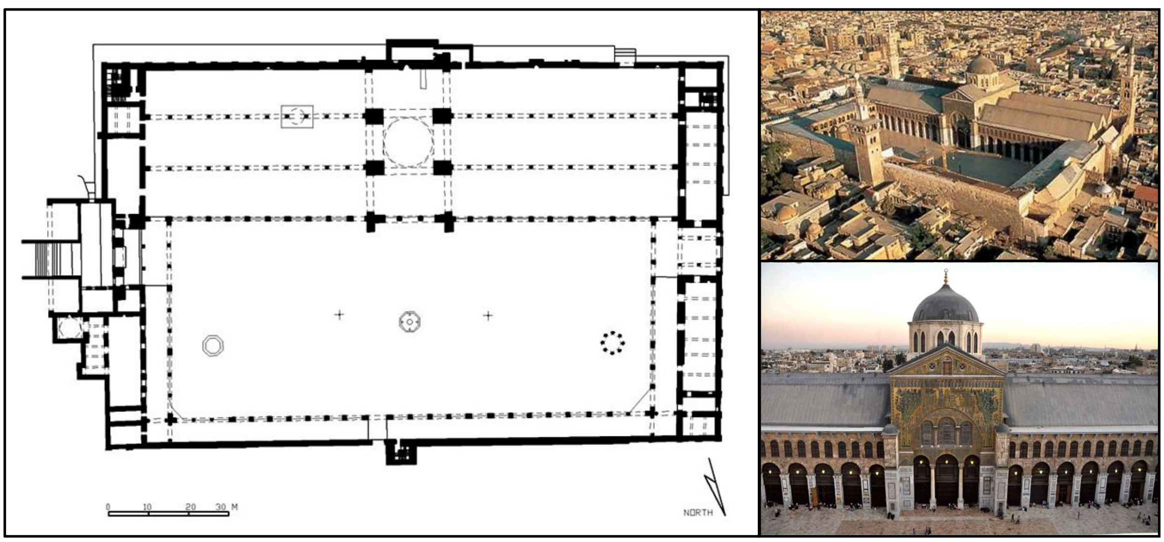


Figure 1.2: Plan and Perspective View of Umayyad Mosque in Damascus. Source: Pinterest 2020 Accessed: 29-12-2020

The two-Liwan Divanhane is among the examples that followed the early Ottoman Divanhances that can be seen in Sofa Mansion at Topkapı Palace (refer to Figure 1.3) using the marble material and the classic Ottoman Divanhane of three-Liwan dome. Within the three-Liwan type of the ottoman period, it is also called Sedir (Erarslan, 2020). The form of the Sofa can't be separated from the Liwan; it is a "T" or "L" form extended with the rectangular recess (Turgut, 2019).

Figure 1.3: Sofa Kiosk at Topkapı Palace plan with Two-Liwan Divanhane. Source: Wikimedia Accessed: 5-1-2021

The domed Divanhane with four-Liwans under a central dome appeared in the Abbasid Era such as the palace in the middle of Baghdad (refer to Figure 1.4) which was one of its kind. The materials used are mud brick, baked brick, and rough stone blocks set in mortar (Erarslan, 2020). Liwan's most prevalent usage is in the form of four-liwan courtyard and the Seljuks introduce the four-liwan scheme to Islamic architecture (Thessaloniki and Arakadaki, 2016).

Figure 1.4: Abbasid Palace in Baghdad of Four-Liwan. Source: Pinterest Accessed: 5-1-2021

The journey of Liwan construction in Mesopotamia can be observed through the Parthian Liwans (Tuncel, 2019). For Thessaloniki and Arakadaki (2016), the Parthian Architecture is one of the best examples for Liwan in palaces, temples, and housings, considering that the first Liwan in its real concept that started with the Parthian Assur Palace (first and second century A.D), in Hatra (refer to Figure 1.5(a)). This was the first known Liwan monumental brick (refer to Figure 1.5(b)) as a part of the four-Liwan courtyard scheme. In the Parthian period, Liwan was purified in decoration that is used in the main living quarters and became the hallmark of which it consists of the architectural traditions (Tuncel, 2019).

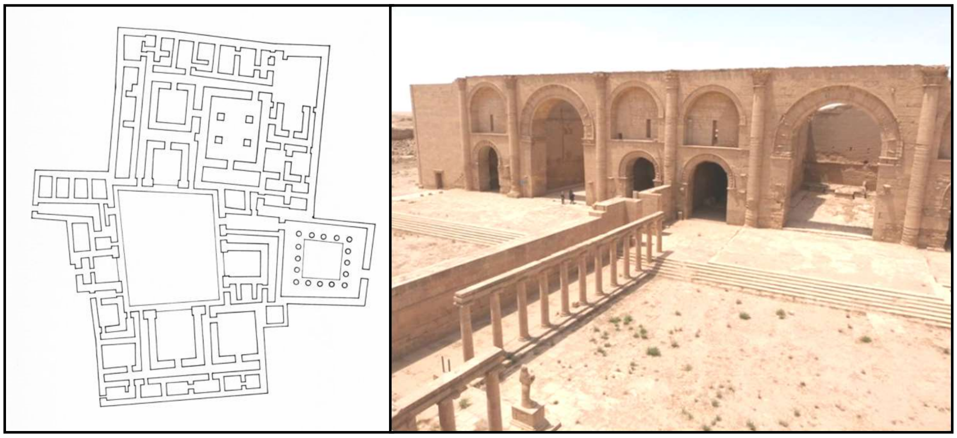


Figure 1.1 (a) Plan of Parthian Assur Palace in Hatra of Four Liwan. (b) Perspective of Parthian Assur Palace in Hatra. Source: Pinterest Accessed 5-1-2021

The Liwan is seen as a part of Parthian and Sasanian architecture. Although Sassanid architecture pays tribute to Achaemenid and Parthian architecture, its style is not repetitive. Liwan House is derived from the Hellenistic House via the Sassanids (Tuncel, 2019). It serves as a significant purpose in spatial organization within the Sasanian Architecture and the arrangement of one, two, or four Liwan situated around the courtyard (Erarslan, n.d.). The evolution of the use of Liwan in different architectural styles and consecutive periods aroused when the centre of power in the Islamic world shifted from Damascus to Baghdad as the architectural influence shifted from Byzantium to the Sasanids. The prevailing architectural style was the pointed arches, vaulted arcades, and Liwans (Thessaloniki and Arakadaki, 2016). Sassanid architecture can be considered as the last great pre-Islamic culture of Persia (Tuncel, 2019). Within the Sasanian architecture, the Tak-i Kisra palace (refer to Figure 1.6(a)) in the city of Ctesiphon dated to circa 550 B.C. containing a Liwan covered by a brick vault (refer to Figure 1.6(b)) that is considered the world's most magnificent Liwan (Erarslan, n.d.). According to this example, it is highly recognized that the Liwan can also be considered as a space ahead which emphasizes on the entrance (Nejadriahi, 2016).

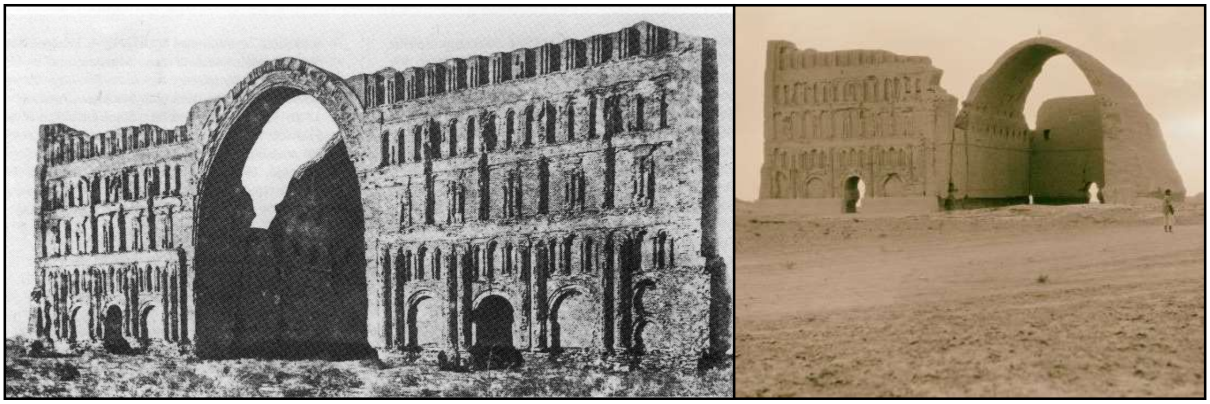


Figure 1.2 (a) Tak-i Kisra Palace in Iraq with a Liwan of Brick Vault Prior to 1888. (b) Tak-i Kisra Palace in Iraq with a Liwan of Brick Vault after 1888. Source: Encyclopedia Iranica and Gettyimages Accessed: 6-1-2021

Liwan is an element in the architecture of the Sassanian, developed in Mesopotamia, and became part of the Islamic and Middle Eastern architecture (Petersen 1996, 130). Liwan has taken place in mosques, palaces, and in other urban elements, but its main use specifically during and after the appearance of Islam was in houses (Kalantari, 2015). There are seven practices in the houses of different Muslim countries that are highlighted; refusing of toilet alignment with the Qiblet, providing natural view and privacy using the Masharabiye, using the Liwan element as a covered platform to enjoy the views of the courtyard, implementing a sunken courtyard, orienting the residential spaces inward, using minimum design feature on the exterior façade, and maintaining privacy as gender based spatial organization (Malik and Mujahid, 2016). Introversion is also an essential feature derived from Islamic beliefs and one of the concepts that values private life (Rouhi et al., 2017). The openings of the internal spaces are open on to the Liwan because there are no windows open to external elevations especially in the ground level except the Majlis (Al-Zubaidi, 2007). Liwan is considered as the main feature in the facade of building and reached the peak since the period after Islam (Kalantari, 2015). Liwan is strongly associated with the architecture of the Middle East (Abdulrahman et al., 2019). In the Islamic period, the Arab Courtyard House was the name of the courtyard with Liwan (refer to Figure 1.7). This type of house carried common features and it's known by different names in Lebanon besides other Middle Eastern countries such as, Southeastern Anatolia, Syria, Iraq, Tunisia, Palestine, Egypt, and Saudi Arabia and even in Iran. In hot climates, the central country and Liwan element is fundamental to the characteristics of Liwan courtyard house or what is known as the traditional Islamic-Arab house (Erarslan, n.d.).

1.2.1 Liwan Typology and Vernacular Sustainable Strategies

The domestic space emerged during the historical formation of the Islamic culture region. The principles of Islam promote sustainable approaches for designing residential spaces, especially during the presence of the Liwan feature in the design of houses (Malik and Mujahid, 2016). Sustainable development improves the social, economic, and environmental conditions for future generations and enhances quality of life allowing people to live in healthy environment (Ortiz, Castells, and Sonnemann , 2009). Building must meet the objectives of sustainability in order to achieve harmonization of the environment, pollution prevention, resource, and energy efficiency (John, Clements-Croome, and Jeronimidis, 2005). According to Akadiri, Chinyio, and Olomolaiye (2012), the resource conservation and cost efficiency are two of the main objectives when implementing a sustainable building's design. The third objective is the human adaptation, which addresses the thermal comfort of the occupants. Solutions of passive strategies used as type and thickness of the envelope fall under the human adaptation to the environment to regulate the temperature (Pérez et al., 2015). The passive building techniques were used in the vernacular architecture that was developed in response to the prevailing climatic conditions of the past (Kumar and Gokarakonda, 2016).

Liwan features spatial and functional values in vernacular architecture (Kakizadeh, 2014). Vernacular architecture is associated with houses that are designed in accordance with the climatic conditions (Salgın et al., 2017). Vernacular architecture is rich with techniques that early dwellers used to protect themselves from diverse weather conditions that they were subjected to (Naciri, 2007). A Vernacular House reflects the site and the microclimate of the context, and respects nearby buildings (Rapoport, 1969). 'Vernacular architecture has been categorized as the study of traditional buildings' (Brown and Maudlin, 2011, pp 340). The Liwan has been widely used as a space to serve different purposes in various forms of traditional buildings including the houses (Abdulrahman et al., 2019). Traditional buildings are a similar concept to the product that people inherited the knowledge or techniques that are accepted by the society as the correct way (Noble, 2013). Traditional buildings are distinguished based on only one attribute: their envelope construction (Webb, 2017). The traditional ways of buildings are the product of the builder's knowledge that are skilled masons and building techniques due to the creative use of local materials to handle environmental features (Karakul, 2016). It was influenced with the envelope construction, use of material, and traditional techniques (Nejadriahi, 2016).

Figure1.3 Lebanese Liwan Courtyard House. Source: Pinterest Accessed: 8-1-2021

> 'The birth of traditional building techniques was mainly caused by climatic and natural factors or else by environmental characteristics and availability of building materials. The construction technique is the means through which a particular culture is able to implement its response to environmental challenge, not by chance wood and earth are the two natural

building materials most used in the elementary building process, because the most widespread and available throughout all Earth's surface' (Baglioni, 2010, p. 3).

Vernacular Architecture is a type of construction that should be studied as it is characterized by having an intrinsic relation with local conditions (Fernandes, et.al, 2016). The relevance of vernacular features is still valid today for it is considered now the basis of sustainable building design (Fernandes, et.al, 2016; C añas & Martín 2004; Cardinale et al. 2013). It is considered an example of sustainability from its orientation, local building material, and the architectural form (Pérez et al., 2015).

Passive Design strategies in vernacular architecture contribute to the increase of energy efficiency in buildings, reduce their energy consumption, and improve the interior comfort conditions (Rodriguez-Ubinas et al., 2010). Vernacular Architecture strategies reduce the thermal deviations from comfort temperatures such as the thermal storage (Foged, 2019). The thermal effects and local availability of the materials conferring to climate were the major factors that were considered in the construction of the building envelope in the Vernacular Architecture (Yildiz and Manioglu, 2015; Florides, et al., 2001). Likewise, the building form that affects the amount of heat transfer through the building envelope (Yildiz and Manioglu, 2015) influences the thermal performance of a building.

1.2.2 Vernacular Envelope System: Thermal Comfort and Performance of Liwan

The presence of Liwan in the household results in thermal comfort, creation of a diversity in the performance of the envelope systems, independence between public and private spaces, and continuity of inside a towards outside and vice-versa (Kalantari, 2015). It plays a role in controlling the heat gain and loss besides resulting in thermal comfort (Feroz, 2014). Thermal comfort parameters include temperature, relative humidity, and the mean radiant temperature to determine whether the indoor environment is comfortable or not (Praseeda et al., 2014). The Liwan House has climatic responsive strategies that differently adapt in climatic conditions providing thermal comfort. The vernacular architecture developed ingenious passive strategies to mitigate the effects of climate and assure the best comfort conditions possible (Fernandes et al., 2017). The thermal comfort in Vernacular Architecture is provided by the passive strategies that are the result of the manipulation of spatial form and building envelope elements that utilize the advantages of the climate (Huang and Liu, 2010). The building envelope is unpacked within three main systems that are wall system, roof system and floor system.

Figure 1.4 Liwan House in Tyr Having Inside and Outside Walls Rendered with Lime. Source: (Corpus and Euromed, 2003) Accessed 10-1-2021

Liwan prevents the inward facing walls from straight solar radiation and excessive heat gain (Feroz, 2014). Despite the high thermal inertia, the thick exterior wall in Vernacular Architecture provides comfortable indoor environment in the inner areas with less energy consumption (Poggi et al., 2015). Lotfabadi and Hançer (2019, p. 5) suggests that 'the thermal insulation can lower heat transfer rates between controlled indoor areas and uncontrolled outdoor environments, leading to a significant reduction in building heating and cooling energy demands'. The optimization of insulation thickness on external walls with respect to cooling loads, in different seasons and climatic zones, is more appropriate for energy savings compared to the heating loads (Dhar et al., 2014). The insulation material is installed in the middle of the wall which results in better performance in winter (Lotfabadi and Hançer, 2019). The thermal performance refers to how well a building is insulated from external weather conditions to achieve comfortable indoor temperature (Dhar et al., 2014). The wall configurations and properties of the building materials are used to maintain comfortable indoor comfort across the seasonal weather variations and optimum thermal performance (Dhar et al., 2014). Different prominent materials were used, such as mud, adobe, and brick that are made with clay for the high thermal capacity to minimize the temperature fluctuations in the inner space between day and night (Hashemi, 2018). In addition to the stone material for walls that was used having positive contributions provided with high thermal inertia (Poggi et al., 2015). Color plays an important role in cooling the structures of exterior surfaces and interior barriers (refer to Figure 1.8), therefore the light color material was applied to maximize the usage of natural lighting and reflect the heat during the hot season (Melki, 2014). The common feature of Vernacular Architecture is the over hangs that acts as a shading mechanism and significantly influence the thermal performance of walls (Dhar et al., 2014).

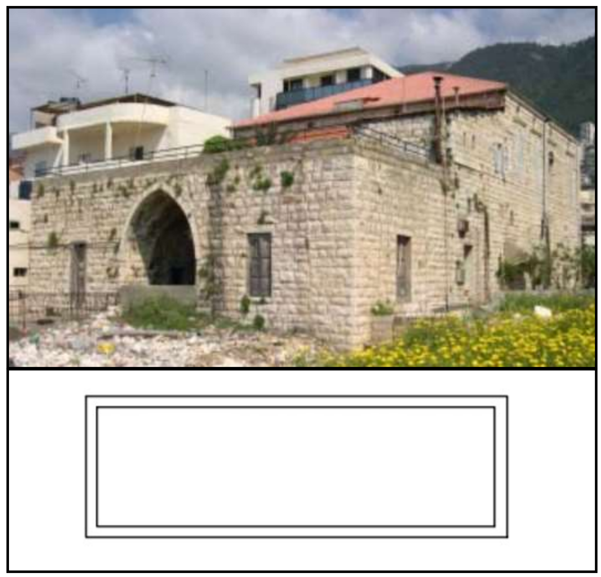


Figure 1.5 Roof of Liwan House in Lebanon from Perspective and Mass plan View.
Source: (Corpus and Euromed, 2003) Accessed 10-1-2021

The number, size, shading and the building openings' orientation (Al Tawayha et al., 2019) potentially influence the building thermal performance. A better performance can be sustained by considering the influence of the windows and walls, orientation, and windows-to-wall ratio (Dhar et al., 2014). The implementation of Liwan with consideration of a proper orientation is a naturally ventilated method for better performance. Usually, the passive cooling of the indoor spaces can be done by natural ventilation during the night and early morning, and then unwanted heat gains can be avoided by shutting the windows and doors during the periods of direct solar radiation (Fernandes et al., 2017). Reducing the size and number of openings are important factors to reduce the solar radiation penetrating the glazing and the building envelope; hence, it helps to reduce heat gain (Sayigh, 2019). The building envelope as if walls and roofs have an important role to play in the heat transfer process between the indoor and outdoor environment of the building (Dhar et al., 2014). The thick walls and roofs are good insulators and help stabilize room temperature (Levant, 2004).

'Vernacular architecture reflects the characteristics of the climate, especially for the roof design' (Lopez-Besora et al., 2019, p364). The roof of the Liwan House (refer to Figure 1.9) is composed of hard-packed earth resting on a flat floor supported by beams and joists. The roof can sometimes include an element to freshen hot summer evenings (Corpus and Euromed Heritage, 2003). Nia et al. (2013) claimed that people applied some roofing strategies to provide well-being and comfort of residents indoors. The roof materials are one of the main parameters of the building envelope that affect the indoor thermal performance in vernacular architecture (Chandel, Sharma, and Marwah, 2016). Vernacular buildings used local and affordable materials such as grass, heather, woven textiles, felt mats, straw, bamboo, tree bark, timber, logs, turf, mud, stone and other materials (Noble, 2013). As for the tile roofs, lightweight roofs, and corrugated sheet metal roofs have an extremely negative effect on the indoor temperature in summer and winter (Meir and Roaf, 2005). The usage of high thermal mass materials that act as an insulation layer in hot and cold climates, in the vernacular roof systems, secure the wellbeing, ensure the comfort for residents, and manage the energy consumption (Nia et al., 2015). The roofs of vernacular buildings moderate the internal temperature by storing solar heat in daytime and releasing heat at night. Its thermal mass delays cold temperature to reach inside (Huang and Liu, 2010). The effectiveness of the thermal mass is related to many factors, including climate conditions, thermal properties of materials, heat gains, ventilation, thermal insulation and occupancy (Philokyprou et al., 2013). Thermal mass can be in the form of walls, roofs or floors, and can possibly be embedded (refer to Figure 1.10) in the different material (Badr, 2014).

*Figure 1.10Liwan House in Lebanon Showing Use of Material in the Envelope System. Source: (*Suzdaltseva*, 2019) Accessed 10-1-2021*

Figure 1.11 Material of Ceiling in Liwan House. Source: (Corpus and Euromed, 2003) Accessed 11-1-2021

The stored heat from the floor influenced the indoor air temperature (Nugroho, 2017). In Liwan Houses, the ceiling which is part of the flooring system is made up with beams (refer to Figure 1.11), joists and wooden laths (Corpus and Euromed, 2003). Different strategies were used for wetting the external surfaces as a method to cool the envelope and reduce the heat gains. This strategy, to spray water on the floor, was done in Liwan Houses of the mountainous regions on a daily basis (Taylor et al., n.d.). The passive cooling strategies were related to the courtyard that are evaporative cooling through the watering of plants and spraying the floor surfaces. Proper vegetation prevents the sun from reaching the building envelope and the floor; hence retarding the heat flow from the exterior to the interior (Philokyprou et al., 2017). Passive designs employ different strategies such as permanent ventilation of the space between ceiling and roof (Nugroho, 2017). A climate responsive design in vernacular architecture lies upon the evaluation of climatic influence, such as wind and sun, the optimization of building environmental performance and reduction of energy consumption, by using passive systems to achieve an environmental comfort (Motealleh et al., 2018).

1.2.3 Liwan Typology: Vernacular Climatic Responsive Strategies

Malik and Mujahid (2016) described the Liwan feature in a house design as an open u-shaped space articulated from three sides along with the fourth side facing the central courtyard to enjoy the beautiful views of landscape and natural environment. However, there are different forms of Liwan depending on the region, cultural and climatic conditions. Meanwhile, the regional climate has an impact on the form of Liwan, whether it is L-shaped, u-shaped, compound, one-sided, two-sided, three-sided, four-sided, middle Liwan or two-consecutive row Liwan (Kakizadeh, 2014). Meanwhile, the climatic responsive strategies of Liwan feature in vernacular architecture are marginal in order to study its effectiveness, environmental performance, and its efficiency with different climatic conditions.

Climate responsive building design is identified by ability of the building envelope to regulate the indoor thermal environment (Dhar et al., 2014). The climate responsive strategies and the use of local building material are the approaches used in the vernacular building for energy saving and environment friendly (Huang and Liu, 2010). Liwan house is introverted and can be used in different climatic conditions (refer to Figure 1.12) because this type of houses respond to environmental conditions (Soleymani, et al., 2011).

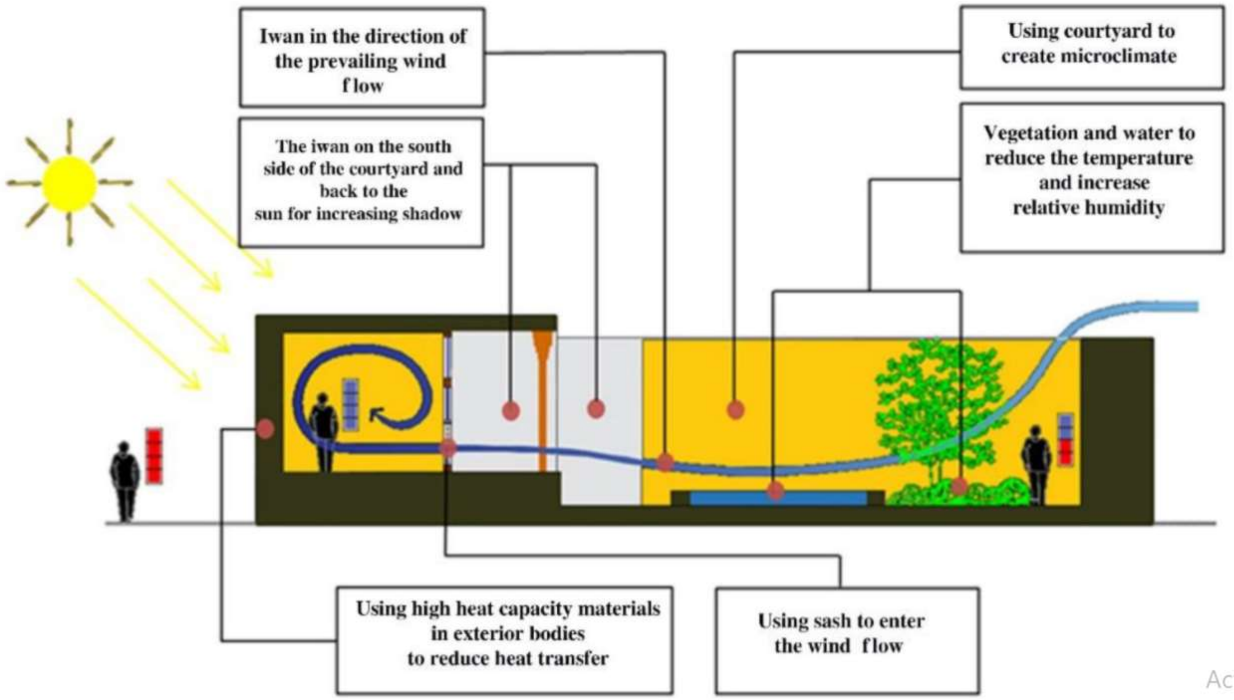


Figure 1.6 Climatic Responsive Strategies for Creating Thermal Comfort. Source: (Shaeri et al., 2018) Accessed 10-1-2021

Firstly, the thick massive walls served as a shading device from high summer exposure, allowing the winter sun to penetrate from the limited size of openings (Melki, 2014). High walls are also an effective solution, in harsh climate, by reducing solar radiation reached by building facades (Hashemi, 2018). In a cold climate, massive walls with limited openings are implemented in order to contain the heat inside (Lee, n.d.). While in hot climates, shading devices were used on walls and particularly windows exposed to summer sun (Hashemi, 2018). The thick walls were designed to shade the opening during the summer but not block sunlight during the winter (Melki, 2014). Thick walls were made of construction materials resulting in cool and warm environments in summer and winter seasons respectively (Hashemi, 2018). Liwan was implemented in hot and humid regions to absorb the maximum moisture inside the house‘s yard (Safarkhani, 2016), and it seems ideal for a person to not step into the hot spaces or hot courtyard, in case the typology of the latter space was Liwan courtyard house which was preferred in hot climates (Al-Zubaidi, 2007). In studying climatic responsive strategies, the orientation of openings, windows and doors, should be well analyzed as passive strategies in vernacular houses. The orientation of Liwan depends on the region in which it is located. The usual strategy of orienting houses includes the normally facing north for ventilation and summer cool breeze, and south for direct sun needed for winter cold days; hence must be in shade to reduce heat gain (Fernandes et al., 2015). The cross openings of rooms ensure airflow in the house's interior and cause cool breezes (Philokyprou et al., 2013). To prevent sunlight from penetrating the interior space, windows and openings are usually placed in the ceiling (Hashemi, 2018). Windows give light and air, and can be designed either down to the floor for a sitting place called mandalun or placed close to the ceiling (Melki, 2014).

Secondly, the roof is one of the elements in the building envelope and of the important elements to assess vernacular architecture as design and construction techniques concerning climate responsiveness (Bodach, Lang, and Hamhaber, 2014). As an example, the flat roofs, such as the liwan, lose less heat than the curved roofs that cause reduction of the indoor temperature, during the night (Tang et al., 2006). The vernacular vaulted roofs were high in order to raise up the indoor warm air and keep the living space in comfort condition (Nia et al, 2013; Moradchelleh, 2011). Therefore, the arched roofs with ventilation cap at the top were the proper choices for hot and dry climate compared to the flat roofs with their indoor warm air exit through the opening (Tang et al., 2006). The self-shading of flat roofs has unchangeable temperature surfaces, in contrast to that of the vaulted roof (Tang et al., 2006). The shading of the flat roof was used as an old practice in the Mediterranean villages, to reduce the indoor temperature up to three degrees

Celsius (Meir et al., 2003). Despite the fact that Liwan is one of the traditional elements which connects the other spaces of the building and provides shading (Eskandari et al., 2017), however, pine trees were also used for shading from solar radiation in summer (refer to Figure 1.13). Agricultural products dried on the roofs (Meir and Roaf, 2005) provide the temporary shading.

*Figure 1.7 Trees in the Surrounding and Vine Trees on the Roof as Shading Devices in Traditional Lebanese Houses. Source: (*Suzdaltseva*, 2019) Accessed 10-1-2021*

Thirdly, the floor systems are considered in the study of the building envelope and the traditional cooling strategies used such as solar shading by thatched roof and earthen floor are effective for interior cooling. This is the case of Liwan House in which the earthen floor demonstrates a good ventilation in the indoor space (Nguyen et al., 2011).

1.3 Research Purpose and Scope

Given that the residential sector in Lebanon accounts 47% of the produced energy (Yathreb, 2006) and the consumption estimates range from 29 to 60% of total electricity consumption (Houri and Ibrahim-Korfali, 2005). The energy consumption in Lebanese building sector is expected to be 250% in 2030 with respect to that in 2010, and it is expected that the main contributor to this energy demand is the inadequate performance of the existing buildings, such as the enormous demand for small air conditioning units, insufficient daylighting, and thermal comfort issues (Yathreb, 2006). It is recognized that the effects of the thermal standards on the energy consumption of the buildings (refer to Figure 1.14) varied widely according to the location (World Bank, 2009). This increase in demand for construction and increase in energy consumption create the need to research climate adaptive strategies for houses to decrease their energy consumption (Juan et al., 2018).

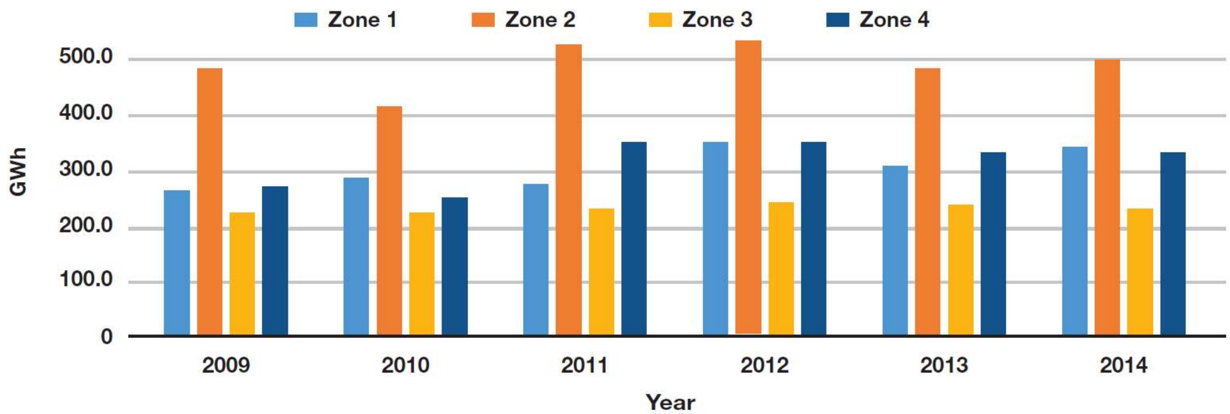


Figure 1.8 Electricity demand (GWh) of the building sector by climatic zone 2009-2014. Source: (LCEC, 2018) Accessed: 11-1-2021

In Lebanon there are four climatic zones; coastal, mid-mountain, inland and high mountain respectively. According to the Lebanese Center for Energy Conservation (LCEC) (2018), the mid-mountainous region in Lebanon which is zone 2 accounts for the second largest energy consumption and the highest thermal demand, in comparison to other climatic zones (refer to Figure 1.15). Due to the highest thermal demand of the building sector in the mid-mountainous region, this thesis will be limited to evaluate the cooling/heating loads and determine its influence on thermal comfort in a residential building, Liwan House typology in specific. Despite the fact that Liwan is commonly found on the coast or average mountain heights, this typology is rather rare in high mountain areas with rough winter climates and such environments are associated with other architectural shapes such as that with three arches (Corpus and Euromed Heritage, 2003). The Liwan typology has adaptive strategies because it is still functional until now.

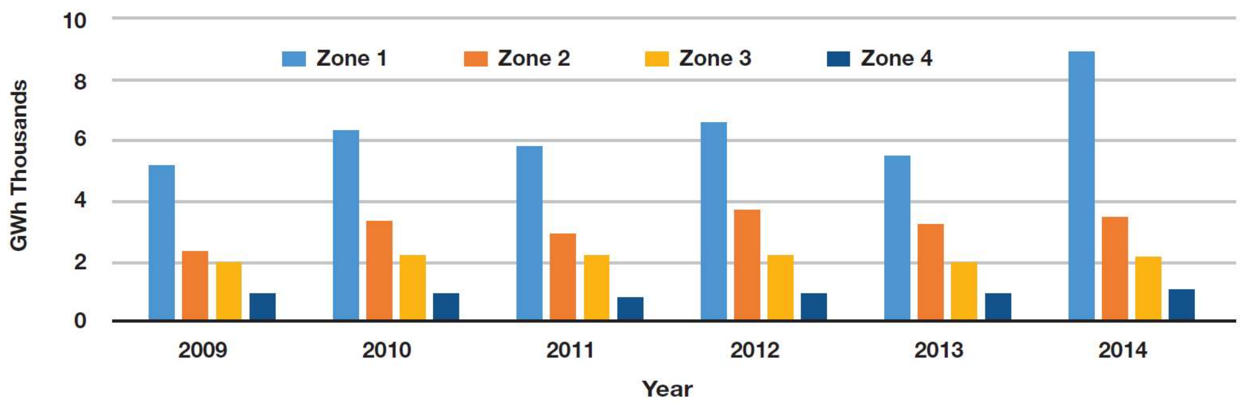


Figure 1.9 Thermal demand (GWh) of the building sector by climatic zone 2009–2014. Source: (LCEC, 2018) Accessed: 11-1-2021

Meanwhile, the envelope system of Liwan House in the mid-mountainous zone will be evaluated to determine the sustainable strategies used of least environmental impacts and how it can be translated in contemporary buildings of this zone. According to Salkini et al. (2017), Liwan is a type of design solution used at modern Lebanese houses for promoting thermal performance in the houses and achieving thermal comfort (Salkini et al., 2017).

The Lebanese mid-mountainous villages have Liwan typology with flat roofs, walls, floors, ceilings, windows and doors having different construction methods and some have added materials to its original form. The traditional construction strategies indicate that the track we have taken in the present days is not the only track that can be taken (Davis, 2013). This thesis will inform architects who are involved in renovating Liwan houses or designing modern sustainable houses in the same climatic zone. Along to artisans who work in this field to expand their knowledge thermal performances of Liwan envelope systems and thus build on it to the enhance passive strategies, conservationists who advocate for the protection of natural resources and minimize the energy consumption aiming to reduce carbon emissions. This research will also benefit those seeking to know about the thermal performance of envelope systems of the Liwan house and to what extent those passive strategies in vernacular houses are used as a basis of sustainability construction in contemporary buildings.

1.3 Research Question and Objectives

This thesis will emphasis on the envelope systems of the Liwan houses to answer the question:

How can the sustainable approaches of the passive envelope systems in Liwan typology be translated in the contemporary application of modern buildings to reduce the heating and cooling loads, and provide thermal comfort?

The research question is addressed within following objectives:

1. To understand the vernacular passive techniques of Liwan envelope system as methods of construction and materials used, in the mid-mountainous region
2. To improve the understanding of the existing material's indoor comfort properties and thermal performance of the Liwan envelope in the study area
3. Show the proper construction material of Liwan in the mid- mountainous region which reduces the energy consumption of the mechanical systems to meet the cooling/heating demands
4. To show the effect of orientation on the performance of Liwan as a climatic responsive strategy
5. To find out whether the difference in the depth to width dimensions of Liwan protects from the climatic conditions of the mid-mountainous region
6. To identify the sustainable elements of the envelope system in Liwan typology and define the recommendations for the modern constructions in the study area

1.4 Thesis Structure

This thesis is composed of six main chapters. The first is the introduction that presents an overview on the subject, defines the research question and objectives of this thesis. The second chapter is the literature review that addresses three themes highlighting studies about the main problem. This chapter sets a theoretical background on climatic responsive strategies of Liwan, its thermal performance and examples to influence modern constructions. Chapter three which is the methodology will set the adopted tools to assess the thermal performance of the building envelope of the Liwan typology which will be needed to answer the research question. This chapter will include a background on the mid-mountainous region as climatic conditions and address the built environment of the case studies which will be assessed. Chapter four is the context analysis. This chapter will describe the studied scenarios and analyze in details the context of each case study as building construction materials, distribution of spaces, roof assemblies, wall assemblies, and floor assemblies. This will provide an overview to better understand each Liwan house prior to the discussion chapter, which is chapter five. The discussion and analysis chapter will analyze and compare the results after using the simulation tools. The Computational Fluid Dynamics (CFD) is the main software used to assess the thermal performance and thermal comfort of the post-lintel and vaulted Liwan houses. Finally, the conclusion will sum up the previous chapters and answers the objectives of the thesis. This includes identifying the adaptability of liwan houses in relevance to the one which provides better thermal comfort and thermal performance, in mid-mountainous regions. Then, the sustainable elements of the envelope system will be presented as guidelines for modern constructions, in addition to the limitations of the thesis and the recommendations for further researches.

Chapter Two
LITERATURE REVIEW

The mid-mountainous region in Lebanon has witnessed high thermal energy as cooling and heating energy consumption. Hence, the passive tools of vernacular architecture can be visited to acknowledge sustainable methods for modern constructions. The passive aspects to reduce the energy strategies of vernacular architecture include: reasonable location and layout, adaptability to the topography and usage of existing local construction materials, usage of natural source for heating and cooling, programming the functions to achieve energy coordination of indoor spaces, and providing ways to create better thermal environment conditions (Tao and Chen, 2019). This chapter will acknowledge previous case studies on similar topics of the thesis. This review starts to explore the sustainable strategies of Liwan typology and its adaptability through the lens of environmental pillar. It then moves to highlight different case studies on its climate responsive strategies. The previous studies on Liwan's thermal performance and occupant's thermal comfort will be analyzed. This chapter will end by investigating the influence of Liwan House techniques in modern strategies of construction, from a sustainable viewpoint.

2.1 Sustainable and Adaptable Vernacular Architecture: Liwan Typology

This section addresses vernacular architecture in respect to sustainability. The environmental dimension is highlighted, including the adaptability of vernacular architecture, Liwan typology.

Bernard Rudofsky (1964) referred to the term vernacular architecture as the architecture without architects (Fauzi and Lin, 2015) as it was developed through time and modified itself through trial and error to fulfill society's needs in harmony with the ambient environment (Salman, 2018). It is useful to develop a series of links including the materials, the constructive system, the adaptation to the surrounding environment, human comfort, durability, energy saving, available

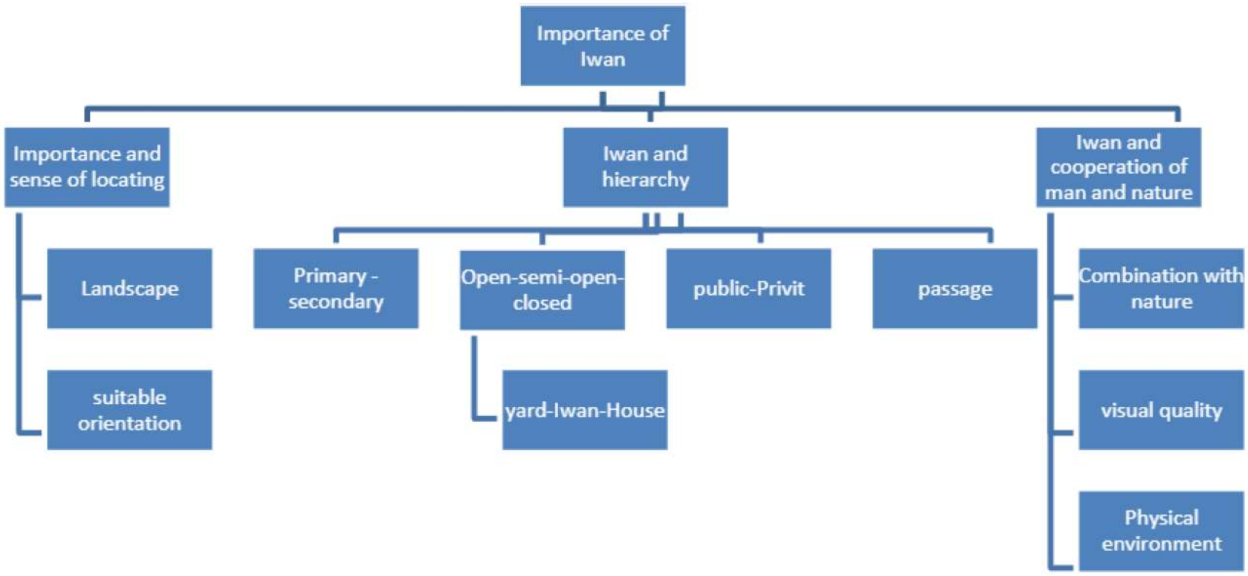


Figure 2.1 Importance of Liwan as location, Hierarchy and Cooperation of Man and Nature. Source: (Kakizadeh, 2014) Accessed: 25-1-2021

The Liwan House is a typology of the vernacular architecture (Corpus and Euromed Heritage, 2003). This typology has low environmental impact and is often considered as an appropriate base for a sustainable design (Sinha, n.d.), which (refer to Figure 2.1) shows interrelations between environmental, economic and social factors (Alrashed et al., 2017). The sustainable building techniques and design form use solutions that are the result of the limitation of resources and building technologies (Kazimee, 2009).

Human beings need open space for using natural light and fresh air. In the past, there was semi-open space called Liwan in vernacular houses, which was responsible for controlling the thermal properties influenced by climatic conditions (Safarkhani, 2016). In the absence of energy, builders developed passive systems that optimize indoor comfort, respond to particular human needs and climatic conditions through the available resources (Fernandes et al., 2014). According to (Figure 2.1), such vernacular typology is built in accordance with the natural environment, including the geography, topography, site, climate, local building materials, labor experience, and building techniques, fulfilling people's physical, economic, social, and cultural norms (Salman, 2018).

Liwan typology is rarely implemented in high mountain areas because it is not adapted to rough winter climates (Corpus and Euromed Heritage, 2003). It is generally accepted that vernacular architecture is well adapted to the dominant climate of the region, geographical and topographical features, in addition to the environment (Nisha and Jayasudha, 2016). The climate responsive material that is adaptable provides good thermal comfort (Biradar and Mama, 2015). It is important to search for solutions for adaptation to the new functional and technical standards (Crespo et al., 2015). Vernacular architecture represents a gradually evolved response to meet environmental and climatic constraints, as well as the socioeconomic and cultural characters of societies to meet changed lifestyles over a period of time (Biradar and Mama, 2015; Broadbent, 1975). Meanwhile, the individual should gain knowledge about the process of shaping the built environment, evolution of the building typologies and their adaptation with change of needs (Sarkar, 2011).

2.2 Envelope of Liwan Typology: Climate Responsive Strategies

Liwan is responsible for controlling the climatic conditions of domestic areas as well as a factor for promoting the spatial value and quality of a house (Safarkhani, 2016). The existence of Liwan in the building keeps its aesthetics role and the climatic role in the initial layer of the structure. This is through protecting the main body of the structure from direct sunlight in summer and as a result providing the shade and thus keeping the inside cool (Kalantari, Singeri and Jourshari, 2015). Meanwhile, it adjusts the temperature of adjacent rooms in warm seasons (Safarkhani, 2016), and allows the visitor to settle down and gaze at the circulation in the building (Tuncel, 2019). Liwan is a space used for circulation, social activities and storage space which is covered but always open to the outside (Melki, 2014). Suzdaltseva (2019) stated that in the mountains Liwan is extended into the terrace further than the two rooms at sides; in the coastal areas, they go hand in hand with courtyards.

Despite the fact that Liwan is discussed in this thesis in mountainous climates, it is significant to introduce the performance of this feature in hot and coastal regions in order to highlight its adaptability in different climatic conditions. Liwan is useful for hot seasons because it is defined as a place for eating, sleeping, doing housework and different activities (Safarkhani, 2016). In summer and spring, it can be used as a living room for sitting or sleeping; in the dusk and at night. In case Liwan is oriented to the south or the east of the house, it prevents the heat from the afternoon sun; therefore, giving priority to use Liwan as a sitting, resting, dining space (Raof, 2018). Liwan is used as well as an open summer sitting room facing north and helps humidify the air equipped with other elements such as trees and fountains (Levant, 2004). This feature is widely used day and night in the hot and arid regions. They have the advantage of both being open and having a roof on top. They usually face north. As such, they continuously provide shade that are naturally ventilated and create a pleasant place for sleeping, sitting, gathering and eating (Rapoport, 1969, p.86; Manzoor, 1989). Schoenauer (2000), Fardeheb (1987), Bonine (2000; 1980), Soflaei (2006) and Memarian and Brown (2006, p.24) all claim that the Liwan element is among the main vernacular architectural innovations in the hot and dry climates which have enabled residents to be relatively comfortable (Foruzanmehr, 2018, p. 65).

Liwan makes sense in warm climates where it is protected from winds, dust, animals and people and is believed to originate in Arab culture (Suzdaltseva, 2019). The configuration of hills and valleys in mountain regions affects relative humidity as well as the orientation of sites with respect to sun and wind (Melki, 2014). Seldom Liwan is found in the mountainous region (Melki, 2014). The Liwan makes only sense when protected from external interference, and requires a warm climate (Ragette, 2012). In regions with cold climates, Liwan was a semi-open space of dwellings (Safarkhani, 2016). In cold and mountainous climates, Liwan promotes shading, prevents direct sunlight into rooms in summer, and prevents rainfall and snow in winter (Eskandari et al., 2017). In the cold and mountainous climate, the heating loads of buildings are slightly higher than the cooling loads because of knowing to what extent Liwan reduces the cooling and heating loads (Eskandari et al., 2017). The expected outcome of a successful house is a warm interior during winter and cool interior during summer (Tuncel, 2019). This is the case with the position of the central living space, be it the Liwan, which is considered the coolest space during hot daytime (Melki, 2014). In the case of Lebanon, Ragette (2003) highlighted that in the summer high and open north oriented rooms such as an Liwan will serve the best. South facing Liwan is suitable for winter (Safarkhani, 2016). Ragette (2012) suggested that Liwan faces north to avoid direct sunshine. Liwan is shielded on its long sides by the adjacent rooms; the open end of the hall was turned either to the north or to the south in order to avoid deep penetration of the sun's rays (Melki, 2014).

Air conditioning has been the main use of Liwan typology (Safarkhani, 2016). Cross-ventilation was achieved by internal windows or vents between the rooms and the central space, which originally was permanently open (Melki, 2014). Because of many variables, such as the sun, winds, topography, view and privacy, many aberrations of the Liwan have evolved. It was oriented to give maximum shade and protection from the prevailing winds, which engender sand and dust hazards. (AlZubaidi, 2007). There is no doubt that are different elements which appeared in the vernacular house to help increase the amount of shaded areas on the inner court that look over the courtyard such as Liwan or on the outer facades, such as the use of protrusions and cornices or covered streets protect external walls from direct sunlight (Levant, 2004). Light intake to Liwans is from the heightened windows of the central space (Tuncel, 2019). It offers a shelter by producing shade from summer's strong sun. In this way, the indoor spaces adjusted to the Liwan will remain cool and create a microclimate by providing cover against winter's rain, snow and wind (Abdulrahman, Ahmed, and Abtar, 2019). Deciduous trees and scaffoldings supporting deciduous vines helped block sunlight in summer. Overhangs were later introduced as shading devices and to keep rainwater away from walls and windows. The thick, sometimes tapered, walls were carefully designed to shade the opening in summer but not block sunlight in winter, in addition to the use of wooden external shutters (Melki, 2014). Meanwhile, the Liwan provides protection to the internal spaces from the hot summer sun and yet it maintains the internal spaces warmth in the winter (AlZubaidi, 2007; Al-Rostomani, 1991). The winter spaces normally have fewer windows, whereas the summer spaces have more windows to get natural ventilation (AlZubaidi, 2007). Liwan, which is a roofed space and three-walled, reduces the cooling requirements especially in the summer seasons (Ozorhon and Ozorhon, 2014).

The following study by Najafi (2013) looks at the relationship between the traditional buildings and sustainable development as well as the climatic conditions and construction patterns in Shiraz, Iran. The purpose of this research is to develop environmental strategies, help promote energy efficient architectural design in semi hot-arid climates of cold winters with hot-arid summers, and suggest new ways for the use of those elements in modern buildings. In this weather condition,

Figure 2.2 Forogh Al Molk house's Liwan. Source: (Najafi, 2013) Accessed: 25-1-2021

Liwan or what is known as Veranda is situated on the south side of courtyards with the open side of the room being to the north to allow northen sunlight to penetrate.

The mud, mudbrick, stone, brick, mortar, lime and wood are used in the building envelope due to its thermo- physical specifications. These materials have thermal resistance, high heat capacity, have pores filled with air acting as thermal insulators and they absorb the sun radiation by their external surfaces. The windows are small and are located in the upper parts of walls just near the ceiling, for ventilation. Sometimes the windows are colored for diffusion of light (refer to Figure 2.2). The courtyard is another feature used in the main central area and provides a comfortable environment without mechanical heating or cooling systems. The cooling system are the thermal properties of air and material of the courtyard, in which as the thermal properties of air is very low, the mass of walls and floor of the courtyard is cooled. The pool humidifies the environment and prevents severe heat in the day and severe cold at night.

A typological variation of the courtyard house with Liwan tradition was elaborated by Erarslan (n.d.), using a comparative analysis between different regions and climatic conditions of Syria, Iraq and Iran.

In Syrian houses, the liwan can appear on the ground floor or on the first floor (refer to Figure 2.3(a)) with at least 40 or 50 centimeters raised from the ground and of varied heights and depths. As mentioned by Nugroho (2017, p. 6), ‘the elevated floor reduced the heat gain from the floor surface to the interior during daytime’. In such houses, there

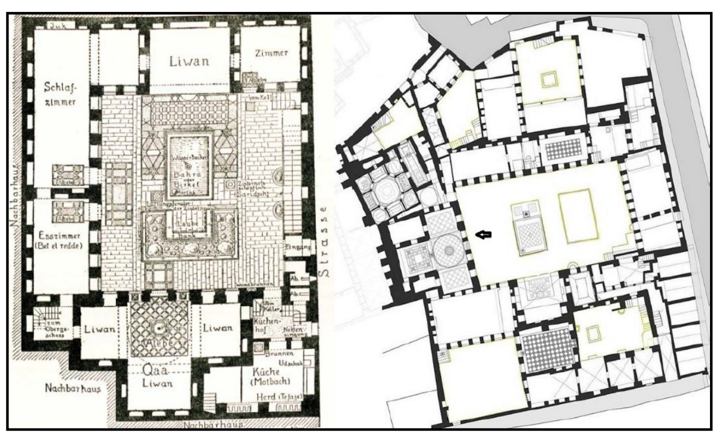


Figure 2.3 (a) Aleppo, Mid-18th century. (b) Inverted-T-shaped Qa'a and center of Liwan. Source: (Erarslan, n.d.) Accessed: 25-1-2021

may be two Liwans–one for winter and one for summer. It faces the north making it possible to avoid the direct sun and allows cool breezes to flow through the space in summer months. In the region of Syria, the reception area is in the form of an inverted T-scheme (refer to Figure 2.3 (b)) or three-Liwaned and there are triple-arched or wooden columns of post-and-beam construction. These units in the Riwaq style are called Liwans in Syria and Iran. In Iranian and Syrian architecture, Liwan was part of the central courtyard, was used in different seasons and implemented in the lower and upper ground floors (refer to Figure 2.4 (a, b)) to serve the same purpose of usage (Malik and Mujahid, 2016).

Figure 2.4 (a) Aleppo House: An Liwan two-stories high. (b) Liwan on the first floor. Source: (Erarslan, n.d.) Accessed: 25-1-2021

As for Iranian houses (refer to Figure 2.5), the Liwan is oriented toward the south and east in order to provide a cool and shaded area for the occupants in the summertime and rooms are located towards the north of the courtyard in the winter season. As for the basement floor ceilings, its height is 2.5 meters tall and the reason behind it is to provide space for ventilation for the foodstuffs stored there (Erarslan, n.d.). The floor to ceiling height provides shade and is ventilated by soothing winds (Levant, 2004).

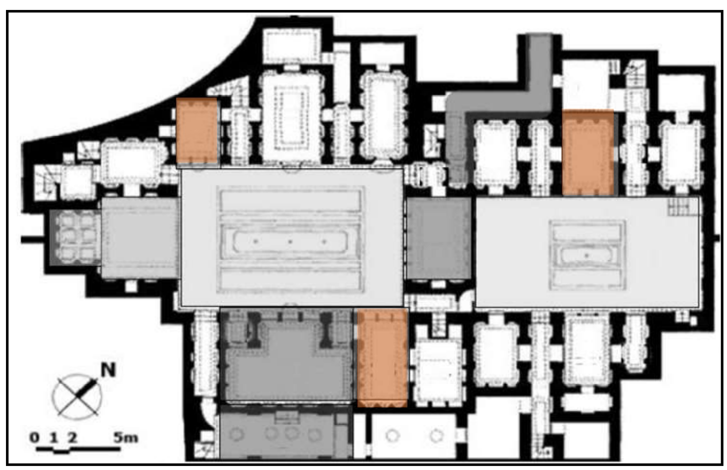


Figure 2.5 Major areas in the Iranian house with Liwan. Source: (Erarslan, n.d.) Accessed: 25-1-2021

In Iraq, houses of typology courtyard with Liwan are mostly found on the first floor and rarely on the ground floor. The decision of having the Liwan feature on the ground or just the first floor, is highly dependent on its performance in this region. The functions on the ground floor showed increased thermal mass and high insulation properties, in winter, with proper wall thickness and openings, whereas the functions on the first floor in the summer season showed reduced thermal mass with ventilation due to an increased number of openings (Philokyprou et al., 2017). Liwans in Iraq (refer to Figure 2.6(a)) were used for winter and summer seasons and the one facing the north was for summertime spaces. The construction material of the traditional Iraqi courtyard house with liwan, is brick (refer to Figure 2.6(b)). The courtyards are paved with stone, marble or mosaic. Different strategies were used in Islamic countries for religious and social needs, such as high walls which provides thermal comfort, regulates the climatic conditions and keeps the air cool in the garden throughout the day (Erarslan, n.d.).

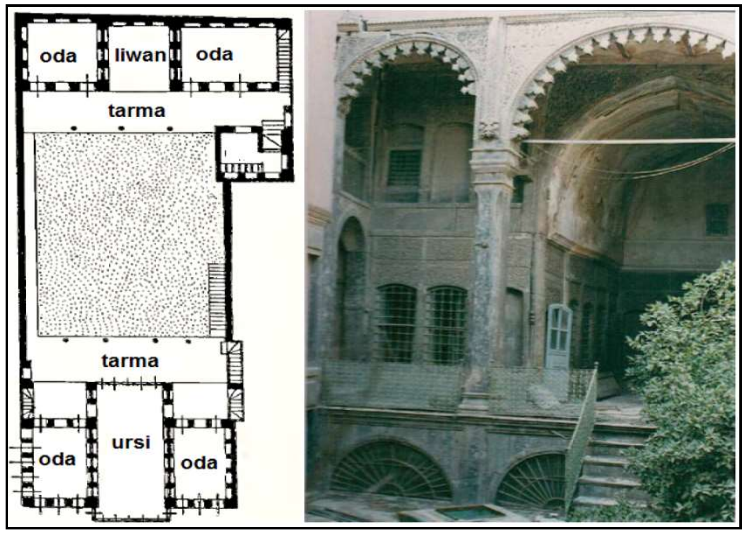


Figure 2.6(a) Plan: An ursi *that is perpendicular to the* riwaq *on its short side; the other wing has a liwan. (b) Old Mosul house. Source: (Erarslan, n.d.) Accessed: 25-1-2021*

2.2.1 Thermal Comfort and Performance: Scenarios of Liwan Typology

Liwan is one of the elements affected by climatic principles, building design and conditions of the region, which play a role in energy saving and thermal comfort. This section will discuss the thermal performance and comfort of the different scenarios of Liwan typology. The construction methods and materials in the Lebanese context is to be studied within the analysis of the vernacular walls, roofs and floors of the Liwan element.

The building envelope design separates the outdoor and indoor environment, controls the climatic conditions and affects the indoor thermal comfort and the materials used (Hashemi, 2018). Within the building envelope, the maximum heat gain and loss occurs in both the extreme seasons respectively (Dhar et al., 2014). It consists of both opaque and transparent parts of the walls and roof in addition to the floor, which are connected to the external environment (Hwaish, 2015).

Different studies were done for Iranian traditional houses and houses in all climate zones in Iran make use of liwans. Iran is divided into four climatic areas; cold and dry, hot and arid, hot and humid, mild and humid.

Kalantari et al. (2015) ensured another research about the climatic role of Liwan and the rate of energy consumption in traditional buildings in the Tibriz city. Tabriz city is located in the mountainous region with a cold and dry climate which has cold winters and temperate summers. In winter, Liwan acted as a cover to prevent the penetration of coldness into the interior. Liwan seemed to take advantage of the southern sun and protects from rain and snow. The rate of solar radiation has been analyzed between four selected traditional houses of different areas of Liwan per floors, having an effect on the energy received by the vertical surfaces in July and January for four different hours in the southern wall (refer to Table 2.1). The sizes of the canopy depth, maximum depth and the adaptation with actual sizes of Liwan were explored. The research ended up showing that the Liwan element has a decorative function in Tibriz and is rarely used as a climatic element, despite the potential of the traditional houses to solar energy in regards to the function of Liwan as well as the climate. Kalantari house with 10% occupied area of Liwan in floors resulted in the most favorable performance in July and January (refer to Table 2.1(c)).

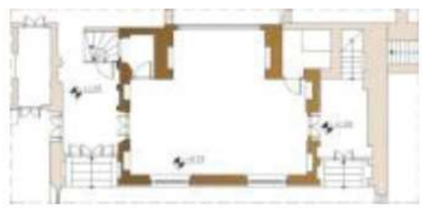
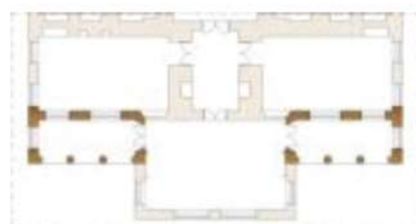
(a)	**Behnam**		One enclosed side - three open sides	6% Occupied Area of Liwan in Floors
(b)	**Mojtahedi**		One enclosed side - three open sides	4% Occupied Area of Liwan in Floors
(d)	**Alavi**		One enclosed side - three open sides	8% Occupied Area of Liwan in Floors
(c)	**Kalantari**		Two enclosed sides- two open sides	10% Occupied Area of Liwan in Floors

Table 2.1 Investigation of Liwan in terms of enclosed body and percentage of the occupied area of Liwan in floors. Source: (Kalantari et al., 2015). Accessed: 25-1-2021

In order to foresee the performance, function, shape, scale, and pattern of Liwan in consideration to climatic conditions, Kakizadeh (2014) studied the spatial fluidity and functional values of Liwan in Bushhehr, Iran. This study informs the readers about the importance of considering the sustainable elements of Liwan in contemporary architecture. Liwan has a rectangular shape with different sizes proportional to the area and the orientation has to be considered as well. This research focused on the different shapes of Liwan and concluded that the strongest performance of Liwan in terms of function, climate and spatial relations are the two-consecutive Liwan (refer to Table 2.2(a)), middle Liwan (refer to Table 2.2(b)) and four-side Liwan (refer to Table 2.2(e)). In terms of beauty and function, the compound Liwan (refer to Table 2.2(h)), L-shaped Liwan (refer to Table 2.2(i)) and the U-shaped Liwan (refer to Table 2.2(g)), are suggested because it gives grandeur to the building, evolved the form of the building and are connected to other spaces of the house such as three-doors and five-doors rooms. Other types of Liwan (refer to Table 2.2(c, d, and f)) have only climatic functions (Kakizadeh, 2014).

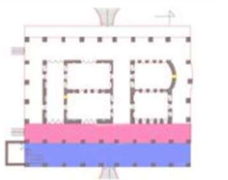
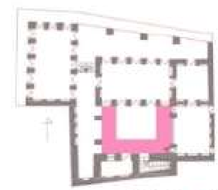
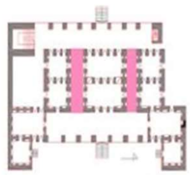
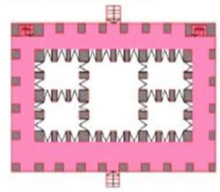
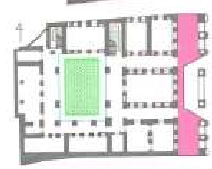
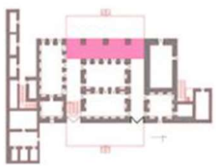
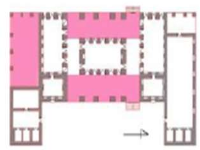
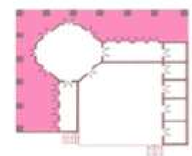
(a)	**Two-Consecutive Liwan**		**(d)**	**Liwan in Two Side**		**(g)**	**U- Shape Liwan**	
(b)	**Middle Liwan**		**(e)**	**Liwan in Four Side**		**(h)**	**Compound Liwan**	
(c)	**Liwan in One Side**		**(f)**	**Liwan in Three Side**		**(i)**	**L-Shape Liwan**	

Table 2.2 Types of Liwan in Bushhehr Buildings. Source: (Kakizadeh, 2014) Accessed: 25-1-2021

The traditional buildings use climatic responsive strategies or what is called solar passive measures to achieve thermal comfort conditions (Bodach, Lang, and Hamhaber, 2014). Thinking that Liwan emerged from the Iranian architecture, it should not be eliminated or replaced by low value terraces in contemporary houses. The fundamental role of Liwan is on the north side to be used in summer season, however the south side of the Liwan is roofed and has little depth, to be used as shadow in summer and doesn't prevent sunlight from entering the depth of the Liwan in winter (Kakizadeh, 2014).

Another study addressed by Abdulrahman et al. (2019) focuses on the environmental aspects of liwan. This investigates the effects of changing the exposure degrees of liwan on its insolation within traditional houses and identifies liwan as a climatic responsive design strategy in

Sulaymaniyah's old town, Iran. Liwan in this town is used as a transitional space and overlooks a private yard. The houses chosen had different length and depth of the space with almost constant height equals three meters.

The results of the climatic responsive strategies include that the Liwan's solar performance improves whenever its width subsides compared to its depth. The best case study of Liwan is to the south of depth to width ratio 1:1.5 (refer to Figure 2.7(a)) and orientation 135° to 225° azimuth angle (refer to Figure 2.7(b)). This ratio for the liwan to the east and west does not seem to affect their solar performance. Meanwhile, the liwan's orientation affects significantly on its solar performance because the rooms of those houses have windows on the liwan making solar penetration desirable in cold seasons and blocked in hot seasons. In this case study, Liwan facing south have better performance to those facing north have it the worst.

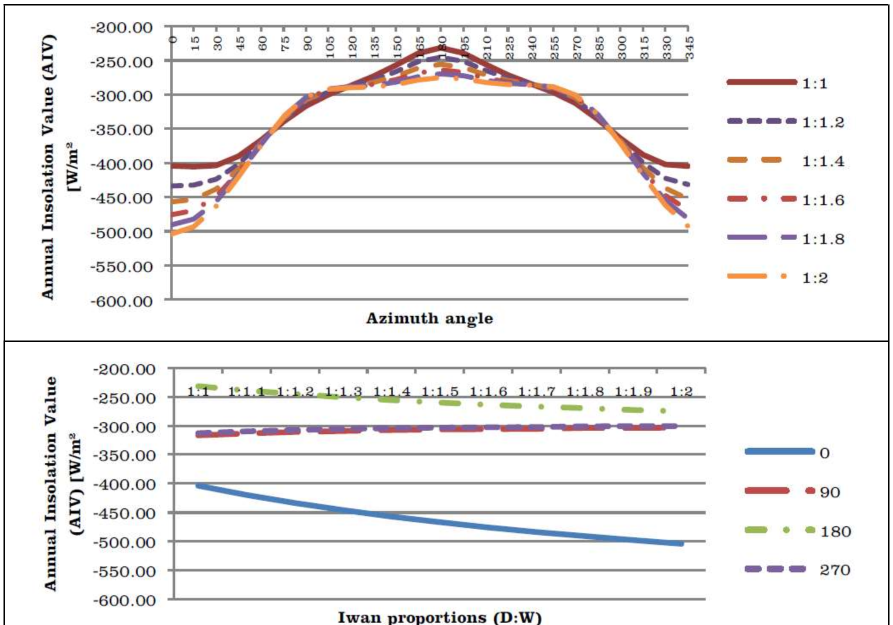


Figure 2.7(a) Annual Insolation Value (AIV) with different Depth: Width ratio (D: W). (b) Annual Insolation Value (AIV) of Liwan in different Orientations. Source: (Abdulrahman et al., 2019) Accessed: 25-1-2021

The previous discussion on the different strategies of Liwan's orientation to improve the solar performance highlights the significance of passive architecture in order to reduce the mechanical air-conditioning requirement (Samuel et al., 2017). The building orientation is an important factor to make the best use of the sun's heat and light, in which all buildings depend on passive cooling in summer and heating in cold weather (Kazimee, 2008). The orientation of a building helps in reducing the exposure to the intensity of the sun (Foruzanmehr, 2018; Fardeheb, 1987). As Dhar et al. (2014) indicated, the orientation has an effect on the indoor temperature and shows the areas exposed to direct solar radiation leading to heat gain. Meanwhile, the building orientation can reduce the cooling loads through minimizing solar absorption through walls and roofs, minimizing solar penetration through windows, and by maximizing cross ventilation (Salah, 2014).

Hegger et al. (2012) indicates that the passive use of solar radiation is one of the different elements that should be taken into consideration to improve thermal performance. Different design strategies in different climatic zones such as the orientation have been developed in order to gain maximum solar exposure for buildings located in cold climates, and reduce solar exposure with an increase of natural ventilation for buildings in hot climates (Lotfabadi and Hançer, 2019). The building designs are affected by the evolution of built-form, inherited knowledge, safety, and thermal comfort in different climate conditions (Shastry et al., 2014).

The performance of Liwan in the traditional architecture of different climatic regions of Iran is studied by (Nejadriahi, 2016), because its form is dependent on the climate. Liwan is one of the sustainable elements, which can provide more comfort with less use of energy.

In a cold mountainous region (refer to Table 2.3(b)), Liwan is located along the main axis of the house to have the maximum advantage of southern sunlight. It acts as a cover and protects the house from the rain and snow. Therefore, the existence of liwan at the initial layer of the building keeps its aesthetics role as well as the climatic role and its depth is much lesser than those in the southern regions of Iran. In the mild humid climate (refer to Table 2.3(a)), building are extroverted, while Liwan is used to protect the building from the rain that is associated with the wind and creates a buffer space. Additionally, it protects the building from direct sunlight during the summer while letting the light come in during the winter. The use of natural ventilation is one of the main strategies to create airflow and to reduce the moisture. Another region of Northern Iran has mild humid climate such as the Qajarieh era, also used natural materials of minimum thermal capacity like wood, plant fibers, stone, soil (Eslami and Malidareh, 2017). As for the other climatic regions, the hot-humid and hot- arid climates (refer to Table 2.3(c, d)) used the central courtyard which was created for shadow and air ventilation.

This study concluded the emphasis of the importance of Liwan, due to the fact that Liwan must neither have the heating/cooling appliances as they would interrupt its performance and nor be replaced with a simple terrace. Liwan has significant climatic values which affect their size, form, direction, location, width, height, in order to assist energy efficiency in the house. Liwan has significant climatic values which affect their size, form, direction, location, width, height, in order to assist energy efficiency in the house. This research emphasized on The importance of Liwan as one of the sustainable

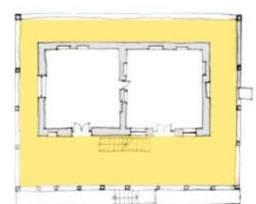
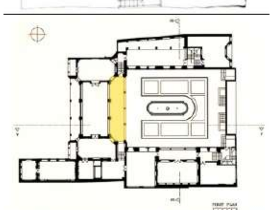
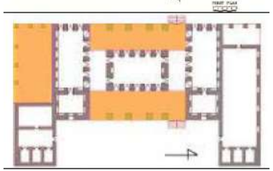
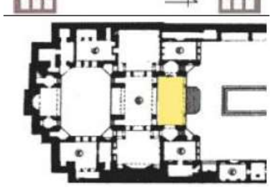
(a)	**Mild and Humid**		
(b)	**Cold Mountainous**		
(c)	**Hot and Humid**		
(d)	**Hot and Arid**		

Table 2.3 Climatic Role of Liwan in the Traditional Houses of Different Climatic Regions of Iran. Source: (Nejadriahi 2016) Accessed: 25-1-2021

elements in the traditional houses of Iran by providing more comfort with less energy use (Nejadriahi 2016).

According to a study of thermal comfort of Talar rooms in the traditional Iranian houses by Shaeri et al. (2018), the space adjusted with a Liwan is 62% more desirable than the same space without the Liwan.

The development of the houses in Gaza strip was investigated by Muhaisen (2016) in order to figure out which architectural design is recommended the most. Ghaza is a coastal area with the climatic conditions of temperate climate with mild winters, dry hot summer and annual temperature. The sandstone house has Liwan with a bearing thick wall structural system with niches (refer to Figure 2.8(b)). Liwan is open to the north elevation since the direct sunlight cannot reach this room (Hadid, 2002) (refer to Figure 2.8(a)). The roofs are also made of sandstones with intersecting vaults and look flat from the top level. In most houses, it consists mainly of one floor. In the study of external openings, it is few in number and protects internal spaces from hot dusty winds during the summer. The main entrance on the western side is overlooking the street, opens to the courtyard and is made of colorful limestones. This architectural style includes a planted courtyard which has an environmental role in modifying the climatic conditions and achieving thermal comfort. The second architectural style is the mud house of narrow openings at the top of the wall, with walls and roofs made up of clay

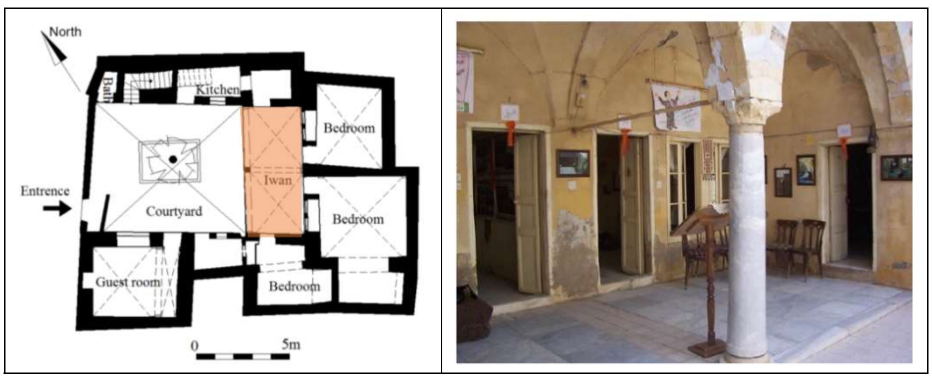


Figure 2.8(a) Plan of Ghalayini House in Gaza. (b) Perspective of the Liwan. Source: (Muhaisen, 2016) Accessed: 25-1-2021

supported by branches. The third architectural style is a concrete house with large external openings, light materials and mechanical system to achieve thermal comforts. This typology lost the architectural elements such as Liwan. The results showed that the first and second typology are appropriate to environmental conditions, are thermal insulators and save energy, however the most style which provides thermal comfort is the concrete house then comes that of sandstone. The mud house is the least to provide thermal comfort. Therefore, it is important to take full advantage of the traditional sandstone features and adapt them in accordance with the properties of concrete buildings Muhaisen (2016).

Muhaisen (2016) investigated three different typologies to show the performance of sandstone and mud vernacular houses with respect to that of concrete; however, different materials were used in the vernacular envelope systems. The use of different wall materials is associated with the climatic conditions such as, the use of thick adobe walls as a vernacular building material which helps to store coolness at night then releases it to the interior space in the hot daytime hours (Sayigh, 2019). Hammoud and Yasmine (2014) stated that vernacular houses were built with natural rubble stones, lime and sandstone, and bricks which were used in some places. As Choughari (2019) mentioned, the filling of the core between the outside and the inner side of stones used to be mud, hay and gravel. A variety of stones were applied, such as ashlar and dressed quarry stone in building and constructing walls. The type of stone differs according to the wall type and its function in the building (Levant, 2004). The two-ashlar stones were implemented in the construction of bearing walls with a rubble core (Melki, 2014). The dressed quarry stone wall is a kind of a vernacular wall, mostly found in low cost buildings of thickness between 20 to 30cm and washed from outside with lime plaster (Hammoud and Yasmine, 2014). The lime plaster plays a role in improving the thermal resistance and protects the layers of the walls (Bianco et al., 2014).

The use of light colors for the building envelope, mainly whitewashed surfaces has various advantages; reduces heat gains by acting as a radiation reflector and minimizes the absorption of solar energy by reflecting about 90% of the incident radiation (Fernandes et al., 2016). Another wall material is the wooden frame wall. It is a composite of timber frame and massive stone techniques, of 20cm wall thickness, has a partition between one space and another, and has a filling of timber frame made of local rubble limestone, earth and lime mortar (Hammoud and Yasmine, 2014). As for the mudbrick walls, it was covered with lime rendering and mortar bonding of the mud units, considering that mud itself is an insulator that keeps the temperature stable in hot and cold seasons (Levant, 2004).

In cold climates, a high solar absorbance rooftop material was recommended while the use of lime rendering is not, because all the solar gains of the building come from its flat rooftop (Lamrhari and Benhamou, 2018). Besides the lime rendering, the wooden roofs covered with leaves and mud were also ancient technologies used for cooling (Hatamipour and Abe, 2008). The use of thick walls, big openings and high ceilings gain more benefit from natural environments in hot summers, with heated spaces in winters (Lotfabadi and Hançer, 2019). According to different case studies, the Liwan element can moderate the temperature of indoor spaces adjacent to it and hence assist in reducing the energy consumption (Nejadriahi, 2016).

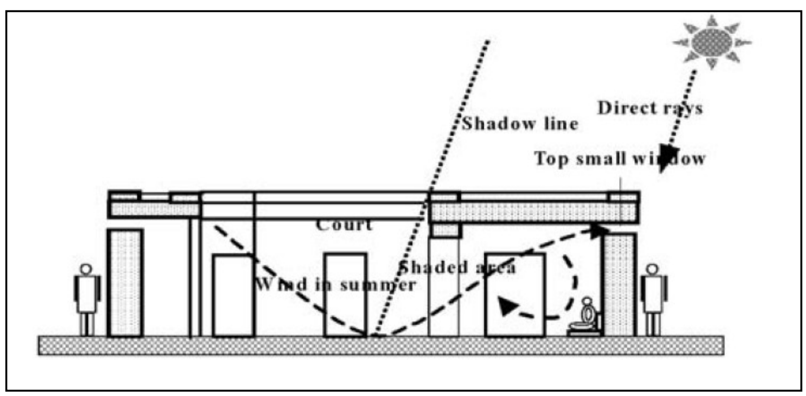


Figure 2.9 Conceptual Section of Liwan's Life Style. Source: (Mushtaha and Noguchi, 2005) Accessed: 25-1-2021

Mushtaha and Noguchi (2005) discusses the historic buildings of the old city in Ghaza and studies the importance of the Liwan feature. The massive walls with long and medium windows are oriented to the Liwan for thermal purposes (refer to Figure 2.9) and cultural aspects to the southwest for prayers. However, the southern and eastern deals with the summer northwest wind which reaches 71.9% (refer to Figure 2.10). Insulative walls with small openings are recommended to decrease heat loss and improve thermal comfort. The houses are oriented north-south axis for climatic conditions; thus it is better to extend the house on the long east-west to take advantage in the case of strong summer wind and winter sunlight. The northern and southern Liwans mitigate thermal stresses, reduce the temperature and decrease the cooling loads.

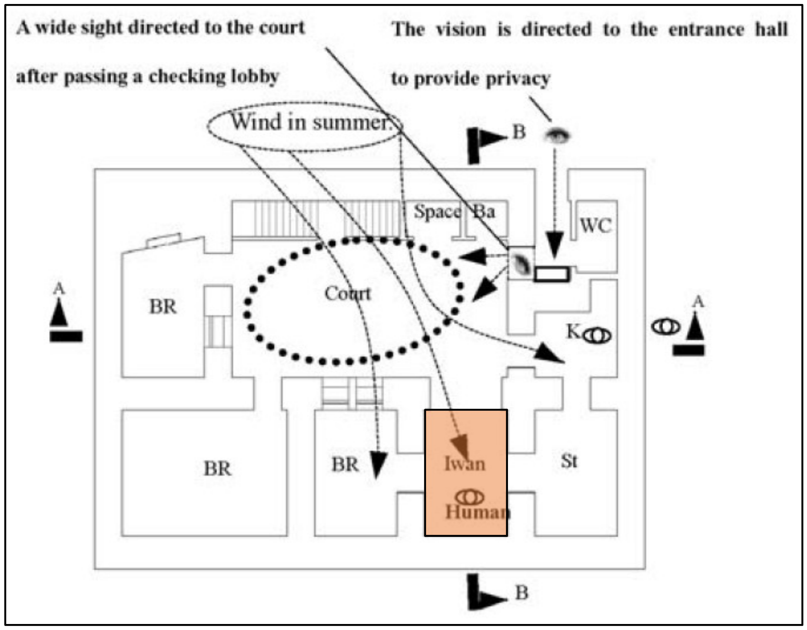


Figure 2.10 Relation between Cultural Indoor and Outdoor Spaces Source: (Mushtaha and Noguchi, 2005) Accessed: 25-1-2021

The walls affect the heating and cooling loads, and provide thermal comfort in the interior space by regulating the weather fluctuations (Jannat et al., 2020). Due to the high thermal mass of external walls, heat storage is an essential process, during winter, to ensure comfort levels through the use of simple heating systems and of low energy consumption (Philokyprou et al., 2018). The roof is another factor of the building envelope which maximizes the thermal mass and is exposed to solar radiation, thus benefit from the warming effect (Kazimee, 2008). As an example, the vault roof form catches less solar radiation; it helps in reducing the heat load inside the building (Patil and Valsson, 2015), because it distributes the incident solar radiation over a larger surface area in comparison to a flat roof (Taylor et al., n.d.). The vaulted roofs also have greater convective cooling potential, because air speed increases over the curved surface making the cooling winds more effective at reducing the temperature of the roof (Taylor et al., n.d.).

According to a study developed by the World Bank (2009), two models were defined for the envelope of residential buildings in the mid-mountainous region of Lebanon with high-energy savings for twenty years. The most appropriate model with highest energy saving is referred to as a building with a single, non-insulated walls of thermal transmittance U=3.432 W/m^{2}C, and an insulated roof with EPS of 6 cm thickness and U=0.524 W/m^{2}C. As for the windows, it is single reflective and U=5.490 W/m2C with the usage of overhangs on the east, west and south sides.

2.2.2 Thermal Performance: Envelope of Liwan Typology in Lebanese Context

An ideal direction in which an Liwan can be used is the south elevation that provides a maximum rate of thermal load, cooling and heating, in the absence of Liwan and a maximum rate of thermal load reduction in its presence (Eskandari et al., 2017). It seems that Liwan house has existed in Lebanon since the eleventh century and it was built till the end of the nineteenth century (Corpus and Euromed Heritage, 2003). This typology consists of only one floor and may include an element on the roof to freshen hot summer evenings (Corpus and Euromed Heritage, 2003). ‘This type of design solution, Liwan, is used at modern Lebanese houses for enhancing privacy, promoting thermal performance in their houses and achieving openness to the natural surroundings’ (Salkini, Greco, and Lucente, 2016, p. 5). The summer rooms which include the Liwan, can be cooler than outside during the day and warmer in the evenings and early night hours, when the outdoor temperature drops, in summer times (Foruzanmehr, 2018; Foruzanmehr, 2006). Those summer rooms have high ceilings, thick roofs to reduce the transmission of heat and it stores heat during the day and releases it in the evening and at night (Foruzanmehr, 2018; Bonine, 2000). The importance of Liwan is one of the sustainable elements in the vernacular houses by providing more comfort with less energy use (Kalantari, Singeri, and Jourshari, 2015). The wall, roof and floor elements of the building envelope in the Lebanese Liwan typology are analyzed in the following paragraphs.

Suzdaltseva (2019) stated that Liwan house is the type of house least found in Lebanon, identified as a covered terrace which is only open with no walls at its front side. The presence of Liwan in the house provides the special environmental situation, which results in the distinctiveness of public and private spaces, continuity of the inside towards the outside and creation of a special atmosphere with a diversity in performance (Kalantari, Singeri and Jourshari, 2015). The Liwan walls are made with stone, rendered with lime from inside and cement rendering from outside, and with thickness from 40 to 100 cm (refer to Figure 2.11). The building walls of Liwan can reduce the absorption of solar radiation and prevent the inward facing walls from straight solar radiation and excessive heat gain, resulting in thermal comfort (Eskandari et al., 2017). Decreasing the exterior wall thickness and enlarging the window size with a constant level of temperature, maintain the thermal comfort with view, natural ventilation and solar gain (Melki, 2014).

'The vernacular wall technique in Lebanon applied bearing wall for the rigid enclosing elements. The simplest type of exterior bearing walls, of thickness around one meter, are made of stones collected from the ground and piled up without mortar as dry

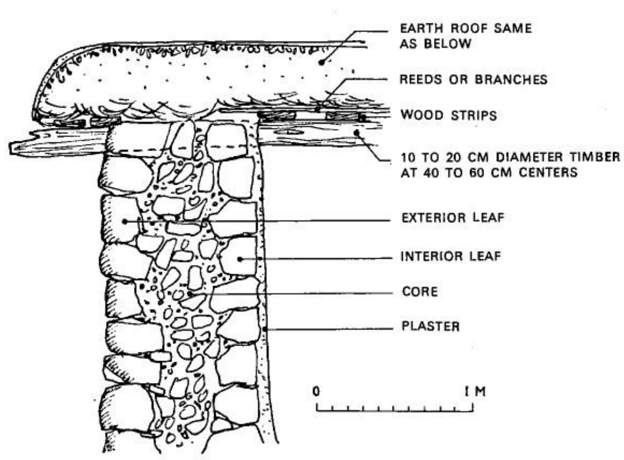


Figure 2.11 Wall Construction with a Flat Roof in Lebanese Context. Source: (Ragette, 1974) Accessed: 22-1-2021

masonry. It consists of three parts: the exterior leaf built in horizontal ranges, the interior leaf covered by plaster and the core is filled with rubble. The mud bricks exist only in the Beqaa plain, but they cannot be distinguished from plastered stone buildings. The mud bricks are prepared in wooden forms from a mixture of loamy earth, chaff and water. The plaster continues around windows and doors' (Ragette, 1974, p. 214).

The use of natural materials in vernacular construction exhibits an ability to regulate the indoor environment (Makhlouf, et al., 2019). This includes the bearing walls for the rigid enclosing elements and a skeleton construction for the roof (Ragette, 2003). As for the openings, the door of the sides opens to the Liwan and the windows open to air and light (Corpus and Euromed Heritage, 2003). The thermal effect of Liwan covers the whole surfaces of walls and openings unlike other shading devices like the overhangs (Eskandari et al., 2017).

In the study of the Lebanese houses, Liwan, a feature of vernacular architecture, is a space with a longitudinal tendency, either roofed over by beams resting on transverse arches (refer to Figure 2.12) or a tunnel vault. Arches or vaults are flush with the wall are supported on brackets (Ragette, 2012).

"In Lebanon, a layered-roof composition is also found. It consists of log beams supporting the roof weight, succeeded by a layer of twigs, branches, or reed matting laid crosswise to the logs, a third layer of thorny brush pressed down into moist mud, and finally a layer of finely crushed stone, with sometimes a lime-chaff coating on

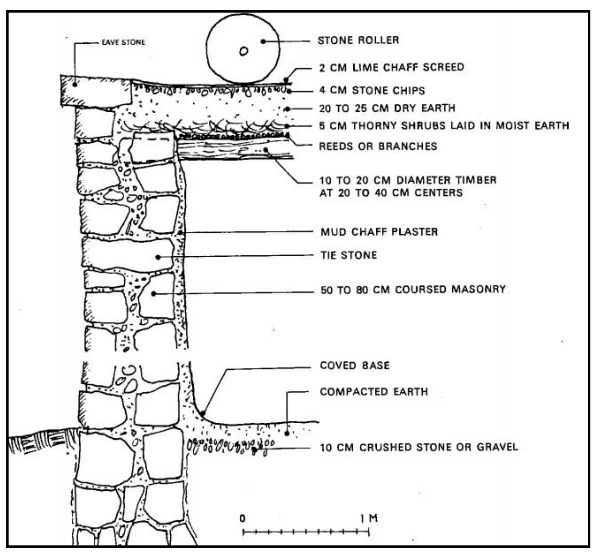


Figure 2.12 Flat Roof Construction in Lebanese Context. Source: (Ragette, 1974) Accessed: 22-1-2021

top. The upper layer is rolled periodically by a heavy stone roller to ensure the continued sealing of the material" (Noble, 2013.as cited in Raggette 1974, 22-5; El-Khoury 1975, p. 69).

Corpus and Euromed Heritage (2003) indicated that some elements might be added on the roof to freshen hot summer evenings. The hard-packed earth roofing is now replaced by reinforced concrete flooring resting on metal joists and beams. The key element in the design of an Liwan is its roof, because it can result in a tangible reduction of temperature. Liwan used wooden roofs covered with plants or mud and brick walls (Levant, 2004).

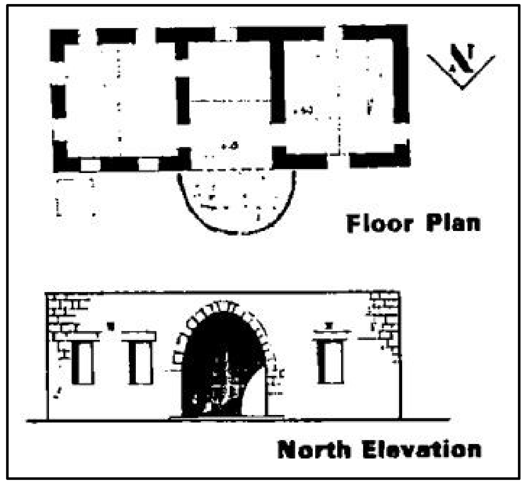


Figure 2.13 (a) Plan of Liwan House. (b) Elevation of Liwan House. Source: (Ragette, 1974) Accessed: 22-1-2021

As mentioned before, Liwan typology consists of only one floor (refer to Figure 2.13) and transformations were implemented on facades or by adding floors and volumes, to adapt the house to modern life (Corpus and Euromed Heritage, 2003). In the Lebanese context, the floor was of compacted earth and the interior plaster merges with floor (Ragette, 1974). Liwan was introduced as a climatic element in traditional and contemporary architectures and has a role in reducing the energy consumption (Eskandari et al., 2017).

2.3 Passive Methods of Liwan Typology to Influence Modern Architecture

This section identifies the theoretical viewpoint between the vernacular and modern architecture. It then moves to show the strategies of Liwan House which can be used to regulate the thermal performance and can be adopted in the modern architecture.

Christopher Alexander (1964) referred to the vernacular architecture and the newly designed architectural building as unselfconscious and self-conscious processes respectively. Alexander presents a powerful critique on modern design illustrating the failure of the professional self-conscious process of design with respect to the unself-conscious process who create their own adapted living spaces (Patel et al., 2000). According to Wakkary et al. (2015), the unselfconscious culture has five features that are resources, adaptation, ensembles, time, and anonymity. The resources and materials are found in the nearby surroundings. The adaptation is to allow the design fit where it does not fit or misfit and includes solving own problems. The ensembles show the relation between the form and context. The time is the process needed to fit and adapt. The anonymity makes this distinction between the unselfconscious and self-conscious, in which the maker of the unselfconscious cultures is unnoticed and has no achievements. The self-conscious process focuses on architecture, art, and engineering to reflect the demands and needs into a structured plan (Alexander, 1964).

Liwan is used in modern Lebanese houses for enhancing privacy, promoting thermal performance and achieving openness to the natural surroundings (Salkini et al., 2017). Traditional architectural typologies such as the Liwan house could play a crucial role in the environmental architectural contemporary framework (Salkini et al., 2017). The fundamentals from the vernacular houses can be used as guidelines for contemporary housing, in order to provide comfort and lessen burdens of the environment. The guidelines consider sustainable issues, including building orientation, site layout, passive design, suitable material, and appropriate structure (Ly et al., n.d.). The study of climate-responsive vernacular strategies is important nowadays to understand how they can contribute both to minimize the energy consumption and guarantee the thermal comfort which are the same strategies for the same type of climate (Al Tawayha , Braganca, and Mateus, 2019). Climate responsive design can play a significant role in reducing the energy demand of buildings without compromising modern living standards (Bodach, Lang, and Hamhaber, 2014).

The new solution has not fulfilled the needs of the people on the level of thermal insulation: traditional buildings surpass modern structures in this field; they provide better acoustic and thermal insulation and are more environmentally adapted. Traditional walls are thick and can reach 70cm wide; mud itself is an insulator that keeps the temperature in the house stable in hot and cold seasons (Levant, 2004).

Materials used in old and contemporary buildings are different in many properties, such as density, thermal conductivity and heat transfer. These differences affect the thermal performance of the buildings (Al Tawayha , Braganca, and Mateus, 2019). With time, buildings changed and roofs became flat, covered with wood, plants and earth. After the emergence of reinforced concrete, cement, and concrete masonry units, it became flat concrete roofs (Levant, 2004). People living in concrete roofed houses express higher thermal discomfort than that of a vernacular roof (Bodart and Evrard, 2011).

Salkini et al. (2017) studied the adaptive residential traditional scenarios in Aleppo and selected the design solution for the building envelope, which can be used for contemporary buildings. Aleppo has one of the coldest regions in Syria. The aim was to reduce the building's cooling and heating loads, with passive design strategies (refer to Figure 2.14) to control building's form, type, materials, orientation and fenestration. Achieving privacy, openness to surrounding, and better climatic conditions, there is an emphasis on the courtyard with Liwan typology, in which the Liwan acts as a shading device and the introversion of the courtyard is able to create pocket for solar gain in the cold climate, hence achieving thermal comfort. The strategies for better thermal performance for external walls include thermally insulated external walls with high thermal mass to replace the thick walls' function, in addition to comprising ventilated cavities. The massive wall stabilizes the outdoor temperature swings by its thermal mass effect, having an effective role on the thermal energy performance (Sozen and Oral, 2019). The stone cladding for external walls can be used as a local material of high level of heating storage capacity and its ability to store the energy during the day and resend it at night, in addition to the wood as a cladding material. The external walls should comprise ventilated cavities (Salkini et al., 2017). In Syrian houses, the rubble was used in between the rough stonewalls, acted as an insulation and consists of large uncut rocks (Levant, 2004). Within the analysis of the openings as Salkini et al. (2017) that mentions, windows should be minimized at the northern side of the external walls and maximized at the southern side (refer to Figure 2.15(a)) with a ratio of opaque glazed of 30% south, 15% west-east (refer to Figure 2.15(b)), and 20% north, in order to increase the heat gain and reduce heat loss in the wintertime. The indirect entrance enhances the air movement control and reduces the heat transfer through the entrance in both hot and cold seasons. In the roof system, the selection of an adequate roof influences the buildings' thermal performance, such as the use of a double roof to promote air passage and reduce solar radiation in summer. The green roof is another strategy proposed to keep the building cooler, saves energy, and extends the useful life of the double roof (Salkini et al., 2017).

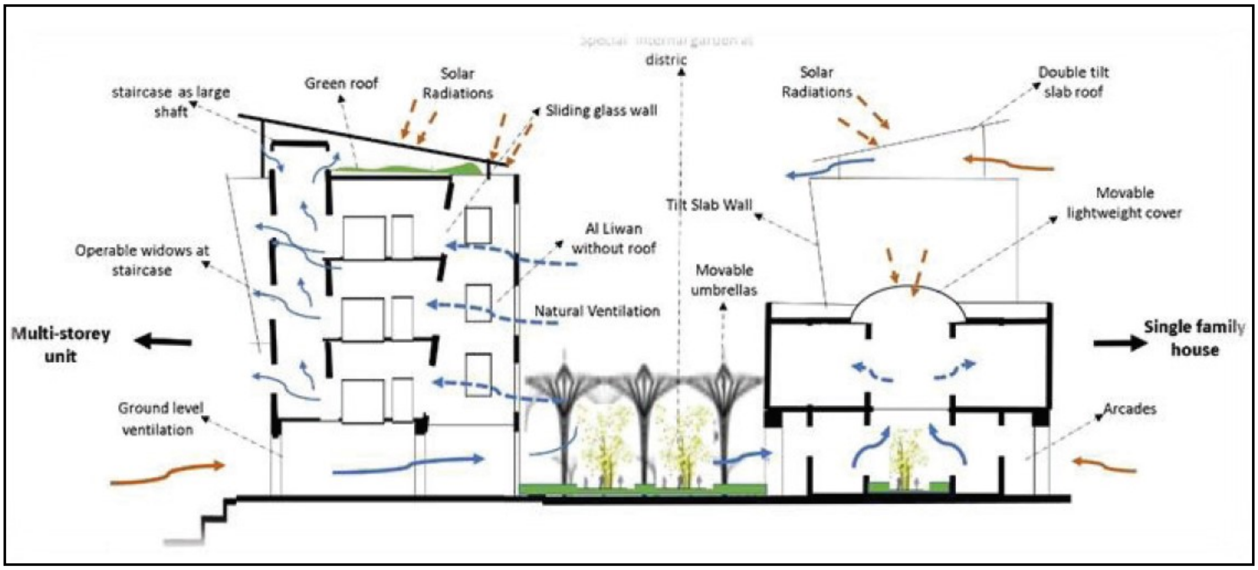


Figure 2.14 The section shows the new inspire Ventilation Systems for the new residential building at the old city of Aleppo. Source: (Salkini et al., 2017) Accessed: 26-1-2021

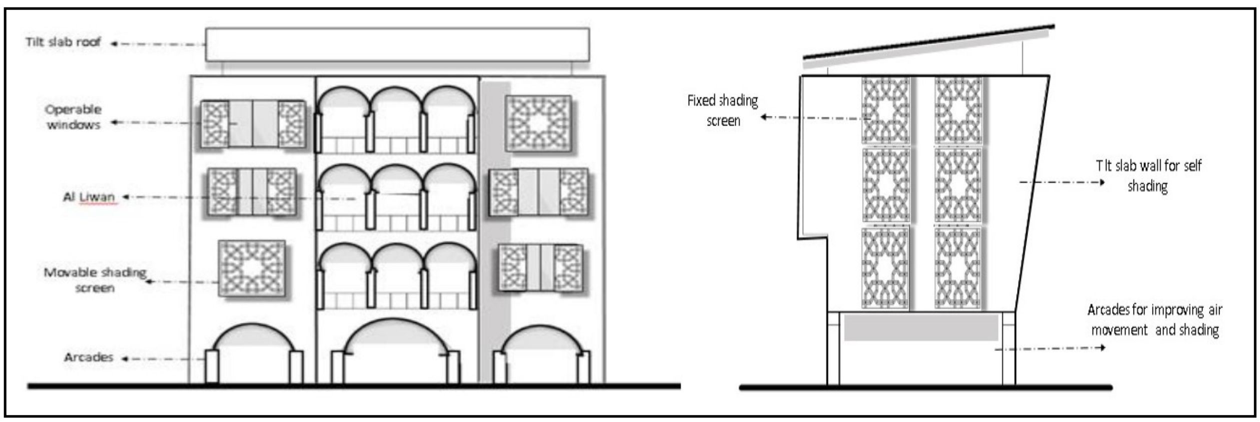


Figure 2.15 (a) Movable shading screen at the southern elevation. (b) Fixed shading screen at western and eastern elevations. Source: (Salkini et al., 2017) Accessed: 26-1-2021

According to Levant (2004), there are three types of vernacular Syrian flat roofing systems: stone roofing, thatched roofing covered with mud and wooden roofing. Roofs were generally supported by timber structures because the quality of the supporting structure influences the seismic response of the whole building, saves energy and provides comfort (Parisia and Piazzab, 2002).

2.4 Conclusion

The sustainable role of Liwan has always controversial (Abdulrahman et al., 2019). This study sheds light on the environmental aspects of liwan. Liwan should be one of the necessities in today's buildings, because this semi-open space is the most applicable space in a building typology with multiple operations. It reduces the heating/cooling loads, and is used in all climatic conditions. The design of liwan differs according to climatic factors, the needs it serves to meet the occupant's thermal comfort in summer and winter seasons, methods of construction as material use, and orientation along other climatic responsive strategies. The aim of using those strategies was to reduce energy consumption, provide thermal comfort and use natural resources. In cold climates, the liwan must be located to the south to allow the penetration of the solar radiation and acts as a pocket for solar gain. In such climatic condition, a vaulted roof is more recommended than flat roofs with thermally insulated external walls of high thermal mass composed of stone or wood material.

This thesis uses a quantitative assessment to study the thermal performance and comfort values. This literature review chapter frames the methodology chapter with better understanding of the different scenarios of Liwan along to the factors affecting the performance of the envelope in the specified area of Al Shouf mid mountainous region in Lebanon.

Chapter Three

METHODOLOGY

3.1 Introduction

Based on simulations to assess thermal performance and comfort values, this chapter discusses the main tool used, CFD, in accordance to other tools to select the adopted one in line with the thesis. Firstly, field studies will be done to identify the context and the existing conditions of the six proposed Liwan houses in the mid- mountainous region. The six houses are selected in Mokhtara, Kfar-Katra, Haret Jandal and Abey, which are of similar climatic conditions but different construction techniques. There are three liwan houses located in Mokhtara, Haret Jandal and Abey of flat roof, in addition to other three houses in Mokhtara, Haret Jandal and Kfar-Katra of vaulted roof. Secondly, the thermal performance and comfort values of the six Liwans will be assessed, using building simulation tools. This will highlight the sustainable envelope techniques to be used in modern buildings. Meanwhile, three sections are discussed to fulfill the objective of this chapter. Section 3.2 investigates the qualitative tools to assess the thermal performance and comfort values, while section 3.3 discusses the quantitative tools.

3.2 Qualitative Research Approaches

To assess the thermal comfort values, different variables are studied and thermal indices are formulated to indicate the effect of combining the different variables. One of the popular indices is the Effective Temperature (ET) that investigated the effect of relative humidity, air velocity, air temperature and clothing (Ogunsote and Prucnal-Ogunsote, 2002). A more advanced and improved index has been developed which is the Corrected Effective Temperature (CET). However, as elaborated by Ogunsote and Prucnal-Ogunsote (2002), both indices overestimated the effects of humidity and underestimated its effects at high temperatures. Moreover, another index is the Predicted Mean Vote (PMV). It is used to predict the mean thermal sensation vote on a standard scale for a group of people. The sensation scale is expressed from -3 to +3 corresponding to the following categories: cold, cool. Slightly cool, neutral, slightly warm, warm, and hot (Yao et al., 2009). As for the Programming-based software, it has been developed for assessing the comfort values. As an example, the PYPI software contains a package for assessing comfort indices (Tartarini and Schiavon, 2020). This package is released under a license and provides very limited documentation on how to use the package (Tartarini and Schiavon, 2020).

Meanwhile, more accurate and reliable tools are needed to assess thermal comfort other than the PYPI software. As for the Thermal Index and the Predicted Mean Vote, it needs excessive documentation and questionnaires to assess the thermal comfort of occupants and this data builds on subjective analysis. Hence, due to the limited duration for the empirical work then quantitative methods are more preferred than doing qualitative research. In addition, to observe only the six case studies will not be enough to frame the sustainable strategies to be used in modern buildings of the studied regions.

3.3 Quantitative Research Approaches

To be in line with the scope of the thesis, quantitative methods are used. In the field research observation, documentation and numerical data analysis, are conducted to identify the existing Liwans in terms of location, orientation, surrounding context and dimensions which affect the Liwan performance. Through the observation studies, documented field measurements are conducted using a compass, meter, notebook for reporting, pen, pencil, and marker. In this case, the six Liwan houses in Mokhtara, Haret Jandal, Kfar-Katra, and Abey, will be identified in order to study the building envelope. Those houses are owned and constructed by different builders;

however, all are within the same climatic conditions and of adjacent geographic locations, sharing a similar structure, which is vaulted ceiling.

In order to test the proposed six Liwan houses, the climatic context and the Liwan building techniques should be first defined using the selected tools, prior to assessing the thermal performances and comfort values. Those tools would later make it possible to compare the energy savings as sustainable strategies to be used in the modern buildings of the studied context. For this purpose, the appropriate building simulation tools are the following: Revit, Green Building Studio (GBS), and Computational Fluid Dynamics (CFD).

The first tool, Revit software, will be used to create virtual Liwan models in which climatic conditions, materials, locations and orientations will be selected. Revit is multi-disciplinary Building Information Modeling (BIM) software that provides 3D modeling with detailed material and environmental variables, and it is efficient and not time consuming (Lung, 2019). In the software the materials of the Liwan 3D model are assigned, the true north for the building is set, a virtual wind tunnel rectangle is created, and all the details are simplified, in order to assure an accurate simulation in the software that follows.

As for the second tool, Green Building Studio (GBS), it is a simulation tool that analyzes the energy performance of the 3D model done in Revit (Han et al., 2018). In other words, the models of Liwan typologies will be imported to GBS for further energy analysis. GBS is a flexible cloud-based service (Aljundi, 2016), where the weather stations in it are based on actual year weather data (Autodesk, 2011). GBS provides energy analysis, detailed weather data, and day lighting (Khoi Le, 2014). The simulation outcomes will indicate the energy performance of the model to study the thermal performance of the envelope. The green building studio uses a DOE-2.2 simulation engine that was developed over four decades and validated by the Lawrence

Berkeley National Laboratory and the Los Alamos National Laboratory. The simulation results will then meet the criteria under ANSI/ASHRAE Standard 140, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, and certified by the U.S. Department of Energy (Autodesk, 2021). In GBS, first, the 3D model exported from Revit is uploaded on the cloud, and then the location, weather station, and the building function are added. The next step is to identify the R-Value for each part of the building envelope, the glass type of the openings, and the spaces functionality. The final step is to run the inputs in order to conduct the data.

The third software is the Computational Fluid Dynamics (CFD), which provides indoor analysis (Kaijima et al., 2013). CFD conducts visual and numerical simulation data for the natural ventilation performance and comfort conditions of the 3D model (PÉREZ, 2017). CFD can provide projection of climate parameters such as air temperature, radiant temperature, air velocity, and ventilation rate (Hartog et al., 2000). The conducted data of the CFD model will indicate the indoor thermal behavior of the proposed model and to what extent it serves the indoor thermal comfort aspect. Moreover, CFD provides temperature maps as the mean radiant temperatures, besides the wind maps (Naboni et al., 2017). The level of accuracy of the CFD simulation compared with the real data recorded in a study conducted by Albatayneh et.al (2018) and indicated that it has 92% of average accuracy. In CFD, the process for conducting the simulation will be as follows: starting by assigning the material physical status and material (fluid- air, solid concrete). The next step is to define the boundary conditions for the wind rectangle (to create a virtual wind tunnel testing) as for the wind entrance and exit, and its condition. The final step is to create a mesh before the model is ready for solving, and conducting diagrams and graphs. In the case of CFD software, it has an automatic mesh creator.

3.4 Conclusion

This chapter investigated the tools to assess thermal performance and thermal comfort. To answer the objective of this thesis, the site observation method is identified followed by Revit software to input the data, then Green Building Studio and Computational Fluid Dyamics will be used to assess both parameters for the three case studies in the mid-mountainous region.

Chapter Four
CONTEXT ANALYSIS

4.1 Introduction

This chapter aims to analyze the context of each of the case studies. Section 4.2 introduces the six case studies of Liwan houses by organizing the information in the form of tables. The chosen Liwan houses are in the mid-mountainous region within two scenarios, post- lintel flat roofs and vaulted roofs. Section 4.3 sums up the analysis of assemblies.

4.2 Liwan houses: Analysis of Six Case Studies

This section analyzes the six case studies within two scenarios, post-lintel flat roof and vaulted roof. The first scenario, post-lintel flat roof, includes the Liwan houses in Mokhtara, Haret Jandal, and Abey. The second scenario, vaulted roof, includes the discussion of Liwan houses in Mokhtara, Haret Jandal, and Kfarkatra. The scenarios are analyzed in regards to the location of the selected case studies because the houses of similar regions share similar context analysis and climatic conditions. This is applicable to the case studies located in Mokhtara and Haret Jandal. In each, the houses are presented in the form of photos and technical drawings. The information of each case study is distributed in the form of layout analysis, and typology analysis as composition. The latter includes the analysis of the envelope system, which is roof, walls and floor assemblies. Figures 4.1 presents the locations of the Liwan houses with its surrounding on google earth.

	Scenario 1 Post- Lintel Flat Roof	**Scenario 2** Vaulted Liwan Roof
	Mokhtara *(Figure 4.1- a)*	Mokhtara *(Figure 4.1- b)*
		
	Haret Jandal *(Figure 4.1- c)*	Haret Jandal *(Figure 4.1- d)*
Locations of Case Studies		
	Abey *(Figure 4.1- e)*	Kfar-Katra *(Figure 4.1- f)*
		

Figure 4.1 (a-b-c-d-e-f) Google Map Showing the Location of the Liwan Houses, Source: Google Earth

The following tables (4.1, 4.2 and 4.3) represent a summary of the previous information of each of the case studies. The tables are distributed according to the post- lintel and vaulted roof scenarios of the liwan houses, and following the assemblies of the building envelope: 1) wall assemblies including the openings (doors and windows) which are elaborated separately, and 2) floors and roofs assemblies. Those tables will introduce the procedures that will be undertaken to discuss the case studies in the following section.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="3">Scenario 1</th><th colspan="3">Scenario 2</th></tr>
<tr><th>House 1</th><th>House 2</th><th>House 3</th><th>House 4</th><th>House 5</th><th>House 6</th></tr>
<tr><td rowspan="5">Walls</td><td>Type</td><td>Original</td><td>Renovated</td><td>Renovated</td><td>Original</td><td>Original</td><td>Original</td></tr>
<tr><td rowspan="2">Dimension</td><td>Post-lintel Side: 26 cm</td><td>North-west side :90 cm</td><td>Exterior side :95 cm</td><td>Exterior side :90 cm</td><td>North-east side :20 cm</td><td rowspan="2">Exterior Side: 70 cm</td></tr>
<tr><td>Barrel-vault Side: 70 cm</td><td>South-west side: 70 cm</td><td>Interior side: 40 cm</td><td>Interior side: 36 cm</td><td>Exterior side :70 cm</td></tr>
<tr><td rowspan="2">Material</td><td>Stone and clay paste</td><td>Stone and mortar</td><td rowspan="2">Stone and mortar</td><td>Stone and clay paste</td><td rowspan="2">Stone and clay paste</td><td rowspan="2">Stone and clay paste</td></tr>
<tr><td>Stone and mortar</td><td>Stone and mortar</td><td>Stone and mortar</td></tr>
</table>

Table 4.1 Wall Assembly of All Scenarios, Source: Author

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="3">Scenario 1</th><th colspan="3">Scenario 2</th></tr>
<tr><th>House 1</th><th>House 2</th><th>House 3</th><th>House 4</th><th>House 5</th><th>House 6</th></tr>
<tr><td rowspan="4">Roof</td><td rowspan="3">Type</td><td>Barrel-vault</td><td>1</td><td>----</td><td>----</td><td>----</td><td rowspan="2">3</td><td>----</td></tr>
<tr><td>Cross-vault</td><td>----</td><td>----</td><td>----</td><td>3</td><td>3</td></tr>
<tr><td>Post-Lintel</td><td>1</td><td>1</td><td>1</td><td>----</td><td>----</td><td>----</td></tr>
<tr><td>Material</td><td>Vault</td><td>Stone and Rubble</td><td>----</td><td>----</td><td>Stone, Rubble, and Concrete</td><td>Stone and Rubble</td><td>Stone, Rubble, and Concrete</td></tr>
</table>

		Post-Lintel	Wood Beams and Rubble	Concrete	Concrete	----	----	----
Floor	**Type**		One level	Two level	Two level	One Level	One Level	One Level
	Material		Concrete and Earth	Concrete and Ceramic tiles	Concrete and Ceramic tiles	Concrete	Earth	Concrete

Table 4.2 Roof and Floor of all Scenarios, Source: Author

The wall system in all the case studies are in its original conditions except for Haret Jandal flat roof and Abey houses were renovated with wall thicknesses 90cm and 95cm. Those two case studies have walls composed of stone and mortar with two level floor systems made of concrete and ceramic tiles. Similarly, both case studies have renovated wood materials for doors and windows with dominant openings from the south-west and north-east directions.

The Mokhtara flat and vaulted case studies have some of its walls stone and mortar while others stone and clay paste. The Haret Jandal and Kfarkatra vaulted liwan houses have stone and clay paste wall materials of exterior wall thicknesses 70cm. The roof materials in the post-lintel scenario are concrete wood beams with rubble for Mokhtara house and concrete for Haret Jandal and Abey houses. In the vaulted scenario, the roof materials of Mokhtara and KfarKatra houses are stone, rubble and concrete while Haret Jandal house is stone and rubble.

				Scenario 1			Scenario 2		
				House 1	**House 2**	**House 3**	**House 4**	**House 5**	**House 6**
	Windows	Orientation	South-West	1	3	4	3	1	1
			North-East	----	4	4	----	1	----
			North-West	1	1	----	----	3	2
			South-East	----	----	----	----	----	----

Openings		Materials		Existing Openings- No Frames	Renovated wood	Renovated wood	Original wood	Existing Openings- No Frames	Renovated wood
	Doors	Quantity		2	3	3	5	5	1
		Material		Existing Openings – No Frames	Renovated wood	Renovated wood	Original wood	Existing Openings- No Frames	Steel and glass

Table 4.3 Openings of all Scenarios, Source: Author

The floor material of Mokhtara vaulted and KfarKatra houses is concrete, Mokhtara flat house is earth and concrete, and Haret Jandal vaulted is earth. Besides, the openings of Mokhtara post-lintel and Haret Jandal vaulted houses are existing without frames because the houses are abandoned. The openings of Mokhtara vaulted and Kfarkatra houses are made up of wood materials except for the doors in Kfarkatra house is of steel and glass materials. To identify the dominant orientations of windows, Mokhtara vaulted house is from the south-west direction while Haret Jandal vaulted and Kfarkatra is from the north west sides.

4.2.1 Two Liwan Houses in Mokhtara

The first and second studied Liwan House are located in Mokhtara Village. Mokhtara is a mid-mountainous village with an altitude of 850m. It is located in the Chouf District that is an administrative division of Mount Lebanon governorate (Localiban, 2016). The location of the Liwan houses are on a mountain hill, overlooking the valley where Barouk and Wadi el Maa rivers meet (Liban, 2021). Both houses are in the same neighborhood and far away with a distance of 100m.

A) Layout

The flat and the vaulted roofs of Liwan houses in Mokhtara have four common rooms in the interior space: Liwan, two units each located on the opposite sides of the Liwan, and a room within the Liwan. The flat roof Liwan house also has a balcony connecting all the rooms (refer to figure 4.2 (b)). The flat roof Liwan house studied in the Mokhtara is composed of two floors: 1) a Liwan house on the upper floor, and 2) barrel vault unit in the basement that was used as an animal shelter. According to the compass, the house is oriented towards the northeast direction. The house is totally opened from the south, north, east side, but closed from the west side. While the second Liwan house of the vaulted roof, it is oriented towards the south-west direction (as shown in Figure 4.3 (a)). This house is still functional. It is completely opened from the north-west and south-west side, and closed from the northeast and southeast side. On the north-west side, there is a private sitting area with an added kitchen, and on the northeast, there is a salon. The Liwan acts as a sitting space facing the bedroom.

Mokhtara Flat Roof Liwan House

Figure 4.2 (a) Orientation of the Flat Liwan House, Source: Author

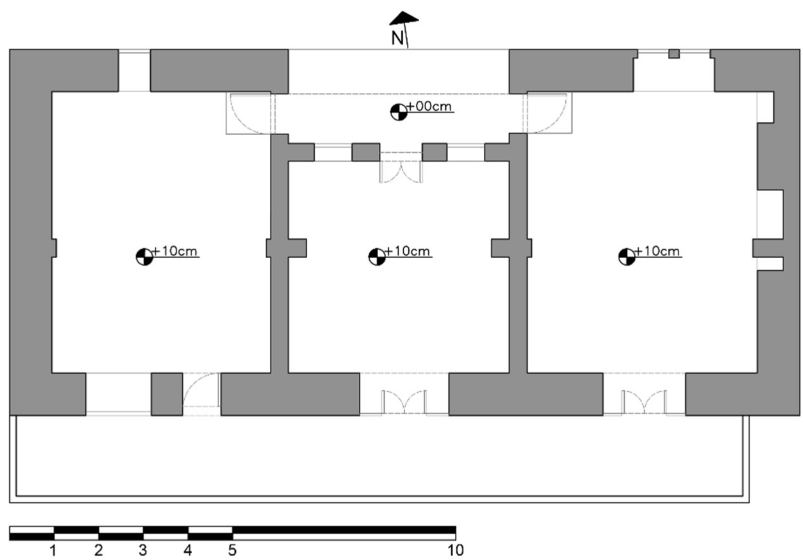


Figure 4.2 (b): Plan of Mokhtara Flat Liwan House, Source: Author

Mokhtara Vaulted Roof Liwan House

Figure 4.3 (a) Orientation of the Vaulted Liwan House, Source: Author

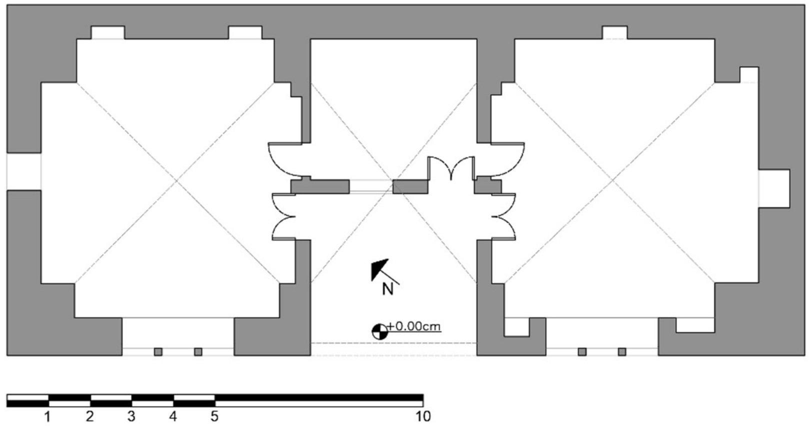


Figure 4.3 (b): Plan of Mokhtara Vaulted Liwan House, Source: Author

B) Composition: Typology Analysis

- *Roof Analysis*

While analyzing the flat Liwan roof house, the Liwan roof type was a post-lintel wood roof carried on a structural arched wall (as in Figure 4.4). Then, it was changed to a concrete roof with additions of concrete beams (refer to figure 4.6).

Roof Analysis of Mokhtara Flat Roof Liwan House

Figure 4.4 Arched structural walls, Source: Author

Figure 4.5 Steel structure for vine trees still exists, Source: Author

Figure 4.6 Concrete structural beams added in roof, Source: Author

The second studied house in the Mokhtara is a liwan house with a vaulted roof of 5.77m height. Additional floors were added on the top of the house (refer to figure 4.7 (a) and (b)). The roof used to be earth and gravel, and afterwards the residents added a layer of concrete to insulate the roof from storm water. The walls are made of stone materials having 36cm depth, and a structure to hold the vaulted ceiling (refer to figure 4.8 (c)). Both studied houses in the Mokhtara have a grapevine tree over a steel structure that serves as a shading device and acts as a place for activities.

Roof Analysis of Mokhtara Vaulted Roof Liwan House			
Exterior	 *Figure 4.7 (a)*	 *Figure 4.7 (b)*	
Interior	 *Figure 4.8 (a)*	 *Figure 4.8 (b)*	 *Figure 4.8 (c)*

Figure 4.7 (a) Photo of the added floor, (b) Photo of South-west side. Source: (Corpus and Euromed, 2003) Accessed 10-1-2021, Source: Author

Figure 4.8 (a) north-west room, (b) north-east room, (c) old photo of the house. Source: (Corpus and Euromed, 2003) Accessed 10-1-2021, Source: Author

- *Walls Analysis*

The exterior walls of the flat roof Liwan house is of depth 95cm, and are made of: 1) two stone layers from both sides, and 2) rubble and earth in between. As for the interior wall of depth 40 cm, it is a single stone structure. Before the renovation, the walls were plastered using a mixture of clay and ashes; however, the finishes of the wall interior are now plastered with a concrete layer and painted white color (refer to figure 4.10). As for the openings, it provides natural ventilation from the doors facing the valley. The wind enters from the south-west windows (as in figure 4.9 (b)), and exits through the facing northeast windows (refer to figure 4.9 (a)). The Liwan creates a cross-ventilation effect. Accordingly, windows that are placed on the Liwan facing room ensure a smooth wind movement through the interior space (figure 4.11). Additionally, small openings exist on the upper part of the walls to keep the rooms ventilated in winter even when the openings are closed.

Wall Analysis of Mokhtara Flat Roof Liwan House

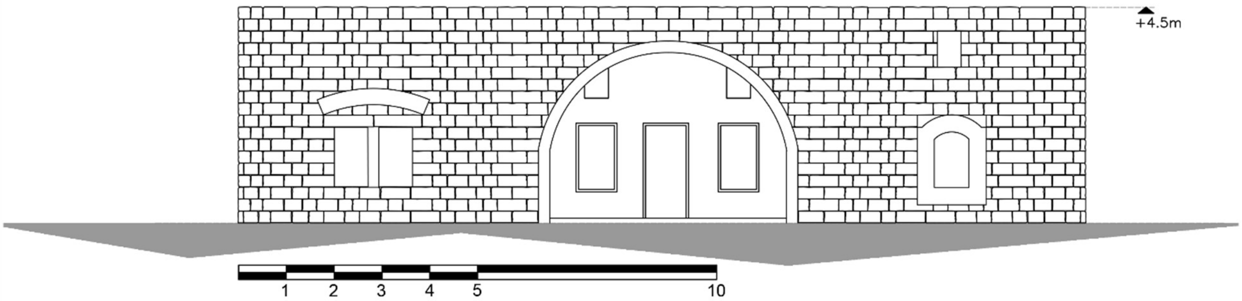


Figure 4.9 (a) Northeast Technical Elevation of Flat Mokhtara Flat Roof Liwan House, Source: Author

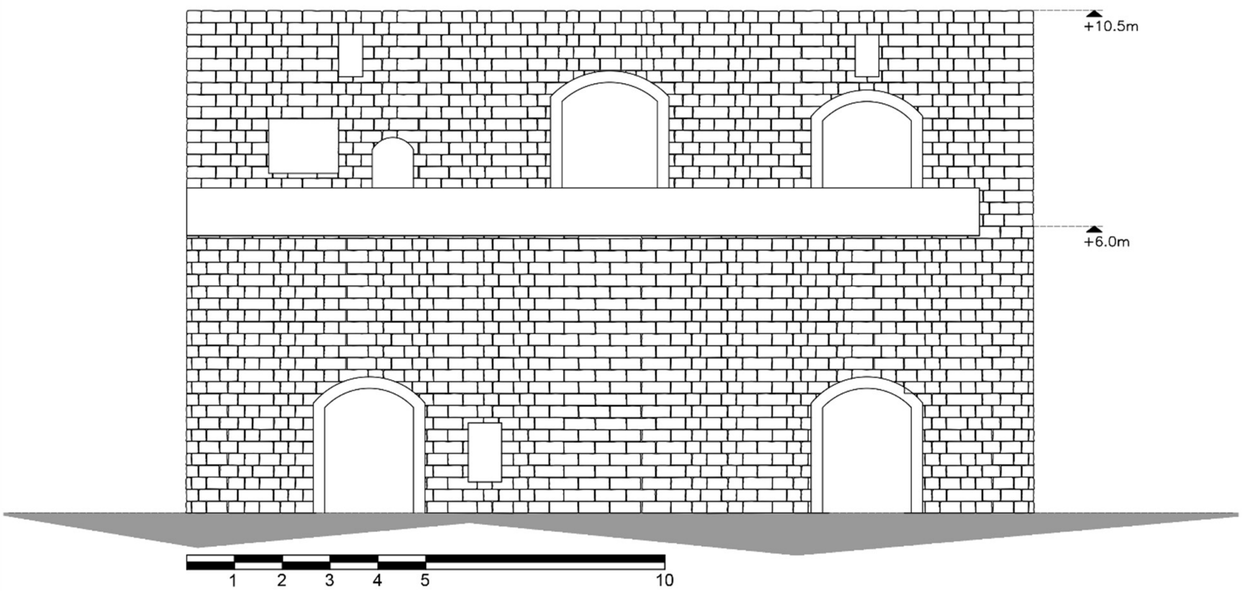


Figure 4.9 (b): South-West Technical Elevation of Mokhtara Flat Roof Liwan House, Source: Author

Openings Analysis of Mokhtara Flat Roof Liwan House

Figure 4.10 Plastered and white painted interior finish, Source: Author

Figure 4.11 Liwan room wall elevation, Source: Author

Figure 4.12 Different levels between the Liwan space and the interior rooms, Source: Author

In Mokhtara, the walls of the vaulted Liwan and the north-west room are plastered with gypsum material and there is some decoration on it (figure 4.8 (a)). Lately, plaster was removed by the owners in the north-east room, to be replaced by cement to fill the gaps between the stones. As for the openings, it provides natural ventilation from the Liwan and windows facing the valley. The wind enters from the south-west openings (refer to figure 4.14 and 4.16), and circulate in the building through the open doors facing each other (as in figure 4.17) to exit from the opening on the north-west side. The opening on the north-west side used to be a window; however, after the addition of the kitchen room, the window was replaced by a door (refer to figure 4.15). The openings on the upper part of the walls as in Figures 4.15 and 4.16 have significant size especially in the Liwan to ensure the ventilation.

Wall Analysis of Mokhtara Vaulted Roof Liwan House

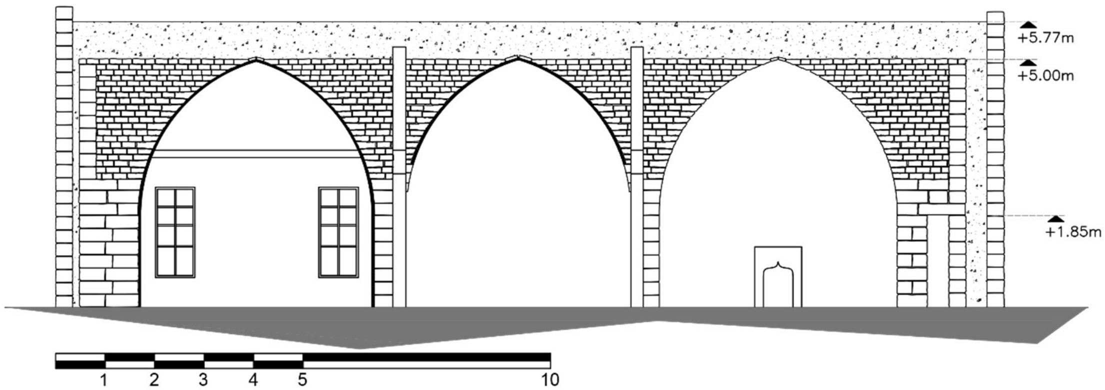


Figure 4.13 Technical Section of Vaulted Mokhtara Roof Liwan House, Source: Author

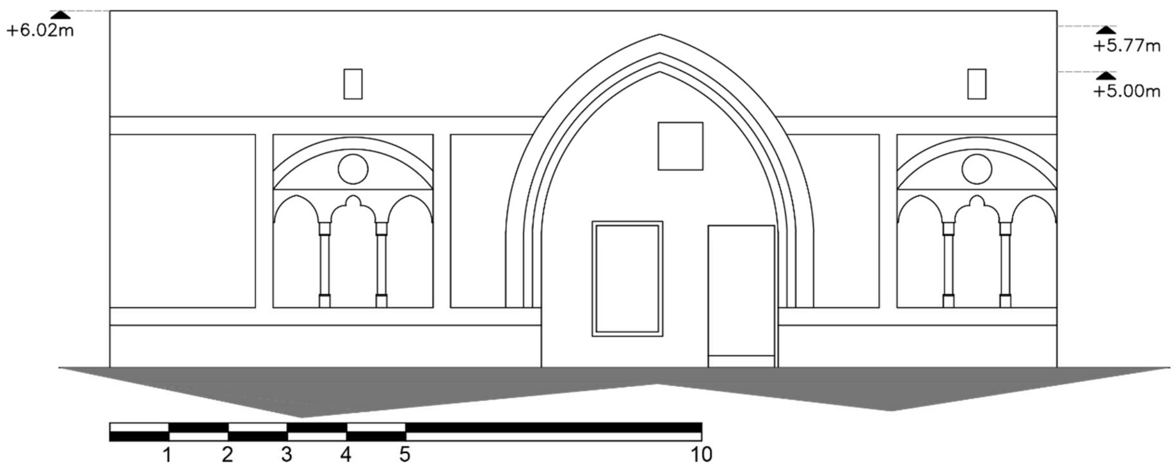


Figure 4.14 South-West Technical Elevation of Mokhtara Vaulted Roof Liwan House, Source: Author

Openings Analysis of Mokhtara Vaulted Roof Liwan House

Figure 4.15 Photo of north- west room where the window is replaced by a door, Source: Author

Figure 4.16 Window opening on the north-west side, Source: Author

Figure 4.17 Photo of the openings facing each other, Source Author

In the case of this vaulted liwan house in Mokhtara, different heating systems are present for the winter season. A chimney has been integrated within the wall since construction on the northeast room (as in figure 4.19). In the north-west room, a wood stove was then added (as shown in Figure 4.18).

Figure 4.18 Photo of the stove used for heating, Source: Author

Figure 4.19 Photo of the existing chimney, Source: Author

- *Floor Analysis*

The floor of the flat roof Liwan in Mokhtara is on a different level to keep the interior space dry from water. Thus, the Liwan is on a lower level in order to drain out the water while the three other rooms are on a higher one (refer to figure 4.12). The floor of the vaulted Liwan is on the same level as the front terrace of the house. In addition, there is a threshold on the door to prevent water from entering inside the rooms (refer to the south- west elevation in figure 4.14).

4.2.2 Location: Two Liwan Houses in Haret Jandal

The third and fourth Liwan House studies are located in Haret Jandal Village. Haret Jandal is a mid-mountainous village with an altitude of 850m. It is located in the Chouf District that is an administrative division of Mount Lebanon governorate (Localiban, 2016). The location of those Liwan houses are on a mountain hill, overlooking the valley where Naher Awali (Bisri) crosses.

A) Layout

As shown in the plan (figure 4.20 and 4.21 (a) and (b)), both Liwan residential houses of Haret Jandal are divided into three rooms: Liwan, and two units each located on the opposite sides of the Liwan. After an earthquake hit Lebanon in 1952, the flat roof Liwan house of Haret Jandal was partially destroyed and left abandoned. This house is oriented towards the South-West direction (refer to the figure of the compass in figure 4.20 (a)). As for the vaulted roof of the Liwan house in Haret Jandal, it is still functional, and the owner has removed the walls separating the rooms and thus created one open space. This house is oriented towards the west direction (figure 4.21 (a)). It harvests the cool wind coming from the valley, optimizes the use of winter sun radiation, and provides shade in the summer season. This vaulted roof house is totally opened from the south-west and north-west side, and closed from the north and east side. However, the flat roof house is opened from the south-west side, partially from the north-west side, yet closed from south and north sides.

Haret Jandal Flat Roof Liwan House

Figure 4.20 (a) Orientation of the Flat Liwan House, Source: Author

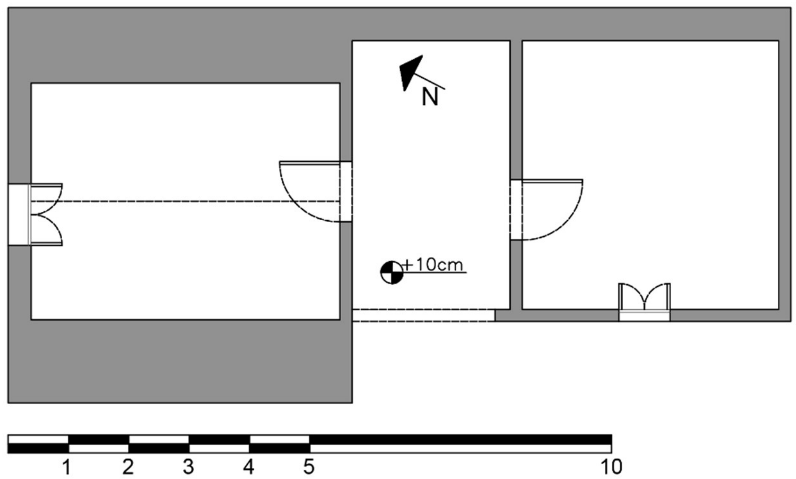


Figure 4.20 (b): Plan of Haret Jandal Flat Liwan House, Source: Author

Haret Jandal Vaulted Roof Liwan House

Figure 4.21 (a) Orientation of the Vaulted Liwan House, Source: Author

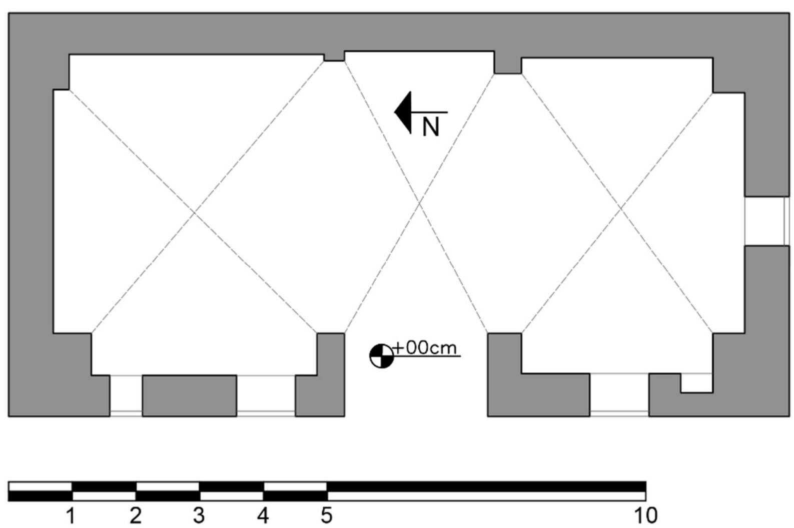


Figure 4.21 (b): Plan of Haret Jandal Vaulted Liwan House, Source: Author

B) Composition: Typology Analysis

- *Roof Analysis*

The Liwan flat roof type in Haret Jandal is a combination of post-lintel (4.1-meter-high) and barrel vaulted roof (3.85- meters-high). Meanwhile, the house is on two-levels-height (refer to figure 4.23). The Liwan space and the roof of the south-side room have a timber roof which is gone in the present time while the north-side room is a still standing barrel-vaulted roof (refer to figure 4.22). The barrel-vaulted roof is composed of two layers: a stone layer of 20cm and an earth layer of 50cm.

Roof Analysis of Haret Jandal Flat Roof Liwan House

Figure 4.22 Photo for the post-lintel and barrel-vault roof, Source: Author

Figure 4.23 Difference in the Stone finishing between the different rooms, Source: Author

Figure 4.24 Present Photo of the Liwan Structure, Source: Author

Accordingly, the Liwan roof in Haret Jandal is a vaulted roof with 4.1m height. As the owner mentioned, the main reason behind the use of stone vaults is its long-term applicability for the future generations. Additional floors were added on the top of the house (refer to figure 4.25). The roof used to be earth and gravel, and the residents afterwards added a layer of concrete to insulate the roof from storm water. The walls are made of stone material with a width of 70cm having a structure to hold the vaulted ceiling (refer to figure 4.26).

Roof Analysis of Haret Jandal Vaulted Roof Liwan House

Figure 4.25 photo of the Liwan house with the additional construction added, Source: Author

Figure 4.26 photo of the cross-vault structural base, Source: Author

- *Walls Analysis*

In the case of the flat roof liwan house, the walls are made of stone material of 26cm depth (Figure 4.23). The exterior stone finish of the vaulted-roof room is rough finish surface, and that of the timber-roof is smooth finish surface. The walls separating the Liwan from the south side room were demolished due to the earthquake, and the main wooden beam rested on the top of the wall before its destruction. The walls were plastered using a mixture of clay and ashes; however, the wall interior finish is now left rough and uncleaned. Similarly, the walls of the barrel vault have plaster and now is left with only stone material (refer to figure 4.28).

In the study of the openings of this Liwan flat roof, the Liwan and the south-west window provide natural ventilation (refer to figure 4.30). The wind enters the right-side room through the door, and exits it from the opposite window side, forming a venture effect (refer to figure 4.29). Accordingly, small openings shown in Figure 4 are present on the upper part of the walls in the right-side room in order to keep the rooms ventilated even in winter when all the openings are closed. As mentioned before, the Liwan house is oriented facing the south-west direction, thus a shading device was added on the window, which has the same orientation of Liwan to prevent the excess of solar radiation from entering the room in the hot season. This is present in figure 4.30.

Wall Analysis of Haret Jandal Flat Roof Liwan House

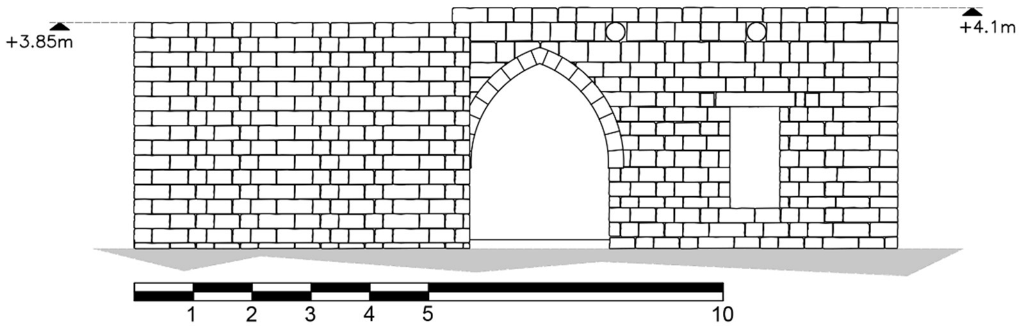


Figure 4.27 (a) South-West Elevation of Haret Jandal Flat Roof Liwan House, Source: Author

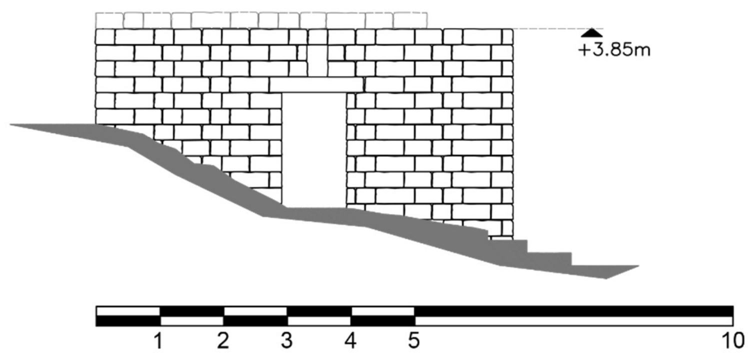


Figure 4.27 (b) Elevation of Haret Jandal Flat Roof Liwan House, Source: Author

Openings Analysis of Haret Jandal Flat Roof Liwan House

Figure 4.29 Photo taken from the north-west window, Source: Author

Figure 4.30: Openings on the south-west side, Source: Author

Figure 4.28 Photo of rough wall finish from the interior showing what is left from the wall under the wooden beam, Source: Author

In the case of the vaulted roof of Liwan house in Haret Jandal, the interior walls in the Liwan were made of wood studs, and filled with mud prior to its removal by the owner. The walls were plastered using a mixture of clay and ashes, and then it was removed, replacing it with a concrete layer. Lately, the owner removed the concrete plaster and left the walls with rough stone finish (refer to figure 4.31).

Wall Analysis of Haret Jandal Vaulted Roof Liwan House

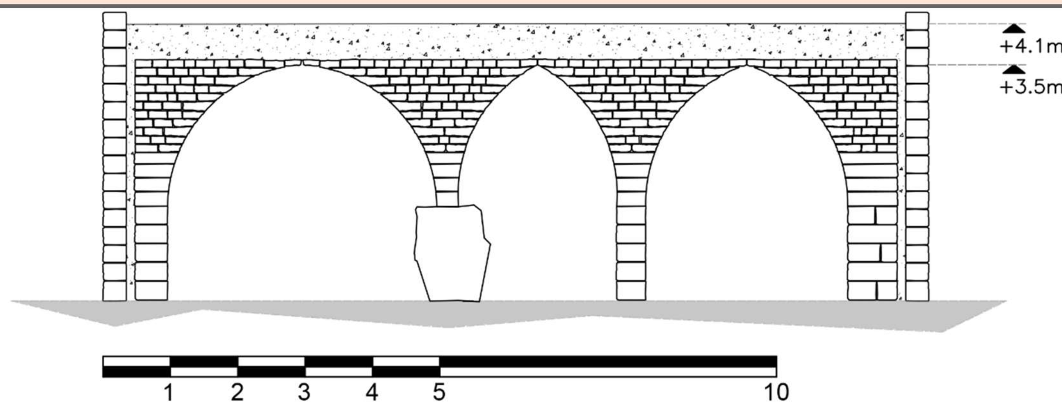


Figure 4.31 Technical Section of Vaulted Jandal Flat Roof Liwan House, Source: Author

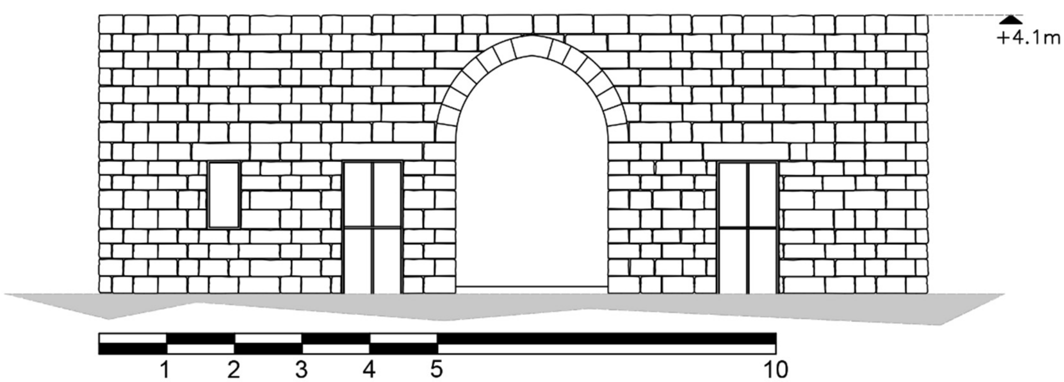


Figure 4.32 (a) North-West Technical Elevation of Vaulted Jandal Flat Roof Liwan House, Source: Author

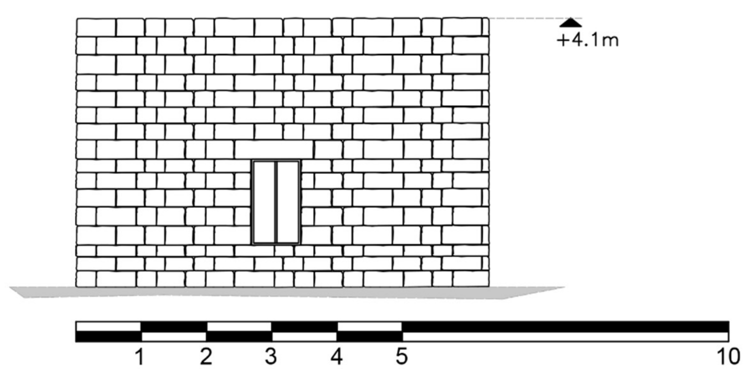


Figure 4.32 (b): South-West Technical Elevation of Haret Jandal Flat Roof Liwan House, Source: Author

`Openings Analysis of Haret Jandal Vaulted Roof Liwan House

Figure 4.33 North-west openings that was a door and then transformed into windows, Source: Author

Figure 4.34 North-West Openings, Source: Author

The openings provide natural ventilation from the Liwan and windows facing the valley. The wind enters from the north-west openings, and circulates in the interior open space of the house, to exit from the opening on the south-west side (as shown in figure 4.32 (a) and (b)). The opening on the north-west side used to be a door; however, the owner replaced it with windows (refer to figure 4.33). The openings on the upper part of the walls ensure the ventilation (Figures 4.34).

- *Floor Analysis*

In both Liwan houses of Haret Jandal, the floors are concrete and only the liwan element of the liwan flat roof house is of earth material.

4.2.3 Location: One Liwan House in Abey

The second studied Liwan house is located in Abey Village. Abey is a mid-mountainous village with an altitude of 720m. It is located in Aley Distric, which is an administrative division of Mount Lebanon governorate (Localiban, 2016). The location of the house is on a mountain hill, overlooking the valley of Ain Ksour and Ain Drafil villages.

A) Layout

The house was owned by Shiekh Rasheed Amin El Deen and was built in the 18th century, in the past decades. As mentioned by residents, due to war and an earthquake, the house faced different phases of destruction (refer to figures 4.36 (a) and (b)), and was left abandoned (Hamzeh, 2021). Afterwards, the house was reconstructed as its original form and using the materials left from the destruction, by its new owner (refer to figure 4.36 (c), (d) and (e)). The house is composed of 2 floors: 1) a Liwan house on the upper floor, and 2) barrel vault unit in the basement which was used as an animal shelter. According to the plan shown in Figure 4.35 (b), the Liwan residential house is divided into four rooms: Liwan, and three units. The two units are each located on the opposite sides of the Liwan, and the third one is attached to the left side unit and was used as a kitchen. The Liwan's opening is oriented towards the South-West direction, as shown in Figure 4.35 (a). The direction of the Liwan element and the openings toward the South-West side ensure the entrance of the needed solar radiation in the winter to warm the interior spaces in afternoon hours. The house is opened from the northeast, south-west, and west, yet closed from the east side. The windows on the northeast side harvest the wind coming from the valley and allow the penetration of the morning solar radiation into the rooms.

Abey Flat Roof Liwan House

Figure 4.35 (a) Orientation of the Flat Liwan House, Source: Author

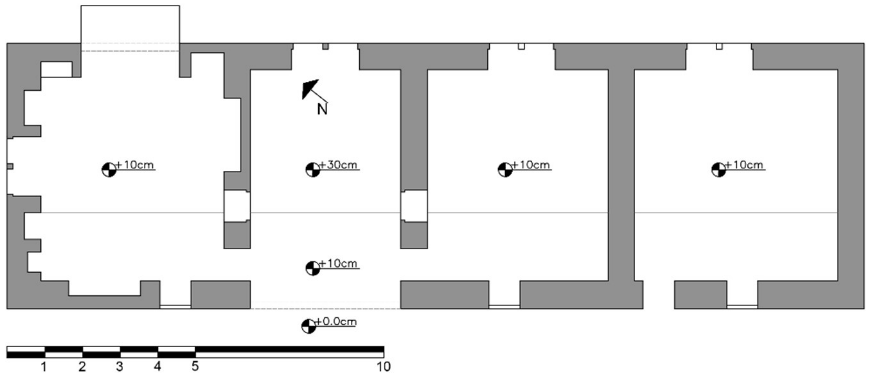


Figure 4.35 (b) Plan of Abey Liwan House, Source: Author

Before

After

Figure 4.36 (a) Old Photo, (b) Drone Photo Before Renovation, (c,d) Renovation Process, and (e) Present Photo of Liwan Structure. Source: (Corpus and Euromed, 2003) Accessed 10-1-2021, Source Author

B) Composition: Typology Analysis

- *Roof Analysis*

The Liwan roof type was a post-Lintel wood roof before it was destroyed. As shown in Figure 4.36 (d), few modifications were present through the renovation process, such as the additions of concrete columns and the roof construction from the concrete material.

- *Walls Analysis*

Wall Analysis of Abey Flat Roof Liwan House

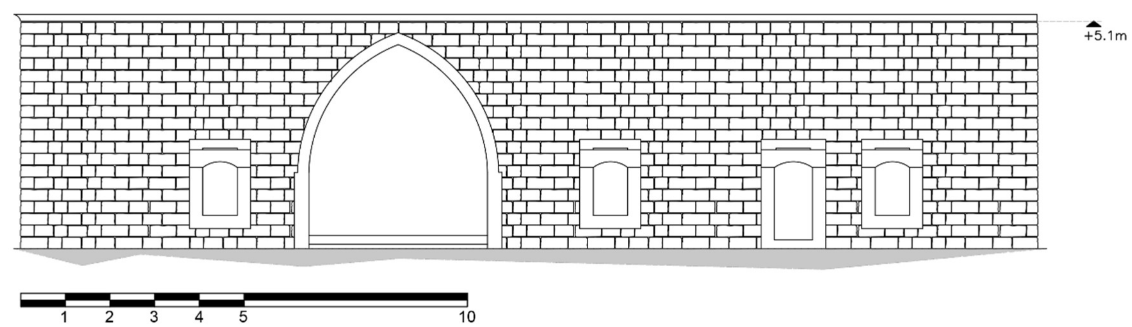


Figure 4.37 (a) South-West Technical Elevation of Abey Flat Roof Liwan House, Source: Author

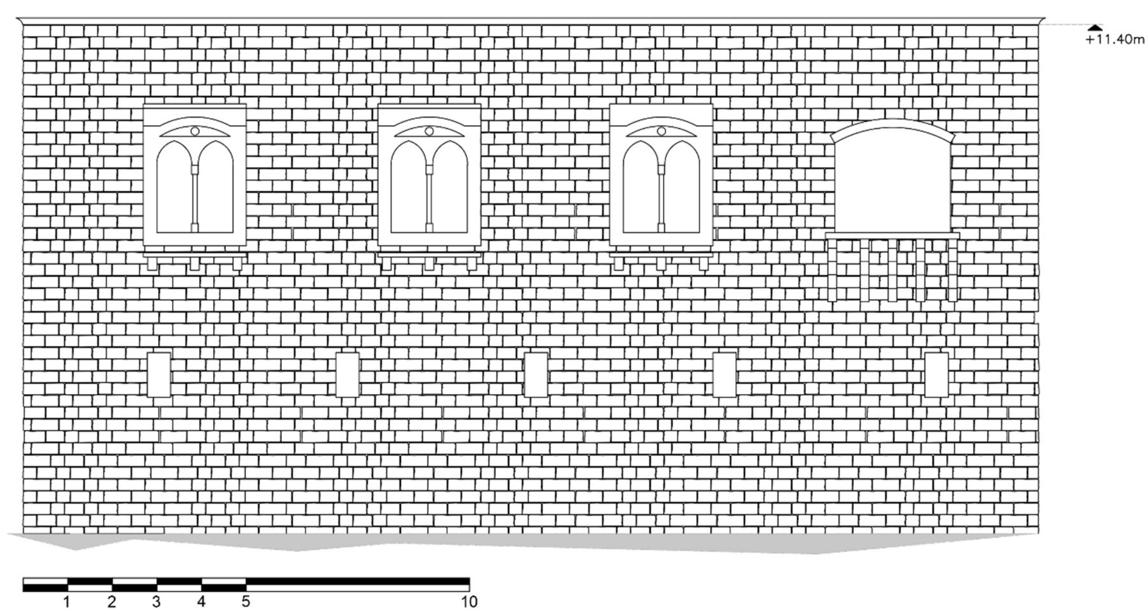


Figure 4.37 (b) North-East Technical Elevation of Flat Abey Flat Roof Liwan House, Source: Author

The walls are made of two stone layers from both sides with rubble and earth in between. However, the depth of the walls differs between the right-side room, which is 90cm, and the two left-side rooms that are 70cm. Before reconstruction, the original walls were plastered using a mixture of clay and ashes; however, the finishes of the wall interior are now left rough (refer to figure 4.39).

Construction Analysis of Abey Flat Roof Liwan House

Figure 4.38 Photo of the Reconstruction Phase, Source: Author

Figure 4.39 Plastered Walls

Figure 4.40 Different Floor Level

Openings Analysis of Abey Flat Roof Liwan House

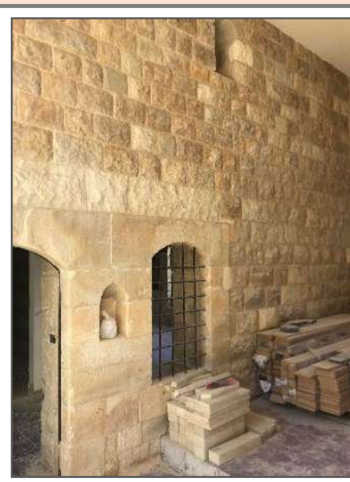


Figure 4.41 (a) and (b) Smaller Windows on Upper Part of Walls

As for the openings, it provides natural ventilation from the windows facing the valley. The wind enters from the northeast windows (figure 4.37 (b)), and exits through the facing south-west windows. The Liwan creates a cross ventilation effect (refer to figure 4.37 (a)). Accordingly, windows that are placed on the Liwan sidewalls and the exterior wall of the north-west room ensure a smooth wind movement through the interior space (refer to figure 4.41(a) and (b)). Additionally, small openings exist on the upper part of the room walls in order to keep the rooms ventilated in winter when all the openings are closed. However, some of those openings were closed in the rebuilding process while others were kept as it is (figure 4.41 (b)).

- *Floor Analysis*

The floor is on a different level to keep the interior dry from water. Similarly, in order to channel water to the drainage system in the room the lower level is sloped (as shown in figure 4.40).

4.2.4 Location: One Liwan House in Kfar-Katra

The last studied Liwan House is located in Kfar-Katra Village. Kfar-katra is a mid-mountainous village with an altitude of 760m. It is located in the Chouf District, which is an administrative division of Mount Lebanon governorate (Localiban, 2016). The location of this Liwan house is on a mountain hill, overlooking the valley, where Naher El Jaouz passes.

A) Layout

The Liwan residential house is divided into four rooms: Liwan, two units each located on the opposite sides of the Liwan, and a room in the Liwan (refer to figure 4.42 (b)). The house is partially destroyed due to the earthquake of 1952 and what is left is the Liwan and northeast room. This house is oriented towards the north-west direction (refer to figure 4.42 (a)). It harvests the cool wind coming from the valley, optimizes the use of winter sun radiation when the sun angle is low, and it is shaded in the morning and noon in the summer seasons. As shown in Figure 4.43, the house is integrated within the topography. It is opened from northeast, north-west, and south-west side, and it is partially closed from the east side.

Kfar- Katra Vaulted Roof Liwan House

Figure 4.42 (a) Orientation of the Vaulted Liwan House, Source: Author

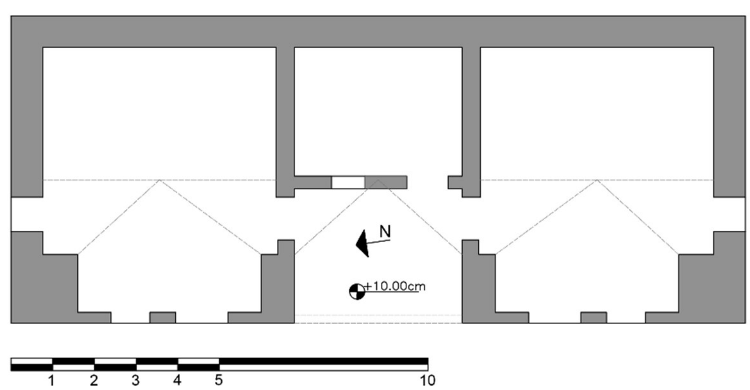


Figure 4.42 (b) Plan of Kfar- Katra Liwan House, Source: Author

B) Composition: Typology Analysis

- *Roof Analysis*

The Liwan roof type is vaulted with 4.45m height (refer to figures 4.46 (a) and (b)). Lately, the rooftop is composed of earth and rubble, and the vault is composed of two types: 1) half a barrel vault from the east side, and 2) half a cross vault from the north-west side. Accordingly, the ceiling is composed of two layers: a stone layer of 20cm, and an earth layer of 50cm.

Roof Analysis of Kfar- Katra Vaulted Roof Liwan House

Figure 4.43 Liwan House and Topography, Source: Author

Figure 4.44 photo of the existing structure of the cross vault and the remaining plaster, Source: Author

- *Walls Analysis*

The walls are made of stone material of 44cm width, having a base structure on the north-west side of the rooms which serves as a support for the cross-vault ceiling (refer to figures 4.44). On the south-west side, the walls are demolished, and the stones in the base are cracked. Therefore, the house is threatened to be totally destructed (refer to figures 4.47). The walls were plastered using gypsum material; however, the wall interior finish is left rough and uncleaned.

Walls Analysis of Kfar- Katra Vaulted Roof Liwan House

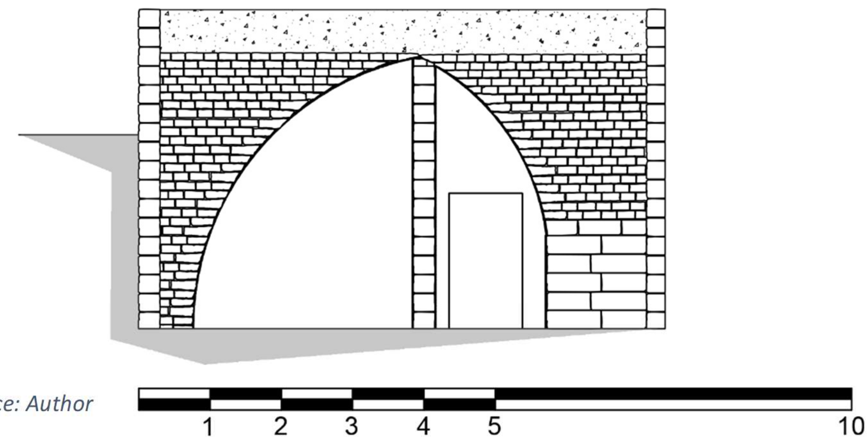


Figure 4.45 Liwan section, Source: Author

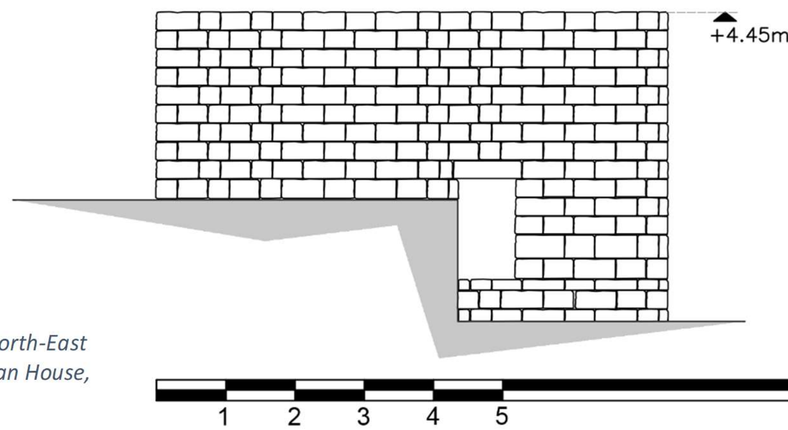


Figure 1.46 (a) Technical North-East Elevation of Kfar-Katra Liwan House, Source: Author

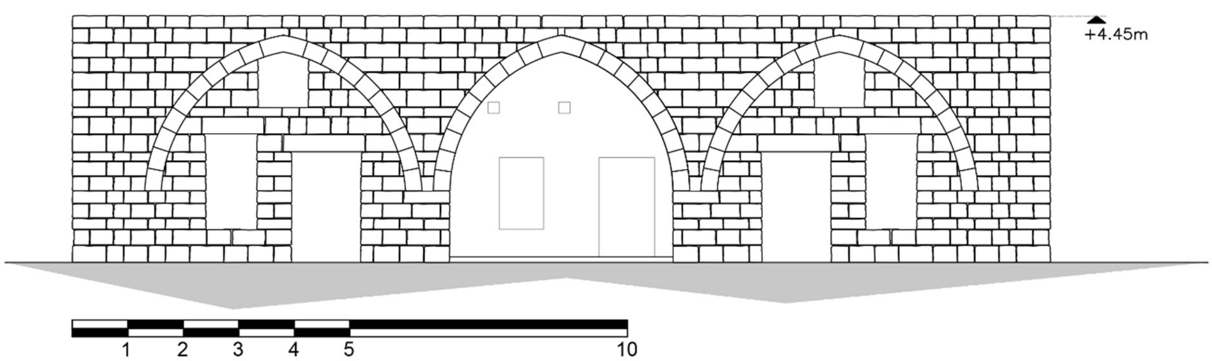


Figure 1.46 (b) Technical north-west Elevation of Kfarkatra Liwan house, Source: Author

Openings Analysis of Kfar- Katra Vaulted Roof Liwan House

Figure 4.47 Leaks found in the house structure and the openings in the Liwan, Source: Author

Figure 4.48 Photo of the existing Liwan house after destruction, Source: Author

Figure 4.49 North-east window, Source: Author

Figure 4.50 Openings on the north-west side, Source: Author

As for the openings, this house has doors on the north-west side leading directly to rooms instead of accessing it just from the Liwan (refer to figures 4.50). The Liwan, the openings on the upper level of the wall, the doors, and the windows on the north-west side, allow the passage of the wind coming from the valley into the interior space. The wind circulates in the interior space throughout entering the room doors facing each other and then exiting from the window on the north-east side (refer to figures 4.49). In addition, the openings on the upper part of the walls in the room of Liwan ensure the ventilation of the space.

- *Floor Analysis*

In Kfar Katra vaulted Liwan house, the floor of the Liwan element is concrete and the rest of the house is of earth material.

4.3 Conclusion: Building Envelope Analysis of Both Scenarios

This chapter analyzed the context of two scenarios, post-lintel and vaulted case studies. The sections were divided into layout analysis and composition typology analysis. The layout analysis elaborated the distribution of spaces with the dominant materials used. The composition typology was analyzed in relevance to the roof, wall and floor assemblies. Therefore, pictures and technical drawings were presented to discuss the liwan spaces, construction materials of the assemblies, number of floors, and orientation of windows and doors.

CHAPTER FIVE
DISCUSSION OF SCENARIOS AND RESULTS

5.1 Introduction

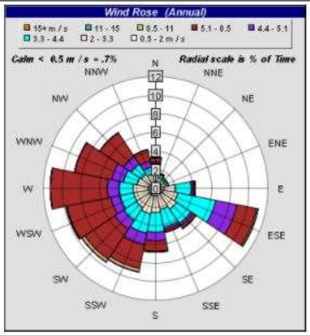
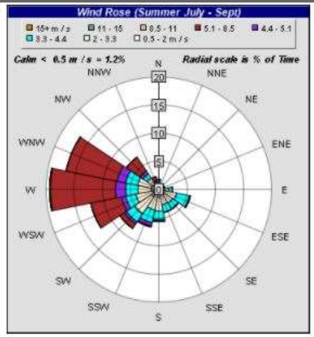
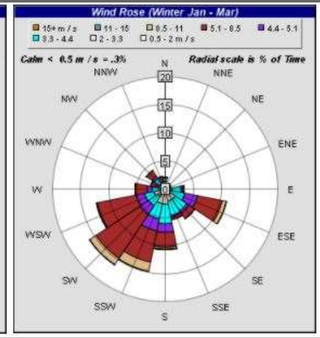
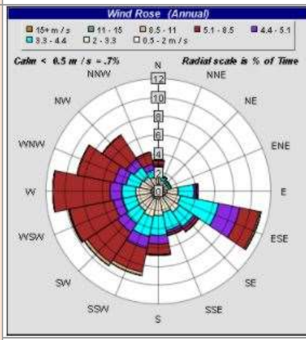
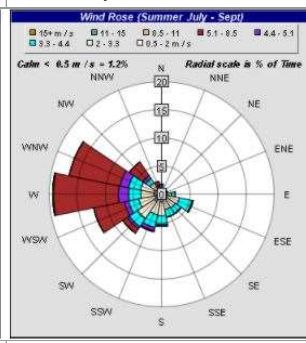
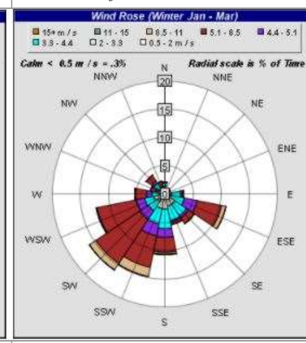
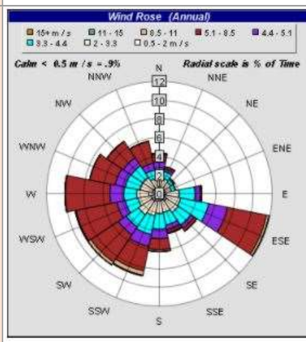
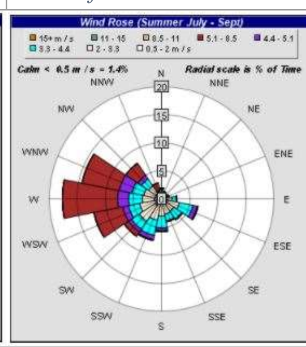
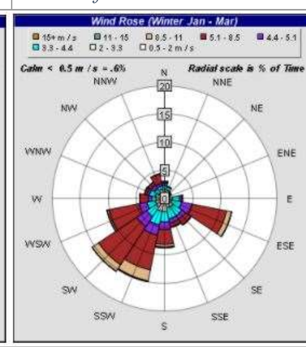
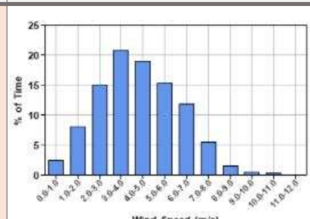
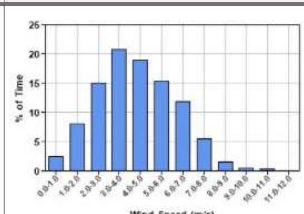
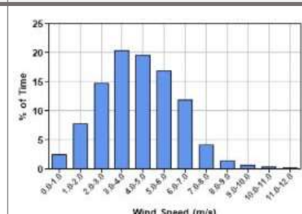
This chapter aims to show the impact of orientation, construction materials, and depth to width dimensions of Liwan, on the thermal performance and indoor thermal comfort of occupants. Thus, the chapter discusses the two scenarios selected in the mid-mountainous region, post- lintel flat roof and vaulted roof. In each scenario, the following factors are compared: wind and sun, thermal performance, and thermal comfort. Firstly, the initial building conditions of each case study is modeled in Revit specifying its true north. This will determine the sun exposure in each case study. Secondly, the GBS is used to indicate from the wind the highest and lowest wind frequencies in summer and winter seasons. The frequencies are presented in percentage, which is meant to be the annual number of days with highest and lowest velocities in winter and summer seasons. Thirdly, the CFD software is used to assess the wind factor, thermal performance and thermal comfort. In CFD, the materials with their thermal properties and the boundary conditions are defined. The boundary conditions identify the thermal transmittance (u-value) of the envelope, define the volume flow rate and temperature of openings, and specify the openings with indirect wind flow as zero pressure. Then, the meshing Auto size and Solve are performed to define the factors that will be assessed in each case study. Before the simulation, the 400 iteration is selected to assess and compare the Liwan houses in scenarios one and two.

5.2 Modeling and Simulation of Scenario One: Post-Lintel Flat Roof

According to the classified scenarios, scenario one has three Liwan houses and is identified as post-lintel flat roof. This section discusses this scenario in accordance with the following factors: wind and sun, thermal performance, and thermal comfort. Meanwhile, this will show the extent of the occupant's thermal comfort in the given climatic conditions, and the cases where cooling and heating systems are needed.

5.2.1 Analysis of Wind and Sun Factors

In the Liwan flat roof houses of Mokhtara, Haret Jandal and Abey, the annual wind is dominant from the west and east-south-east directions. The annual highest dominant wind is from the west direction in the summer season, and the south-west direction from the winter season. The highest wind speed frequency distribution is around 3 m/s to 4 m/s of 21% per year. Mokhtara and Haret Jandal are around 5.4km away from each other. Thus, both share the same weather station in Revit. Between July and September, the Mokhtara and Haret Jandal Liwan houses have a dominant wind from the west direction. It has a frequency approximately 20% which ranges between 5.1 to 8.5 m/s velocity in the summer season. In the winter season, the dominant wind is from the west side. Thus, between January and March, 15% of the frequency is of range 5.1 to 8.5 m/s velocity, and 1.5% of 8.5 to 11 m/s. In the case of the Abey Liwan house, it has the same direction of dominant wind with different frequencies. In summer, 17.5% of the wind is of velocity 5.1 to 8.5 m/s. In winter, 14% of the dominant wind ranges between 5.1 to 8.5 m/s velocity, and 1.5% of velocity 5.1 to 8.5 m/s (refer to figures 5.1 and 5.2).

	Annual Wind Data	Summer Wind Data	Winter Wind Data
Mokhtara Liwan House *(Source: GBS, by Author)*			
	Figure 5.1 (a) Annual wind data of Mokhtara house	*Figure 5.1 (b) Summer wind data of Mokhtara house*	*Figure 5.1 (c) Winter wind data of Mokhtara house*
Haret Jandal Liwan House *(Source: GBS, by Author)*			
	Figure 5.2 (a) Annual wind data of Haret Jandal house	*Figure 5.2 (b) Summer wind data of Haret Jandal house*	*Figure 5.2 (c) Winter wind data of Haret Jandal house*
Abey Liwan House *(Source: GBS, by Author)*			
	Figure 5.3 (a) Annual wind data of Abey house	*Figure 5.3 (b) Summer wind data of Abey house*	*Figure 5.3 (c) Winter wind data of Abey house*
	Mokhtara Liwan House	**Haret Jandal Liwan House**	**Abey Liwan House**
Annual Wind Speed Frequencies Distribution *(Source: GBS, by Author)*			
	Figure 5.4 (a) Annual wind speed frequencies distribution of Mokhtara house	*Figure 5.4 (b) Annual wind speed frequencies distribution of Mokhtara house*	*Figure 5.4 (c) Annual wind speed frequencies distribution of Mokhtara house*

Each case study has different wind flow properties. As mentioned by khanacademy (2021), the volume flow rate (Q) is equal to the cross sectional area (A) multiplied by the speed of the fluid (v). The highest and lowest wind directions are chosen in regards to the one which has high velocity in one of the seasons with respect to the other. This will build an understanding which room directions need cooling and heating systems. Because the annual dominant wind is from the south west and east-south-east direction (refer to figures 5.1 (a), 5.2 (a), 5.3 (a)), and the wind roses in the summer and winter seasons indicated high wind frequencies from the west direction with low velocities from the east-south-east directions, then the latter side will be analyzed as the direction having the lowest wind. The lowest wind from the east-south-east side is the case especially in summer (figures 5.1 (b), 5.2 (b), 5.3 (b)). In the summer season, the majority of the wind in the three case studies has a velocity of 3.3 to 4.4 m/s with a frequency of 6% (figures 5.1 (b) and 5.2 (b)). As for the winter, the frequency is around 11% with a dominant wind velocity of 5.1 to 8.5 m/s (as shown in figures 5.1 (c), 5.2 (c), 5.3 (c)). The air flow in each house is a case of turbulence. As assigned by GBS, the Mokhtara liwan house has 8m/s wind velocity then comes the Abey and Haret Jandal house which are 6.8 m/s and 5 m/s, respectively. To identify the volume flow rate, the areas of windows and doors facing the south-western dominant wind are firstly defined in each study (Table 5.1).

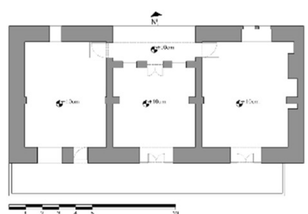
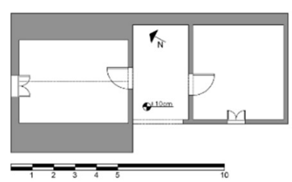
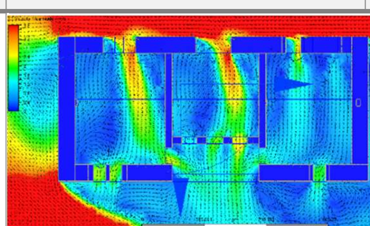
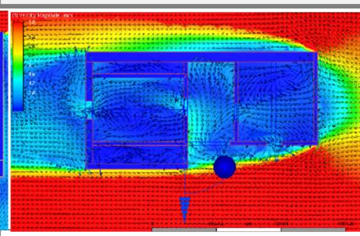
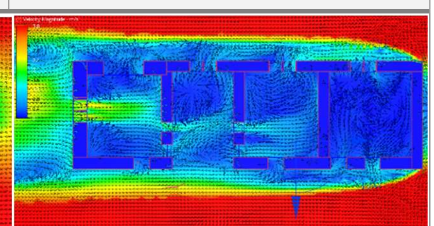
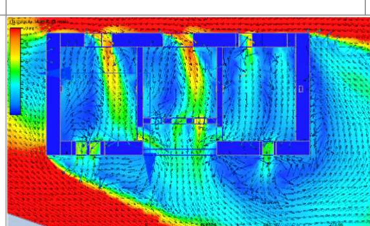
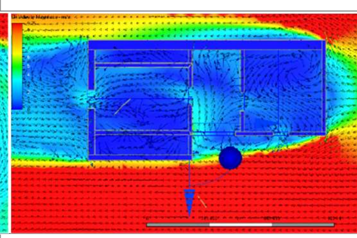
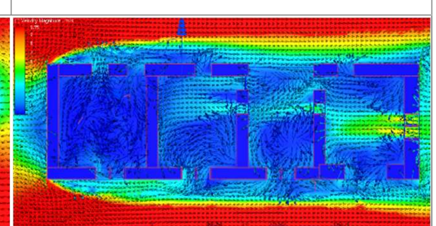
		Mokhtara Liwan House	Haret Jandal Liwan House	Abey Liwan House
Doors	Area	1.48 m^2/4.6 m^2/5.8 m^2	2.2 m^2	-
	Velocities	8 m/s	7.95 m/s	-
	Total	- 1.48 m^2 * 8 m/s = 4.82 m^3/s - 4.6 m^2 * 8 m/s = 36.8 m^3/s - 5.8 m^2 * 8 m/s = 46.4 m^3/s	- 2.2 m^2 * 7.95 m/s = 17.49 m^3/s	-
Windows	Area	1.61 m^2	1.4 m^2	1.22 m^2
	Velocities	8 m/s	5 m/s	6.8 m/s

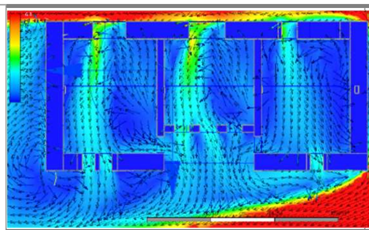
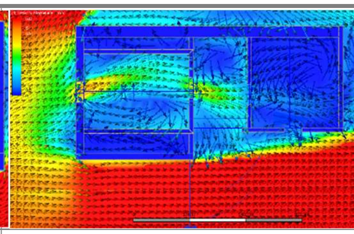
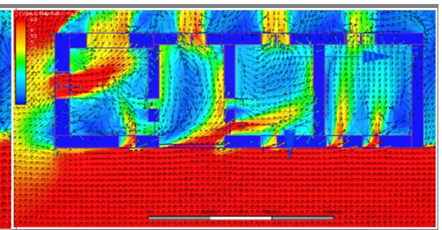
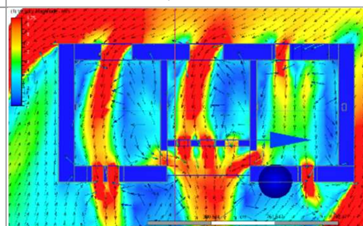
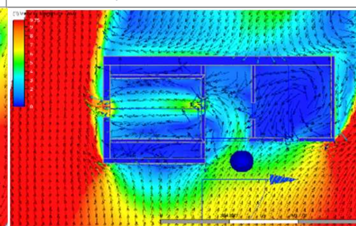
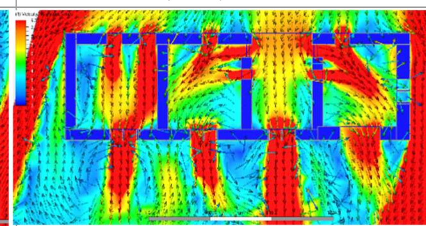
	Total	- 1.61 m^2 * 8 m/s = 12.8 m^3/s	- 1.4 m^2 * 5 m/s = 7 m^3/s	- 1.22 m^2 * 6.8 m/s= 8.3 m^3/s

Table 5.1 Showing the volume flow rate of doors and windows in Mokhtara, Haret Jandal and Abey Liwan houses, Source: Author

The southwest wind is the main wind direction in the three Liwan houses of the post-lintel scenario, Mokhtara, Haret Jandal and Abey flat roof houses. While analyzing the wind simulation in Mokhtara and Abey Liwan house, both case studies show high wind turbulence especially in winter season. The simulation of the closed space Liwan of Mokhtara house indicated a higher wind effect in the Liwan compared to Abey house, from the south west wind direction in the winter season (figures 5.9 (a) and 5.9 (c)). Meanwhile, in winter, the Mokhtara case study from the south west wind direction has high turbulence, around 8.5 to 9 m/s, especially for the north and south openings facing each other. Due to the dominant south-western wind especially in winter, the wind velocity which is set as 8m/s and the areas of openings were identified to calculate the volume flow rate. From this wind direction, the envelope system has a window and three doors of the following volume flow rate: 12.8 m^3/s, 11.84 m^3/s, 46.4 m^3/s and 36.8 m^3/s, respectively (Table 5.1). While Abey house has the south west openings, which will allow significant and extensive wind turbulence, due to the openings which are directly facing each other. This allows the flow of wind circulation in the inner space with high velocity of 9.75 m/s (figures 5.9 (c)). Hence, the south western wind enters from one window, having a velocity of 6.8 m/s and volume flow rate of 8.3 m^3/s (Table 5.1). In summer, the Mokhtara case study has the least effect from the south west direction, which is an approximately 2 m/s. As for Haret Jandal flat roof Liwan house, the opening on the north west direction, which is also facing the doors on each side of the Liwan, allow for wind circulation. Though, the circulation is around 3.5-4.6 m/s next to openings. Considering that in Haret Jandal house the south western wind velocity entering the door is 7.95 m/s and that from the window is 5 m/s, the volume flow rates are 17.49 m^3/s and 7 m^3/s respectively (Table 5.1).

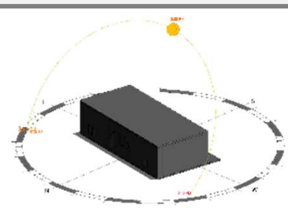
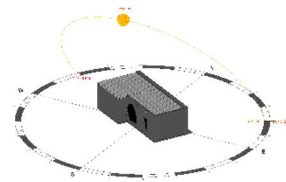
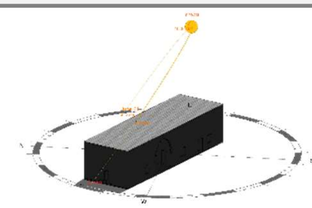
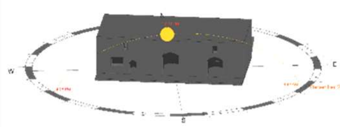
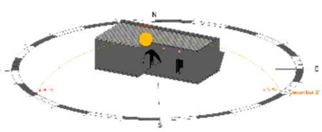
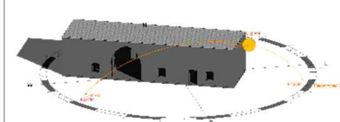
In the east-south-east wind directions in summer and winter, the Mokhtara case study shows effects of wind in the inner space more than Haret Jandal and Abey houses (figures 5.6 (a) and 5.7 (a)). This is the result of northern openings. While considering the Haret Jandal Liwan flat roof house, the east- south- east side of the house does not have openings. This will limit the wind circulation in the interior space (figures 5.6 (b) and 5.7 (b)). Thus, the wind simulation diagrams show slight wind turbulence in the inner spaces in summer and winter seasons. Accordingly, the Abey house receives slight east-south-east wind from the west façade (figures 5.6 (c) and 5.7 (c)).

	Plan of Mokhtara Liwan House	Plan of Haret Jandal House	Plan of Abey Liwan House
			
	Figure 5.5 (a) Plan of Mokhtara House	*Figure 5.5 (b) Plan of Haret Jandal house*	*Figure 5.5 (c) Plan of Abey house*
East South East			
Summer *(Source: CFD, by Author)*			
	Figure 5.6 (a) East South East summer wind of Mokhtara House	*Figure 5.6 (b) East South East summer wind of Haret Jandal house*	*Figure 5.6 (c) East South East summer wind of Abey house*
Winter *(Source: CFD, by Author)*			
	Figure 5.7 (a) East South East winter wind of Mokhtara House	*Figure 5.7 (b) East South East winter wind of Haret Jandal house*	*Figure 5.7 (c) East South East winter wind of Abey house*
South West			

Summer *(Source: CFD, by Author)*			
	Figure 5.8 (a) South West summer wind of Mokhtara House	*Figure 5.8 (b) South West summer wind of Haret Jandal house*	*Figure 5.8 (c) South West summer wind of Abey house*
Winter *(Source: CFD, by Author)*			
	Figure 5.9 (a) South West winter wind of Mokhtara House	*Figure 5.9 (b) South West winter wind of Haret Jandal house*	*Figure 5.9 (c) South West winter wind of Abey house*

The simulations of the sun factors were not analyzed in accordance to the actual sun on the studied houses such as, the consideration of longitude, latitude, time zone, date, time and sunshine factor. Hence, the sunshine factor, as set by Revit, is analyzed to determine the heating effect of the solar radiation in the case studies. After identifying the location and true north in Revit, the highest and lowest sun angles were automatically specified in order to draw a better understanding to the Liwan houses that need less heating and cooling systems.

The wind in Mokhtara house is oriented from the south western to the northern direction. The sun exposure on the southern side provides a natural heating factor in the winter season for the Liwan and the spaces on each side (figure 5.11 (a)). However, in the summer season, the sun exposure with slight wind velocity will result in usage of cooling devices (figure 5.10 (a)). Similarly, Haret Jandal case study needs cooling systems in summer for the room located on the east side of Liwan because it has no wind circulation (figure 5.10 (b)). In winter, the direct sun exposure from the west window and the slight wind circulation will dispense with the heating systems, at least in the daytime (figure 5.11 (b)). The sun exposure in Abey case study does not penetrate the inner space as it is not directly facing the openings. This means heating systems are highly needed to heat the space. As for the south-east-south wind directions, it has limited effect on the interior space (figures 5.10 (c) and 5.11 (c)). In summer and winter, the wind enters from the north west opening with a velocity reaches around 1.6 to 2 m/s and 4.5 to 6 m/s, respectively.

	Mokhtara Liwan House	Haret Jandal Liwan House	Abey Liwan House
Summer (June 21) *(Source: Revit, by Author)*			
	Figure 5.10 (a) Sun exposure in summer for Mokhtara House	*Figure 5.10 (b) Sun exposure in summer for Haret Jandal house*	*Figure 5.10 (c) Sun exposure in summer for Abey house*
Winter (December 21) *(Source: Revit, by Author)*			
	Figure 5.11 (a) Sun exposure in winter for Mokhtara House	*Figure 5.11 (b) Sun exposure in winter for Haret Jandal house*	*Figure 5.11 (c) Sun exposure in winter for Abey house*

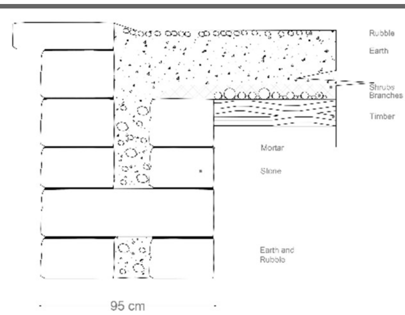
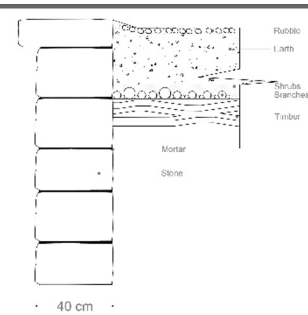
This indicates that the Haret Jandal flat roof has the least wind turbulence from the east southeast and the southwestern directions. From the east-southeast winter and summer wind directions, Mokhtara flat roof has the dominant wind flow in the inner spaces. However, in the south western winter and summer wind, Abey house has the most wind turbulence compared to Mokhtara house which showed high wind velocity in winter season only. Since the sun exposure is facing the Liwan space in winter for Mokhtara house, then this can help reduce the reliance on heating systems in daytimes at least. Due to the south western wind turbulence in Abey house and the sun exposure in Abey house is not directly facing the main façade, this would result in the use of active systems to heat the spaces in winter.

5.2.2 Analysis of Thermal Performance

The following paragraphs discuss the thermal performance of the post-lintel in both seasons, summer and winter. The simulations analyze the envelope system to determine the heating and cooling effects in each case study. According to GBS, the highest angle in summer was selected as 30 degrees Celsius and the lowest angle in winter as 5 degrees Celsius. The section one in summer and winter seasons is the simulation of the Liwan space, and section two is in the room next to the Liwan. This will build an understanding on Liwan's performance and its effect on the rooms aside.

As previously mentioned, the case studies in this section are of post lintel roof liwan houses. Thus, the Liwan spaces are flat. Prior to the thermal performance analysis, the u-value of the envelope system has an effect on its performance. The u-value measures how much heat will pass through one square meter of a structure when the temperature differs. The lower the thermal transmittance, the better is the thermal performance of a structure (Baker, 2011). Each case study has a different envelope u-value. The internal and external wall compositions are studied to understand the effect of difference in wall thicknesses on the u-value. As shown in the list of figures below, the u- value decreases with the increase in the thickness of the wall and roof systems. In Mokhtara Liwan house and Abey house, the houses were wooden post-lintel roof type and then it was replaced by a concrete slab (figures 5.12 (b) and 5.14 (b)). Hence, the wooden roof systems have lower u-value 0.59 $W/m^2.K$ compared to the existing concrete roofs that are 3.04 $W/m^2.K$. In the wall systems, Mokhtara Liwan house is of thickness 95cm and u-value 2.19 $W/m^2.K$ while Abey house has u-value 3.06 $W/m^2.K$ and 2.52 $W/m^2.K$ for wall thicknesses 70cm and 90 cm, respectively. In Haret Jandal house, the Liwan space has a flat roof of wood material with a barrel- vaulted space (figure 5.13 (b)). The external wall of thickness 70 cm has u- value 3.06 W/m^2.K, which is lower than the internal wall of 26cm and 9.19 W/m^2.K (figure 5.13 (a)). Accordingly, the roof system has lower u-value 0.62 W/m^2.K compared to the barrel vaulted of 1.42 W/m^2.K.

This means, the walls of Mokhtara Liwan house of thickness 95cm have the lowest thermal transmittance in comparison to Haret Jandal and Abey houses, thus better performance. Besides, the wooden roofs showed the lowest u-value compared to barrel vaulted and concrete roofs. Though, barrel vaulted roofs have significantly lower thermal transmittance in relevance to that of concrete material.

	Walls	**Roofs**
Mokhtara Liwan House	 *Figure 5.12 (a) Technical drawing of wall system in Mokhtara liwan house, Source, Author*	 *Figure 5.12 (b) Technical drawing of roof system in Mokhtara liwan house, Source: Author*
	Post - Lintel Side	Flat Roof
	- Thickness: 95 cm - u-value: 2.19 W/m^2	Existing Concrete Roof - u-value: 3.04 W/m^2.K Original Wooden Roof - u-value: 0.59 W/m^2.K

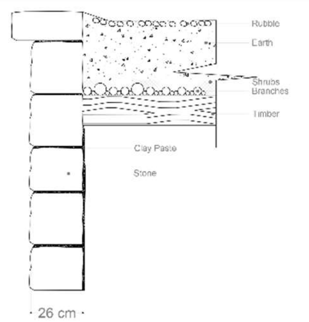
<table>
<tr>
<td rowspan="5">Haret Jandal Liwan House</td>
<td>

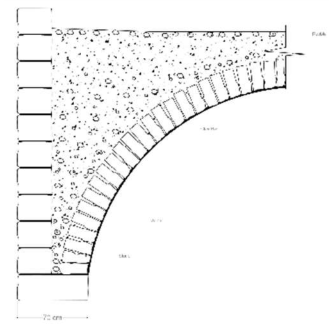
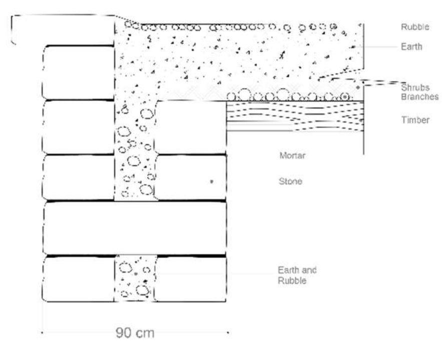
Figure 5.13 (a) Technical drawing of wall system in Haret Jandal liwan house, Source, Author</td>
<td>
Figure 5.13 (b) Technical drawing of roof system in Haret Jandal liwan house, Source, Author</td>
</tr>
<tr><td>Post - Lintel Side</td><td>Wooden Roof</td></tr>
<tr><td>- Thickness: 26 cm
- u-value: 9.19 W/m2.K</td><td>u-value: 0.62 W/m^2.K</td></tr>
<tr><td>Barrel - Vault Side</td><td>Barrel - Vault Side</td></tr>
<tr><td>- Thickness: 70 cm
- u-value: 3.06 W/m^2.K</td><td>u-value: 1.42 W/m^2.K</td></tr>
<tr>
<td rowspan="5">Abey Liwan House</td>
<td>

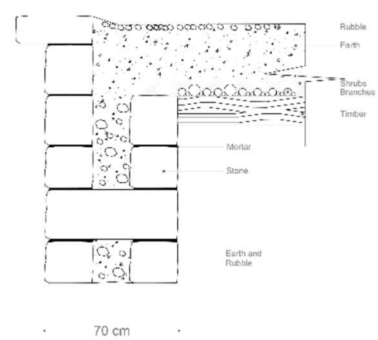
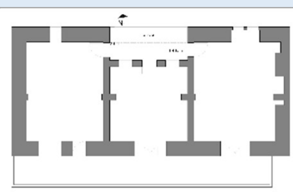
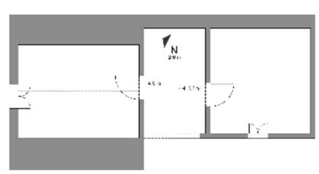
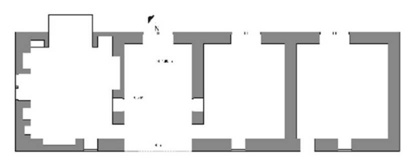
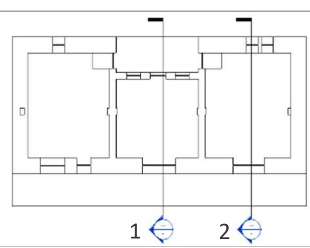
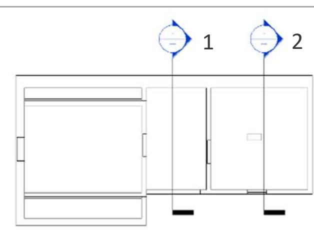
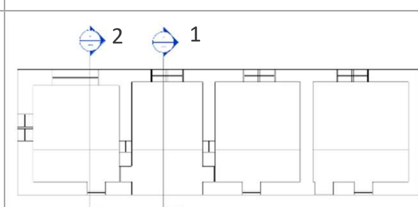
Figure 5.14 (a) Technical drawing of wall system in Abey liwan house, Source: Author</td>
<td>

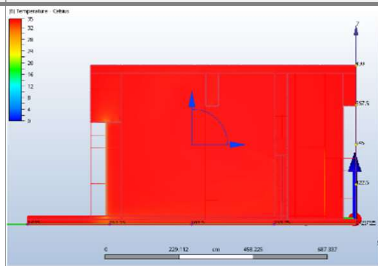
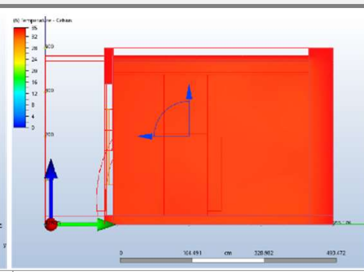
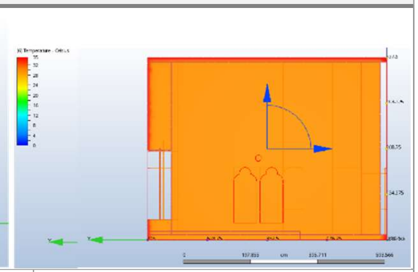
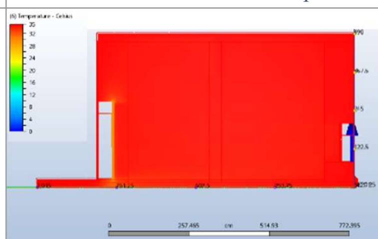
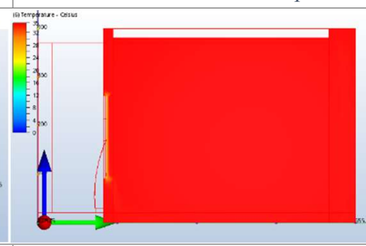
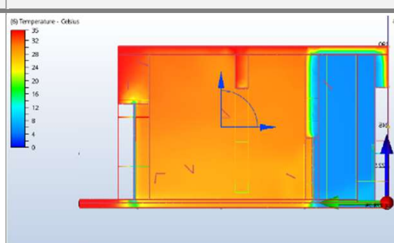
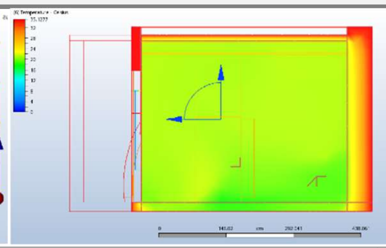
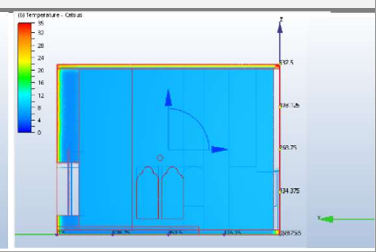
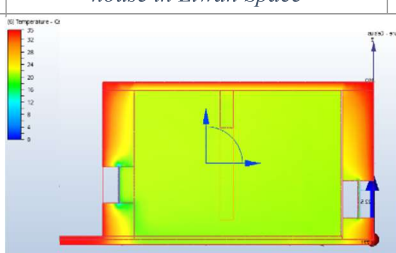
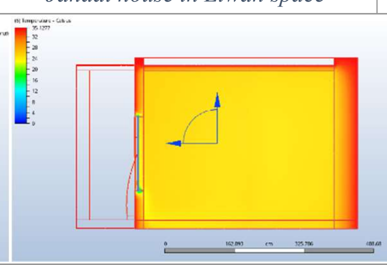
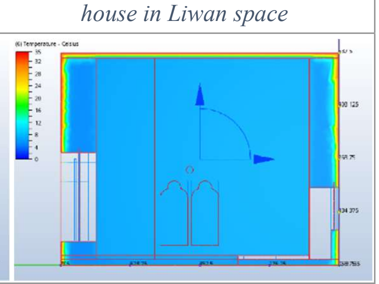
Figure 5.14 (b) Technical drawing of roof system in Abey liwan house, Source: Author</td>
</tr>
<tr><td>Post - Lintel Side</td><td>Flat Roof</td></tr>
<tr><td>- Thickness: 90 cm
- u-value: 2.52 W/m^2.K</td><td rowspan="3">Existing Concrete Roof
- u-value: 3.04 W/m^2.K
Original Wooden Roof
- u-value: 0.59 W/m^2.K</td></tr>
<tr><td>Post - Lintel Side</td></tr>
<tr><td>- Thickness: 70 cm
- u-value: 3.06 W/m^2.K</td></tr>
</table>

Table 5.2 Showing the Thermal Transmittance of Mokhtara, Haret Jandal and Abey Post-Lintel Liwan House. Source: Author

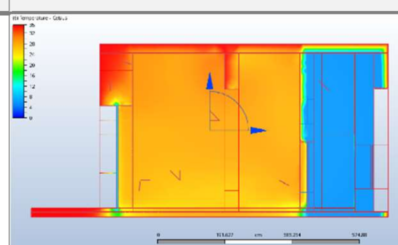
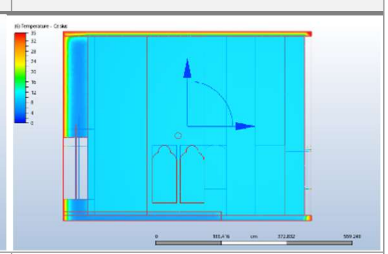
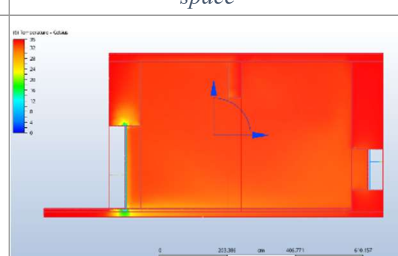
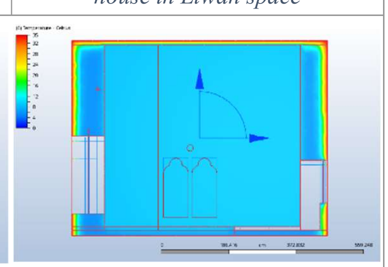
While analyzing the thermal performance of the envelope systems in Liwan houses having post-lintel flat roofs, the below figures discuss three case studies in winter and summer seasons.

As mentioned before, section one indicated the thermal performance of the Liwan space while section two discussed the rooms next to Liwan. As mentioned by the UNDP (2005), the temperatures in the summer season which are below 22 ºC and above 28 ºC fall outside the comfort zone in the mid-mountainous region. In summer, Abey house showed a 26 ºC temperature in the Liwan space and the rooms aside which is lower compared to the Mokhtara and Haret Jandal houses of 34 ºC (figures 5.17 (c) and 5.18 (c)). However, the Liwan space of Haret Jandal is of 32 ºC (refer to figure 5.17 (b)), which is a lower temperature than that of Mokhtara house (figure 5.17 (a)). On the outer skin of the Abey house, the temperature is of 34 ºC due to the direct sun exposure on the envelope system but this temperature decreases in the Liwan spaces and the rooms aside. Thus, in summer, the envelope system of Abey house regulates the temperature between the exterior thermal conditions and the inner spaces including Liwan.

	Plan of Mokhtara Liwan House	Plan of Haret Jandal House	Plan of Abey Liwan House
Depth-to-Width and Height of Liwan Plans			
	- Length (L)= 4.95 m - Height (H)= 4.10 m - Depth= 2.1 m Area of Liwan Opening: 14.6 m^2	- Length (L)= 2.6 m - Height (H)= 3.6 m - Depth= 4.6 m Area of Liwan Opening: 5.9 m^2	- Length (L)= 4 m - Height (H)= 4.80 m - Depth= 6.3 m Area of Liwan Opening: 15 m^2
	Figure 5.15 (a) Plan of Mokhtara Flat House showing dimensions of Liwan opening, Source: Author	*Figure 5.15 (b) Plan of Haret Jandal Flat House showing dimensions of Liwan opening, Source: Author*	*Figure 5.15 (c) Plan of Abey House showing dimensions of Liwan opening, Source: Author*
Schematic Plans with Two Sections			
	Figure 5.16 (a) Schematic plan of Mokhtara House with sections one and two, Source: Author	*Figure 5.16 (b) Schematic plan of Haret Jandal house with sections one and two, Source: Author*	*Figure 5.16 (c) Schematic plan of Abey house with sections one and two, Source: Author*

Summer			
Section 1 *(Source: CFD, by Author)*			
	Figure 5.17 (a) Thermal Performance in summer of Mokhtara house in Liwan Space	*Figure 5.17 (b) Thermal Performance in summer of Haret Jandal house in Liwan space*	*Figure 5.17 (c) Thermal Performance in summer of Abey house in Liwan space*
Section 2 *(Source: CFD, by Author)*			
	Figure 5.18 (a) Thermal Performance in summer of Mokhtara house in section two	*Figure 5.18 (b) Thermal Performance in summer of Haret Jandal house section two*	*Figure 5.18 (c) Thermal Performance in summer of Abey house in section two*
Winter			
Section 1 *(Source: CFD, by Author)*			
	Figure 5.19 (a) Thermal Performance in winter of Mokhtara house in Liwan Space	*Figure 5.19 (b) Thermal Performance in winter of Haret Jandal house in Liwan space*	*Figure 5.19 (c) Thermal Performance in winter of Abey house in Liwan space*
Section 2 *(Source: CFD, by Author)*			
	Figure 5.20 (a) Thermal Performance in winter of Mokhtara house in section two	*Figure 5.20 (b) Thermal Performance in winter of Haret Jandal house in section two*	*Figure 5.20 (c) Thermal Performance in winter of Abey house in section two*

In winter, the three flat Liwan houses signified different thermal performances of the envelope systems and the inner spaces. In the UNDP (2005) report, it is noted that in the mid-mountainous regions in winter seasons, the temperature falls outside the comfort zone of occupants. The Mokhtara Liwan house and the Abey house had wooden flat roofs and it was lately replaced by concrete slabs of 25cm. Due to the significant role of roofs on the performance of the building envelope, both houses were assessed having the same composition but one simulation for each having wooden roof as in table and the other having concrete roof material. The simulations in summer did not indicate a variation in results so the houses were compared in the winter season. The Abey house has the lowest thermal performance in its spaces compared to the other case studies, in winter. The thermal performance ranges between 10 ºC in the rooms and 8 ºC in the Liwan space for the existing conditions (figures 5.19 (c) and 5.20 (c)). Using the wooden roof material, the Liwan space had a higher temperature 12 ºC than that of a concrete slab. Lately, the Liwan space in Mokhtara house has a 6 ºC temperature (figure 5.19 (a)), 34 ºC for the outer envelope, and a room opened to the Liwan of temperature 28 ºC (figure 5.20 (a)) compared to the wooden roof of 6 ºC, 32 ºC, and 23 ºC, respectively (as shown in figures 5.21 (a) and 5.22 (a)). However, the rooms next to the Liwan space have a temperature of 32 ºC for a wooden roof, which is significantly higher than the existing concrete roof of 21 ºC.

	Mokhtara Liwan House	**Abey Liwan House**
Winter-Section 1 *(Source: CFD, by Author)*		
	Figure 5.21 (a) Thermal Performance in winter of Mokhtara house in Liwan space	*Figure 5.21 (b) Thermal Performance in winter of Abey house in Liwan space*
Winter-Section 2 *(Source: CFD, by Author)*		
	Figure 5.22 (a) Thermal Performance in winter of Mokhtara house in section two	*Figure 5.22 (b) Thermal Performance in winter of Abey house in section two*

The temperature of the existing outer envelope ranges between 24 ºC and 32 ºC compared to the original roof material which signified an increase in temperature 33 ºC and a slight decrease in temperature near the southern openings of 28 ºC. Compared to Mokhtara house, the Haret Jandal case study has lower temperatures in the inner spaces. The thermal performance is 20 ºC with a 24 ºC for the spaces aside (figures 5.19 (b) and 5.20 (b)). The envelope system of this Liwan house has lower thermal performance of 24 ºC for the walls and roof facing the inner spaces with 34 ºC for the outer skin of the envelope facing the environmental conditions such as the sun exposure.

Another factor to analyze is the depth-to-width and height, which differently affects the flow of wind and sun exposure because the increase in height provides more cooling into the Liwan space. With the increase in the area of Liwan opening to $15m^2$ and in its depth to 6.3m, this marked a significant decrease in temperature in summer and winter seasons in comparison to the Mokhtara and Haret Jandal Liwan houses. The case study of Haret Jandal has a lower area of the Liwan opening and an increase in depth with respect to Mokhtara house. This implies that both have similar results except for the Liwan space of Mokhara house, in winter, which showed high temperature due to its small depth so the sun can penetrate easily.

This means, in summer, Abey Liwan house is the effective case study in terms of thermal performance compared to Mokhtara and Haret Jandal houses, which showed significantly higher temperature in Liwan spaces and the rooms aside. In winter, Haret Jandal house indicated a moderate thermal performance in the inner spaces in relevance to the Mokhtara house and Abey house of high and low thermal performance, respectively. Though, in Mokhtara house, the spaces next to Liwan with indirect sun exposure have a moderate thermal performance similar to that of Haret Jandal. The change in the roof material from wood to concrete in Abey and Mokhtara house demonstrated a main effect on the performance of the rooms next to the Liwan space, only in Mokhtara house.

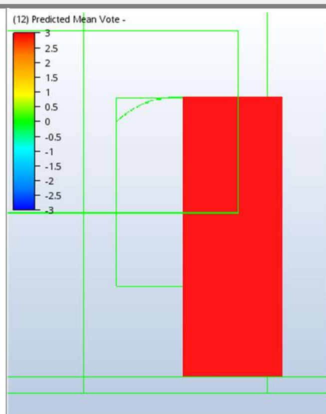
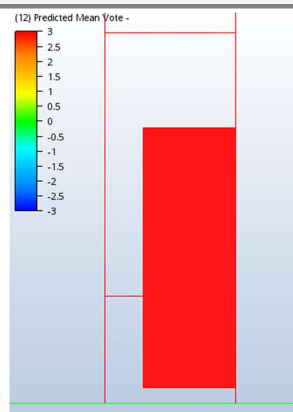
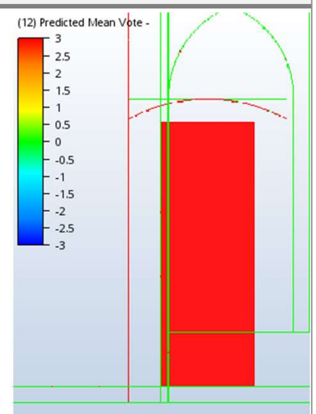
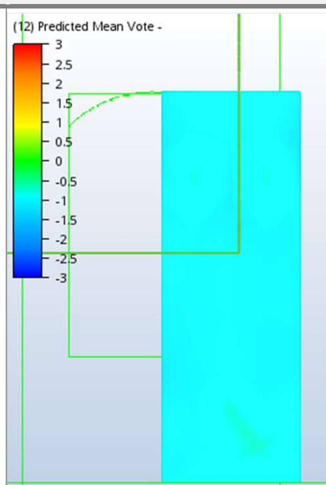
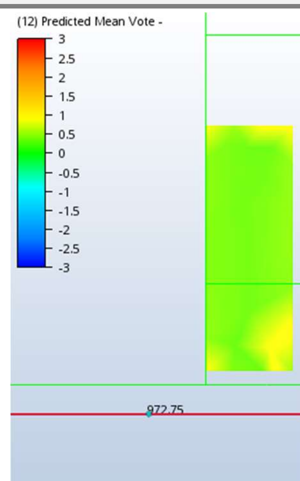
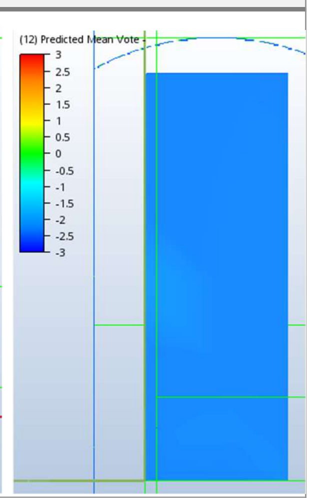
5.2.3 Analysis of Thermal Comfort

The thermal comfort is analyzed in the three case studies, Mokhtara, Haret Jandal, and Abey houses. To determine the thermal comfort per person, the predicted mean vote (PMV) has to be discussed using CFD. The predicted mean vote index scale ranges from -3 to 3. The following table discusses the ranges of the PMV in which minus three (-3) is defined as cold human scale and three (3) as hot. According to Dyvia and Arif (2021; Karyono, 2001), a person feels comfortable if the PMV index value is zero (0); therefore, the neutral thermal conditions will be achieved.

Each case study in scenario one will be discussed and analyzed in accordance to the table of PMV index scales. Referring to table 5.3, the rectangles presented in the simulations are the human scale, by which the thermal comfort is assessed. In summer, the three case studies show an index scale of 3, which means the thermal perception of human is hot. In winter, the existing conditions marked a PMV index of -1 for Mokhtara Liwan house (as in figure 5.24 (a)), 0.5 for Haret Jandal house (figure 5.24 (b)) and -2 for Abey house (figure 5.24 (c)). In other words, the thermal perception of a person is slightly cool in Mokhtara house, somehow comfortable in Haret Jandal, and cool in Abey house.

PMV Index Scales with Thermal Perception	
3	Hot
2	Warm
1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

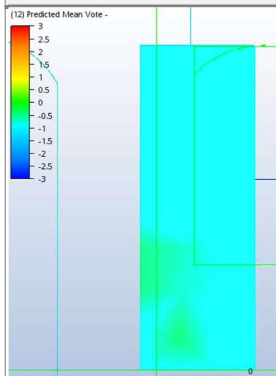
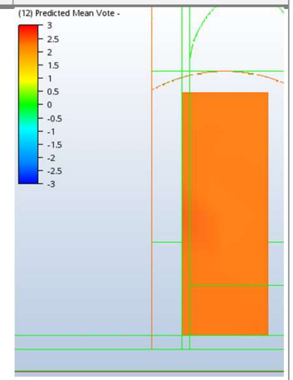
Table 5.3 Showing the PMV index scales with thermal perception, Source: Dyvia and Arif (2021) Accessed: 12-10-2021

	Mokhtara Liwan House	Haret Jandal House	Abey Liwan House
Summer			
Existing Conditions *(Source: CFD, by Author)*			
	Figure 5.23 (a) Thermal comfort in summer of Mokhtara house	*Figure 5.23 (b) Thermal comfort in summer of Haret Jandal house*	*Figure 5.23 (c) Thermal comfort in summer of Abey house*
Winter			
Existing Conditions *(Source: CFD, by Author)*			
	Figure 5.24 (a) Thermal comfort in winter of Mokhtara house with concrete roof slab	*Figure 5.24 (b) Thermal comfort in winter of Haret Jandal house with concrete roof slab*	*Figure 5.24 (c) Thermal comfort in winter of Abey house with concrete roof slab*

As previously mentioned, the roof has an impact on the occupant's thermal comfort, especially that Mokhtara house and Abey house were previously of wooden structure to be replaced after that with a concrete slab.

The assessment of existing conditions in both case studies, are the houses with a concrete slab. As shown in figures 5.25 (a) and 5.25 (b), the occupant’s comfort with a wooden roof is slightly cool to comfortable in Mokhtara house and warm in Abey house.

<table>
<tr><th>Winter</th><th>Mokhtara Liwan House</th><th>Abey Liwan House</th></tr>
<tr><td rowspan="2">Before (Wooden Structure)

(Source: CFD, by Author)</td><td>
</td><td>
</td></tr>
<tr><td>*Figure 5.25 (a) Thermal comfort in winter of Mokhtara house with wooden roof structure*</td><td>*Figure 5.25 (b) Thermal comfort in winter of Abey house with wooden roof structure*</td></tr>
</table>

This implies that in the summer season, the three case studies are not in the comfort zone. In winter, Haret Jandal flat roof house is in the comfort zone of occupants compared to Mokhtara and Abey houses which are cool. The Abey house showed a warm thermal perception for the original wooden roof structure in comparison to the concrete roof which is cool. In contrast, the Mokhtara wooden roof structure is within the comfort zone in regards to the existing concrete roof.

5.3 Modeling and Simulation of Scenario Two: Vaulted Roof

This section analyzes the second scenario, which is a three liwan houses of vaulted roofs. The discussion of this scenario includes the wind and sun, thermal comfort, and thermal performance. This indicates the case studies which need cooling and heating systems, in a given climatic conditions, and thus meet the occupant’s thermal comfort.

5.3.1 Analysis of Wind and Sun Factors

The three vaulted Liwan houses share the same wind conditions due to the similar weather station in Revit. Mokhtara is around 5.4km away from Haret Jandal, and 3.5km from Kfarkatra. In the Liwan vaulted roof houses of Mokhtara, Haret Jandal and Kfarkatra, the annual wind is dominant from the west and east-south-east directions (figure 5.26 (a)). In the summer season, between July and September, the highest dominant wind is from the west direction with a frequency approximately 20% which ranges between 5.1 to 8.5 m/s velocity (figure 5.26 (b)). In the winter season, January and March, the highest dominant wind is from the south-west direction with 15% of the frequency is of range 5.1 to 8.5 m/s velocity, and 1.5% of 8.5 to 11 m/s (figure 5.26 (c)). The highest wind speed frequency distribution is around 3 m/s to 4 m/s of 21% per year (refer to figure 5.26 (d)).

Annual Wind Data	Summer Wind Data	Winter Wind Data	Annual Wind Speed Frequencies Distribution

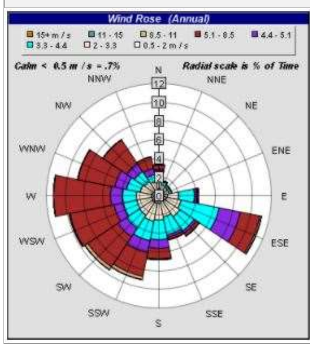
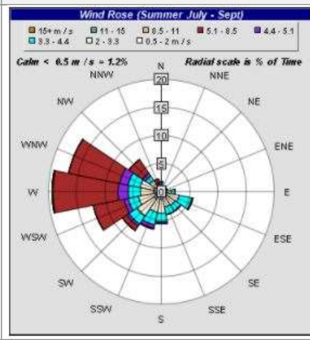
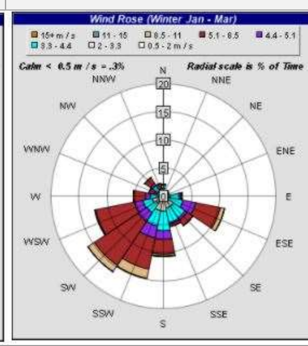
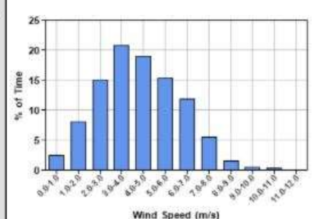

			

Figure 5.26 (a) Annual wind data of three houses, Source: GBS, Author	*Figure 5.26 (b) Summer wind data of three house, Source: GBS, Author*	*Figure 5.26 (c) Winter wind data of three house, Source: GBS, Author*	*Figure 5.26 (d) Annual wind speed frequencies distribution of three house*

In the summer season, the three case studies have a wind velocity of 3.3 to 4.4 m/s with a frequency of 6%. As for the winter, the frequency is around 11% with a dominant wind velocity of 5.1 to 8.5 m/s.

		Mokhtara Liwan House	Haret Jandal Liwan House	Kfar-Katra Liwan House
Doors	Area	-	-	2.75 m^2
	Velocities	-	-	4.5 m/s
	Total	-	-	- 2.75m^2 * 4.5m/s= 12.37m^3/s
Windows	Area	5.13 m^2 - 2.3 m^2	1.01 m^2 - 1.01 m^2	1.59 m^2
	Velocities	6 m/s - 4 m/s	7 m/s - 7 m/s	4.5 m/s

	Total	- $5.13m^2 * 6m/s = 30.78m^3/s$ - $2.3m^2 * 4m/s = 9.2m^3/s$	- $1.01m^2 * 7m/s = 7.07m^3/s$ - $1.01m^2 * 7m/s = 7.07m^3/s$	- $1.59m^2 * 4.5m/s= 7.15m^3/s$

Table 5.4 Showing the volume flow rate of doors and windows in Mokhtara, Haret Jandal and KfarKatra Liwan houses, Source:

The below figures discuss the Mokhtara, Haret Jandal and Kfar-Katra vaulted roof Liwan as wind simulation. In the south west wind direction, the southern space in Mokhtara and Haret Jandal Liwan houses have wind turbulence. In the Mokhtara case study, the south openings allow wind circulation into the interior space especially in the summer season (figure 5.30 (a)) but with higher wind turbulence in the Liwan space in the winter season of velocity 3.5 m/s (figure 5.31 (a)). Considering that the south western façade of Mokhtara house in winter receives the dominant wind of velocities 4m/s and 6 m/s, the volume flow rates are 30.78 m^3/s for the south western window and 9.2 m^3/s for the one facing Liwan (as shown in Table 5.4). Similarly, the case of Haret Jandal Liwan vaulted roof house has south western wind velocity of 2 to 3 m/s in winter (figure 5.31 (b)) and 1.5 to 2 m/s in summer (figure 5.30 (b)), especially in the west façade near the entrance of Liwan. Though, the western window on the southern space showed the highest wind circulation in comparison to Liwan space, having a volume flow rate $7.07m^3/s$ and wind velocity 7m/s (as in Table 5.4). In Kfar-katra vaulted Liwan house, the south western wind enters the windows of the southern and northern facades, in summer, with velocity 2 to 3 m/s (figure 5.30 (c)). In winter, the flow of southwestern wind circulates in the southern space with a high velocity of 5 to 9 m/s (figure 5.31 (c)). Having a dominant south western wind on the north western façade, the latter has a door and window of volume flow rate 12.37 m^3/s and 7.15 m^3/s of same velocity 4.5m/s (refer to Table 5.4).

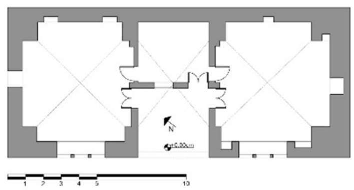
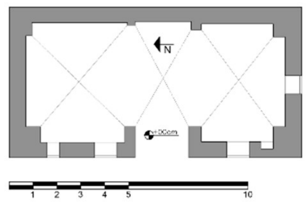
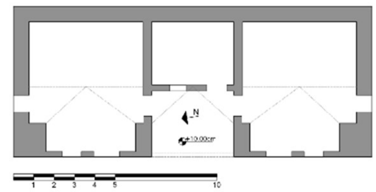
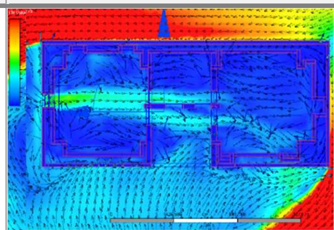
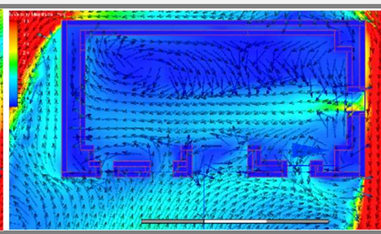
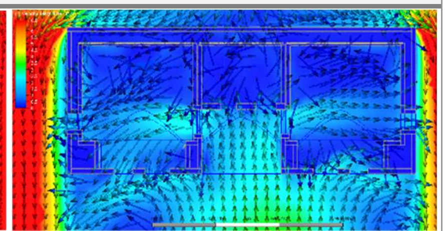
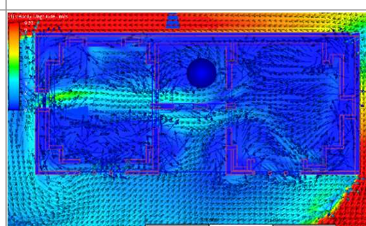
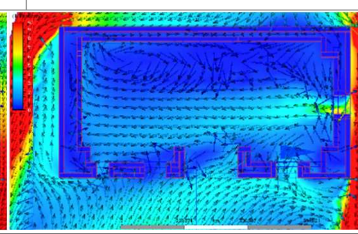
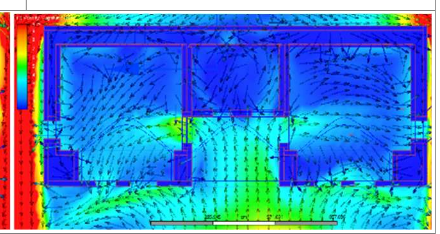
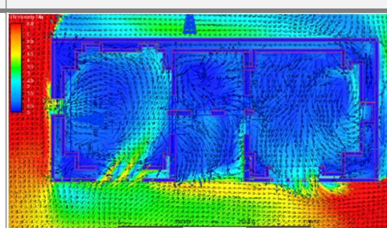
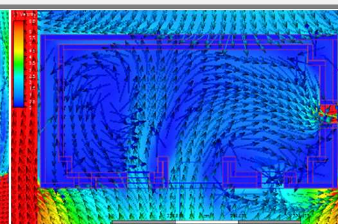
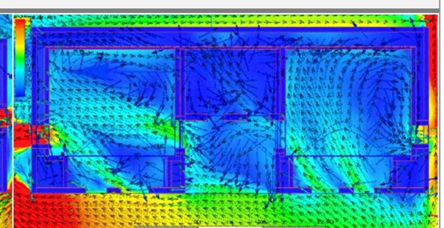
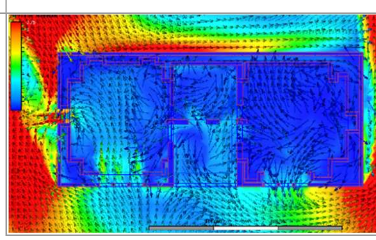
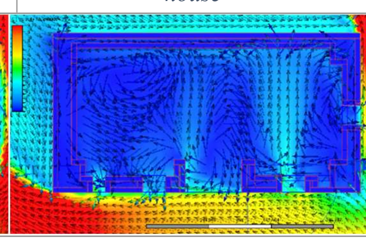
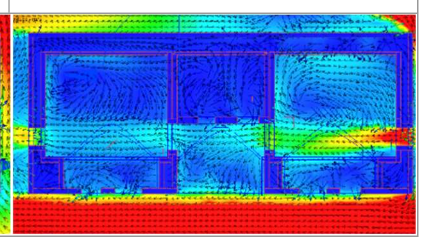
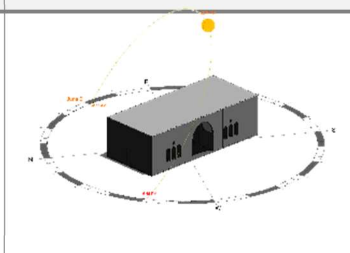
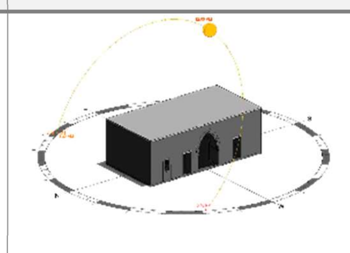
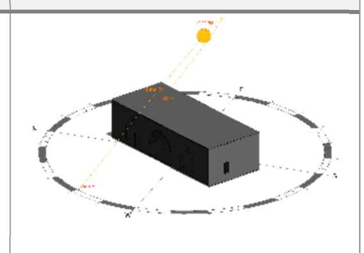
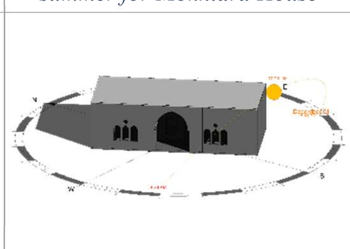
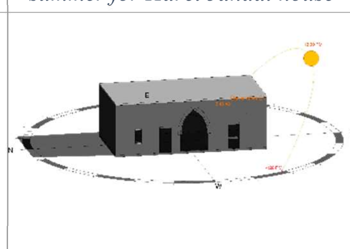
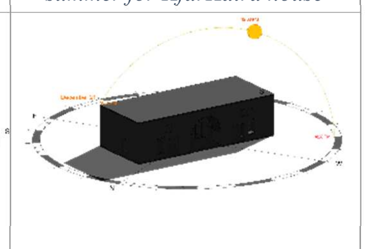
	Plan of Mokhtara Liwan House	Plan of Haret Jandal House	Plan of Kfar-Katra Liwan House
			
	Figure 5.27 (a) Plan of Mokhtara House, Source: Author	*Figure 5.27 (b) Plan of Haret Jandal house, Source: Author*	*Figure 5.27 (c) Plan of KfarKatra house, Source: Author*
East South East			
Summer *(Source: CFD, by Author)*			
	Figure 5.28 (a) East South East summer wind of Mokhtara House	*Figure 5.28 (b) East South East summer wind of Haret Jandal house*	*Figure 5.28 (c) East South East summer wind of Kfarkatra house*
Winter *(Source: CFD, by Author)*			
	Figure 5.29 (a) East South East winter wind of Mokhtara House	*Figure 5.29 (b) East South East winter wind of Haret Jandal house*	*Figure 5.29 (c) East South East winter wind of Kfarkatra house*
South West			
Summer *(Source: CFD, by Author)*			
	Figure 5.30 (a) South West summer wind of Mokhtara House	*Figure 5.30 (b) South West summer wind of Haret Jandal house*	*Figure 5.30 (c) South West summer wind of KfarKatra house*
Winter *(Source: CFD, by Author)*			

	Figure 5.31 (a) South West winter wind of Mokhtara House	*Figure 5.31 (b) South West winter wind of Haret Jandal house*	*Figure 5.31 (c) South West winter wind of KfarKatra house*

The winter and summer seasons of the east south east direction of wind in the Mokhtara case study, is around 1.2 to 2 m/s (figures 5.28 (a) and 5.29 (a)). The wind enters from the west opening, directly facing the openings of the Liwan space. As for Haret Jandal vaulted Liwan house, the east-south-east wind from the south window reaches the northern side in winter and summer seasons (figures 5.28 (b) and 5.29 (b)). The northern space has limited wind especially in the summer season, and the absence of openings in the north and east sides limit the wind circulation in the interior space. Accordingly, the majority of the east-south-east wind in the Kfar-Katra case study enters the lobby of the Liwan space. Its wind velocity in winter season is 1.5 to 2.5 m/s and 1.5 m/s in the summer season (figures 5.28 (c) and 5.29 (c)).

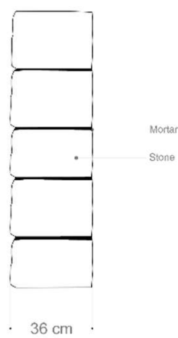
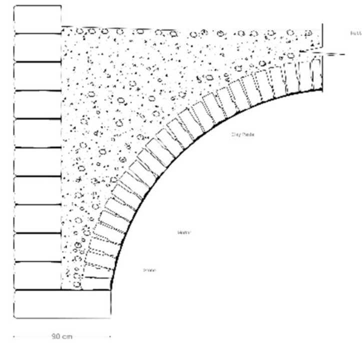
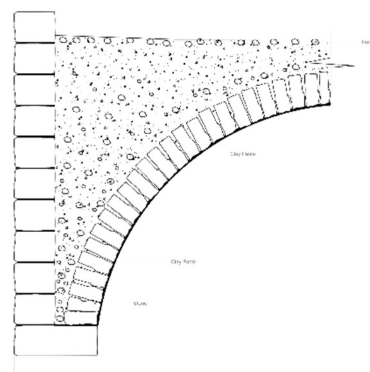
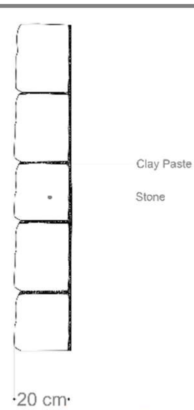
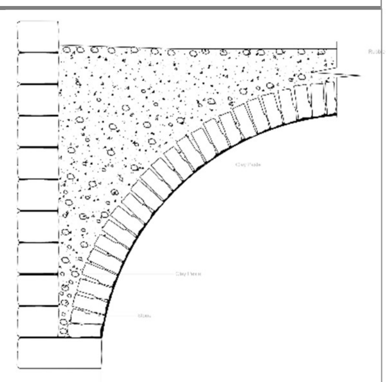
	Mokhtara Liwan House	**Haret Jandal Liwan House**	**Kfar-Katra Liwan House**
Summer (June 21) *(Source: Revit, by Author)*			
	Figure 5.32 (a) Sun exposure in summer for Mokhtara House	*Figure 5.32 (b) Sun exposure in summer for Haret Jandal house*	*Figure 5.32 (c) Sun exposure in summer for KfarKatra house*
Winter (December 21) *(Source: Revit, by Author)*			
	Figure 5.33 (a) Sun exposure in winter for Mokhtara House	*Figure 5.33 (b) Sun exposure in winter for Haret Jandal house*	*Figure 5.33 (c) Sun exposure in winter for Kfarkatra house*

In winter during the day, the sun exposure provides heating for the Mokhtara vaulted Liwan house on the east-southern spaces for the Liwan and the spaces on each side (figure 5.33 (a)), and for Haret Jandal in the southern space only (figure 5.33 (b)). In summer, the south west wind of Mokhtara Liwan house cools the spaces from the southern openings, where the sun is exposed (figure 5.32 (a)). The orientation of the house does not receive high wind velocity for the Liwan space, except for its opening facing the west windows. As for the southern façade of Haret Jandal house in summer, it allows wind circulation in the interior space, and least affects Liwan. This is due to its location on the western and eastern façades (figure 5.32 (b)). While discussing the Kfar-Katra case study, the sun exposure does not penetrate the inner space as it is only facing the southern window in the daytimes. In the main façade, which has windows and the main opening to Liwan, the sun exposure has the least impact to heat the space due to its location on the western side. This means heating systems are highly needed in the winter season while the wind turbulence cools the space in summer (figures 5.33 (c) and 5.32 (c)).

This implies that Kfar-katra Liwan house has the highest wind flow in its inner spaces compared to Mokhtara and Haret Jandal houses. Haret Jandal house has more wind flow from the east south east while Mokhtara house has more from the south western direction. The sun exposure of Kfar-katra house has the least effect on Liwan space and the rooms aside with respect to Mokhatar and Haret Jandal Liwan houses, especially in the winter season.

5.3.2 Analysis of Thermal Performance

This paragraph analyzes the thermal performance of the case studies having vaulted roofs. This indicates the distinct temperatures of the Liwan houses in Mokhtara, Haret Jandal and Kfar-Katra houses. Firstly, the envelope systems are illustrated in blow-up technical drawings to be able to compare the u-value of the walls and roofs in accordance to the existing materials and their thicknesses. The wall systems of the three vaulted case studies have different thermal transmittance as the thicknesses vary.

	Walls	**Vaulted Roofs**
Mokhtara Liwan House	 *Figure 5.34 (a) Technical drawing of wall system in Mokhtara liwan house, Source, Author*	 *Figure 5.34 (b) Technical drawing of roof system in Mokhtara liwan house, Source: Author*
	- Thickness: 90 cm - u-value: 2.52 W/m^2.K	u-value: 1.42 W/m^2.K
Haret Jandal Liwan House	*Figure 5.35 Technical drawing of wall and roof system in Haret Jandal liwan house, Source: Author* - Thickness: 70 cm - u-value: 3.06 W/m^2.K	 - u-value: 1.42 W/m^2.K
Kfar-Katra Liwan House	 *Figure 5.36 (a) Technical drawing of wall system in KfarKatra liwan house, Source, Author*	 *Figure 5.36 (b) Technical drawing of roof system in Kfarkatra liwan house, Source: Author*

	Base of Barrel Vault - Thickness: 70 cm - u-value: 3.06 $W/m^2.K$ Barrel Vault Side Wall - Thickness: 20 cm - u-value: 9.78 $W/m^2.K$	u-value: 1.42 $W/m^2.K$

Table 5.5 Showing the Thermal Transmittance of Mokhtara, Haret Jandal, and KfarKatra Vaultted Liwan house. Source: Author

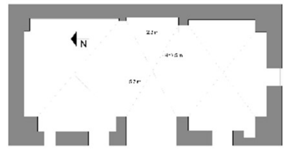
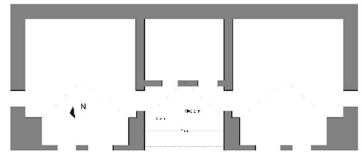
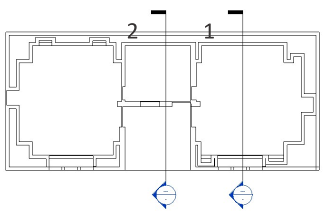
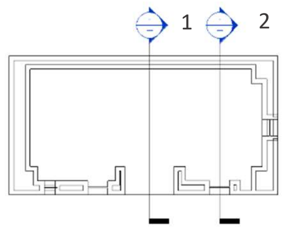
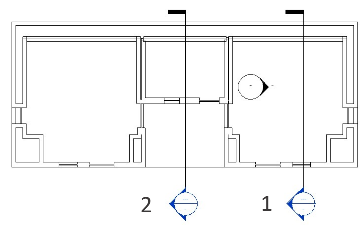
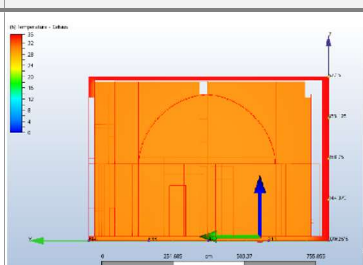
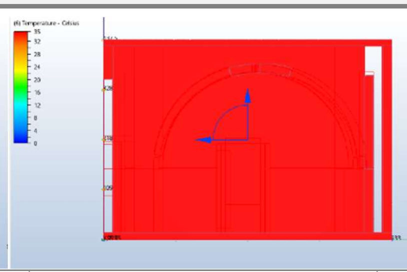
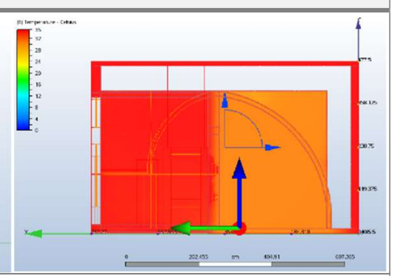
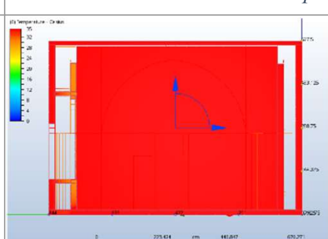
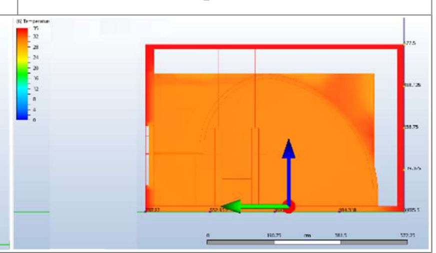
Mokhtara vaulted Liwan house has wall thickness of 90cm (figure 5.34 (b)), which is higher than Haret Jandal Liwan house of 70cm (figure 5.35). This indicates a better thermal transmittance of Mokhtara house 2.52 W/m^2. K compared to the u-value of Haret Jandal house that is 3.06 W/m^2.K. The highest thermal transmittance 9.78 W/m^2. K is the case of Kfar-katra house, which has the least wall thickness of 20 cm (figure 5.36 (a)). Since the three roofs are vaulted, the three houses have the same u-value of 1.42 W/m^2. K (refer to Table 5.5). As mentioned in scenario one, the roof systems showed a better thermal transmittance which means better thermal performance compared to wall systems.

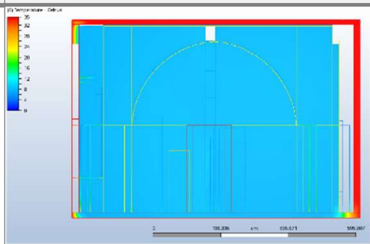
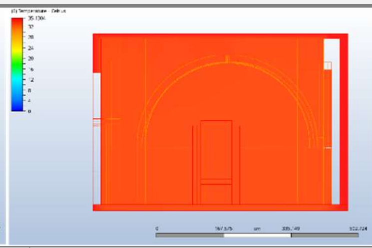
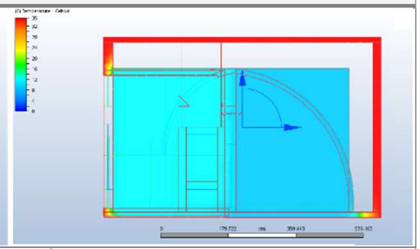
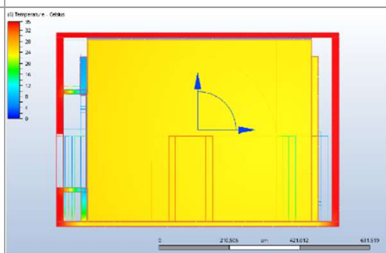
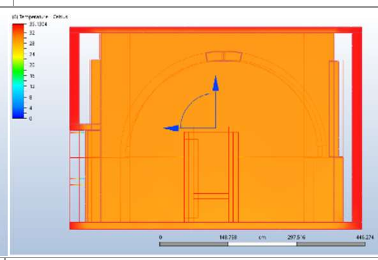
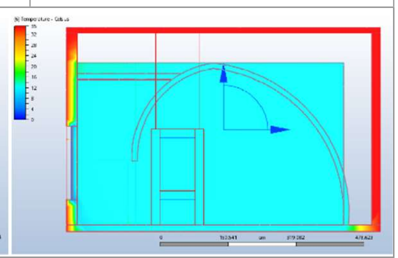
After the analysis of the thermal transmittance of the envelope system, the below figures discuss the thermal performances of the three vaulted case studies. It is compared to show the impact of the envelope system on the temperature of the inner spaces. This will also designate the impact of the Liwan on reducing the temperature of other spaces.

The Haret Jandal house resulted in a high thermal performance of 34ºC in the inner spaces, in the summer season, even for the Liwan space (figures 5.39 (b) and 5.40 (b)). Similarly, Mokhtara case study in summer has a lower thermal performance of the Liwan space in comparison to the room aside which are 26ºC and 34ºC, respectively (figures 5.39 (a) and 5.40 (a)). In the Kfar-Katra liwan house, it has a thermal performance of approximately 30ºC (figure 5.40 (c)). In the winter season, Haret Jandal showed the least temperature reduction in its inner spaces, which ranges between 26 ºC in the Liwan space (figure 5.41 (b)) and 32 ºC in the other spaces (figure 5.42 (b)). Besides, the spaces in the Mokhtara house has a slight temperature reduction in the inner spaces of 22 ºC (figure 5.42 (a)). However, the Liwan space of Mokhtara house and the spaces of Kfar-katra case study showed a significant decrease in the thermal performance, which is equal to 12 ºC (figures 5.41 (a), 5.41 (c) and 5.42 (c)).

While analyzing the depth-to-width and height factor, Haret Jandal that has the smallest area of Liwan opening with highest depth, indicated the highest thermal performance among Mokhtara and Kfar-Katra houses (figure 5.37 (b)). The Mokhtara case study which has an increase in the area of opening 16.9m^2, depth of 3.9m, and height of 5m, signified a higher thermal performance in the rooms next to liwan in winter and summer seasons compared to Kfarkatra of 12.3 m^2, 3.2m, and of 3.8m (refer to figures 5.37 (a) and 5.37 (c)).

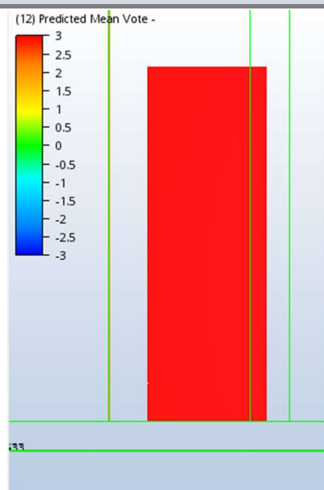
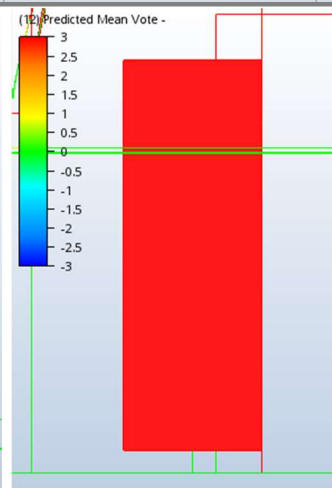
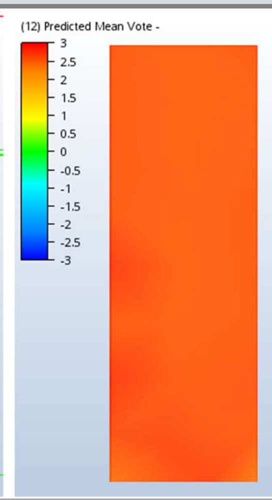
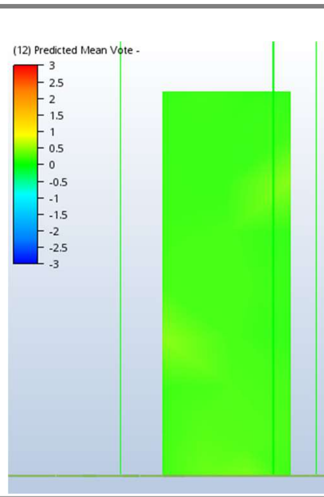
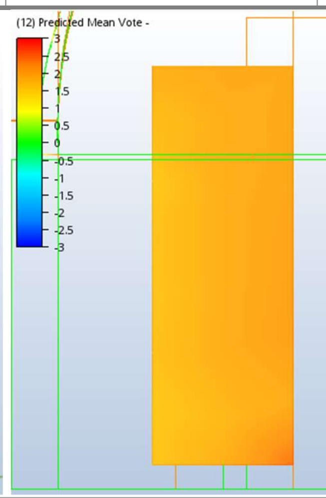
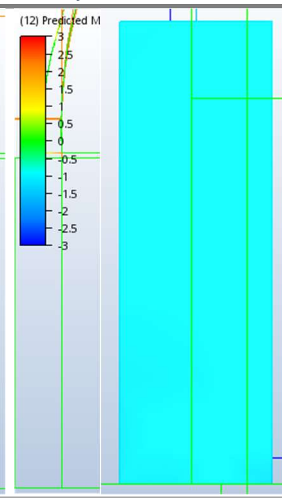
To sum-up, the increase in the exterior wall thickness, such as in the case of Mokhtara Liwan house, marked the lowest thermal transmittance. Regarding the thermal performance, Haret Jandal showed the highest temperature in Liwan space and the rooms aside, in winter and summer seasons. The lowest thermal performance is shown in Kfarkatra house with respect to Mokhtara house which signified a higher temperature in the rooms next to Liwan, in winter and summer seasons.

	Plan of Mokhtara Liwan House	Plan of Haret Jandal House	Plan of Kfar-Katra Liwan House
Depth-to-Width and Height of Liwan Plans			
	- Length (L)= 4m - Height (H)= 5m - Depth= 3.9 m Area of Liwan Opening: 16.9 m2	- Length (L)= 2.3m - Height (H)= 3.5m - Depth= 5.7m Area of Liwan Opening: 7.2 m2	- Length (L)= 4m - Height (H)= 3.8m - Depth= 3.2 m Area of Liwan Opening: 12.3 m2
	Figure 5.37 (a) Plan of Mokhtara House showing dimensions of Liwan opening, Source: Author	*Figure 5.37 (b) Plan of Haret Jandal House showing dimensions of Liwan opening, Source: Author*	*Figure 5.37 (c) Plan of KfarKatra House showing dimensions of Liwan opening, Source: Author*
Schematic Plans with Two Sections			
	Figure 5.38 (a) Schematic plan of Mokhtara House with sections one and two, Source: Author	*Figure 5.38 (b) Schematic plan of Haret Jandal house with sections one and two*	*Figure 5.38 (c) Schematic plan of KfarKatra house with sections one and two, Source: Author*
Summer			
Section 1 *(Source: CFD, by Author)*			
	Figure 5.39 (a) Thermal Performance in summer of Mokhtara house in Liwan Space	*Figure 5.39 (b) Thermal Performance in summer of Haret Jandal house in Liwan space*	*Figure 5.39 (c) Thermal Performance in summer of Kfarkatra house in Liwan space*
Section 2 *(Source: CFD, by Author)*			
	Figure 5.40 (a) Thermal Performance in summer of Mokhtara house in section two	*Figure 5.40 (b) Thermal Performance in summer of Haret Jandal house section two*	*Figure 5.40 (c) Thermal Performance in summer of KfarKatra house in section two*

Winter			
Section 1 *(Source: CFD, by Author)*			
	Figure 5.41 (a) Thermal Performance in winter of Mokhtara house in Liwan Space	*Figure 5.41 (b) Thermal Performance in winter of Haret Jandal house in Liwan space*	*Figure 5.41 (c) Thermal Performance in winter of KfarKatra house in Liwan space*
Section 2 *(Source: CFD, by Author)*			
	Figure 5.42 (a) Thermal Performance in winter of Mokhtara house in section two	*Figure 5.42 (b) Thermal Performance in winter of Haret Jandal house in section two*	*Figure 5.42 (c) Thermal Performance in winter of KfarKatra house in section two*

5.3.3 Analysis of Thermal Comfort

The thermal comfort is analyzed in order to know which case study in scenario two meets the occupant's comfort. As mentioned in scenario one, the results of the figures are compared to the PMV index scales. In summer, the Mokhtara and Haret Jandal Liwan houses have a PMV index +3, which is hot (figures 5.43 (a) and 5.43 (b)). However, Kfarkatra showed a lesser PMV index which is +2, indicating a warm condition (figure 5.43 (c)). Meanwhile, Kfar-katra houses marked better thermal properties, in summer, in comparison to Mokhtara and Haret Jandal houses. In winter, the vaulted Mokhtara Liwan house meets the comfortable conditions of occupants, having a zero PMV index (refer to figure 5.44 (a)). Haret Jandal house approximately indicates a warm thermal perception of occupants having a PMV index +1.5 (figure 5.44 (b)) while Kfarkatra house signifies a slightly cool of -1 index (figure 5.44 (c)).

	Mokhtara Liwan House	Haret Jandal House	Kfar-Katra Liwan House
Summer *(Source: CFD, by Author)*	 	 	
	Figure 5.43 (a) Thermal comfort in summer of Mokhtara house	*Figure 5.43 (b) Thermal comfort in summer of Haret Jandal house*	*Figure 5.43 (c) Thermal comfort in summer of KfarKatra house*
Winter *(Source: CFD, by Author)*	 	 	
	Figure 5.44 (a) Thermal comfort in winter of Mokhtara house	*Figure 5.44 (b) Thermal comfort in winter of Haret Jandal house*	*Figure 5.44 (c) Thermal comfort in winter of KfarKatra house*

This illustrates that in summer the three case studies do not meet the thermal comfort of occupants whereas in winter, Mokhtara house is within the occupant’s comfort zone compared to Haret Jandal house which is warm and Kfar-Katra which is cool.

5.3.4 Analysis of Humidity

The thermal comfort depends on the following factors: metabolic rate, clothing insulation, air temperature, relative humidity, air velocity, and mean radiant temperature. Due to the limitations of the thesis, the metabolic rate and clothing insulation are not surveyed. Meanwhile, the temperature, air velocity, and humidity are analyzed. Following the previous discussion on temperature, wind analysis and thermal performance of the envelope system, the relative humidity is provided from the UNDP source. This is due to the presence of both scenarios in a mid-mountainous region with near locations. As mentioned by the UNDP (2005), the comfort zone of the mid-mountainous region has a corresponding 20% to 90% relative humidity. However, according to a recent study of the UNDP thermal standard (2020), the relative humidity in a mid-mountainous region is 40% to 60%. The relative humidity in the summer and winter seasons of the mid- mountainous regions fall outside the comfort zone of occupants (UNDP, 2005). This points out that it is a necessity to integrate passive strategies into the case studies. One way to reduce humidity is through applying a wall coating, which is mainly made from lime mixed with sand and hemp. This will allow the wall to breathe and thus reduce the indoor humidity (Hammoud and Abi Rached, 2020). According to the analyzed case studies, the Liwan houses with lime from the inner spaces are Abey, Haret Jandal flat roof Liwan house, Kfarkatra and Mokhtara vaulted Liwan house. Another strategy proposed by Prianto et al. (2000) to remove humidity, begins with ground open space, a veranda of hardened clay material, and a main room made of a wood scaffold to provide air circulation. This room relates to a space similar to Liwan. The only case study having a wood roof is Haret Jandal post-lintel house. Meanwhile, providing ventilation reduces humidity (Khotbehsara et al., 2018).

5.4 Conclusion

This chapter discussed the temperature, wind flow, and wind velocity to find out the impact of orientation, construction materials, and depth to width dimensions of liwan, on the thermal performance and indoor thermal comfort of occupants. In summer, all the case studies do not meet the thermal comfort of occupants and show high thermal performance. In winter, Haret Jandal flat roof and Mokhtara vaulted house are within the occupant's comfort zone. By means of this, the thermal performance of Liwan space in Haret Jandal flat roof is 20 ^{o}C while that of Mokhtara house is 12^{o}C. The sun factor, in winter, reduces the use of heating systems for liwan spaces facing the south direction and with smaller depth. Accordingly, the increase in thickness of walls marked lower thermal transmittance.

Chapter Six
CONCLUSION

This thesis aims to assess the thermal performance and thermal comfort of the envelope systems of six Liwan houses in the mid-mountainous region. This will build guidelines to the sustainable strategies of Liwan typology and its adaptability to the occupant's needs in modern buildings; therefore, reducing the use of thermal energy as heating and cooling demands. The three case studies of post-lintel flat roofs are Mokhtara, Haret Jandal and Abey Liwan houses. The other three vaulted case studies are Mokhtara, Haret Jandal and KfarKatra Liwan houses. In order to better understand the indoor comfort properties and thermal performance of Liwan envelope in the mid-mountainous regions, previous studies were analyzed to highlight different climate responsive strategies and study the influence of Liwan house techniques in modern strategies of construction. Then, the six case studies of this thesis were analyzed by presenting photos and technical drawings, to study the orientation, functions distribution, wall, roof, and floor systems. Finally, to find out the effect of orientation, proper construction material, difference in the depth to width dimensions, and the vernacular passive and sustainable elements of the Liwan envelope system, assessments of the six case studies were simulated. The factors included in the assessments are: wind analysis to show the dominant wind, sun factor to know which case study needs active systems, thermal performance to study the inner temperature influenced by the envelope system, and thermal comfort to assess the occupant's needs.

Firstly, the wind analysis was studied using the wind rose taken from GBS and CFD software to assess the wind flow in each case study. Annually, the east southeast and the western side are the dominant wind directions. What matters is the prevailing wind in the winter season, which is from the southwestern direction. The southeast has the least effect in summer, hence considered the direction of lowest wind velocity while the southwest is the highest. For this reason, the analysis of the volume flow rate is discussed from the southwestern wind flow. The wind turbulence in all the case studies of scenario two showed a low wind velocity of 2 m/s in contrast to Mokhtara and Abey case studies in scenario one, which marked the highest wind flow of 8.5 m/s especially in the southwestern wind direction.

Secondly, the influence of solar radiation was discussed under the environmental settings of each case study. The sun factor was set by Revit without further consideration to the actual sun such as longitude, latitude, time zone, date, time and sunshine factor. This will determine the Liwan houses that need less heating and cooling systems. After specifying the location and true north in Revit, the highest and lowest sun angles were automatically specified. In summer, the case studies in both scenarios need cooling systems. In winter, the sun exposure penetrates the Liwan space in Mokhtara house without facing the main façade of Abey and Kfar-katra case studies despite its south western wind turbulence. This will help in reducing the reliance on heating systems at least in daytimes in Mokhtara flat Liwan house but with the use of active systems in Abey and Kfar-katra to heat the spaces. It can be assumed that the houses of high wind velocity in the Liwan space with a higher thermal performance in the other spaces, meet the thermal comfort of occupants, as in the case of Haret Jandal flat roof and Mokhtara vaulted roof houses. This will limit the use of heating systems in the winter season.

Thirdly, the amount of heat flowing through a building depends mainly on the thermal transmittance of the envelope. Thus, the use of insulation materials will lower thermal transmittance and thus improve the indoor conditions, protect against high wind velocity and improve the thermal performance of the envelope system. The roofs showed the lowest thermal transmittance compared to the wall systems. The flat roofs have higher u- value with respect to barrel-vaulted spaces. Within the flat roof systems, the wooden roofs showed the lowest u-value than that of concrete roof, as in the case of Mokhtara and Abey flat roof houses, and the barrel-vaulted roofs; therefore, wooden roofs have better performance. However, barrel vaulted roofs have significantly lower thermal transmittance in accordance to that of concrete material. In the wall systems, the increase in thickness of the wall will have a lower thermal transmittance. This is the case in the Mokhtara case study, which has the highest wall thickness and lowest thermal transmittance, thus higher thermal performance.

Fourthly, the greater the air temperature, then the greater the PMV index value, or the thermal perception will get hotter. In summer, both scenarios indicate high thermal performance around 34ºC except for Abey flat house, Kfar-Katra vaulted house and Liwan space in Mokhtara vaulted house, are of lower thermal performance around 28 ºC. Not all houses meet the thermal comfort of occupants in the summer season. In winter, the Liwan houses that meet the occupant's comfort are Haret Jandal flat house and Mokhtara vaulted house. Accordingly, the thermal performance in the winter season of those houses is around 22 ºC of moderate temperature. Since both Abey and Mokhtara flat roofs were originally of wooden roof structures, the Mokhtara wooden roof structure is within the comfort zone while Abey is not, in regards to the existing concrete roof. The change in the roof material from wood to concrete in Abey and Mokhtara house demonstrated a main effect on the performance of the rooms next to the Liwan space, only in Mokhtara house. Hence, it is better to preserve the wooden roof instead of its replacement with concrete materials. This will ensure a better thermal transmittance and performance of the envelope system.

The composition of the wall and roof systems with the appropriate choice of materials can be defined to improve the performance of the envelope during the different seasons. In relevance to the outcomes associated with the analysis of the simulations, this will draw an understanding to the choice of materials in the envelope systems and the passive strategies used in the mid-mountainous regions for modern constructions. The outcomes encompass:

- The Liwan space reduces the total heat gain by providing passing cooling effect if it is oriented properly. The results showed that in the summer season, Liwan space has high thermal performance with high wind flow; therefore, acting as a cooling system
- The indoor temperature of vaulted roof systems is lower than the flat roofs due to the lower absorbed solar radiation, thus offering greater thermal stability especially during the daytime
- The increase in the wall thickness will ensure a better thermal transmittance, which will lower the heat flow and act as a heat insulator; hence reduce the need of heating systems in the winter season
- In order to reduce the heat or warm air in the summer season, the ventilator openings are suggested for heat loss and thus decreasing the thermal performance in the inner spaces and decrease the need of active systems in the summer season
- With the increase in the height of liwan space, this will provide more cooling loads and wind flow in the summer season
- The decrease in depth dimensions of liwan space facing the southwest direction, this will ensure high wind flow in winter but with high thermal performance throughout the year due to the penetration of sun exposure during daytime; this is the case where cooling systems are needed in summer

- In the flat roof systems, the increase in the area of Liwan opening through the increase in depth and height, will result in a better thermal performance of the house in summer but with lower temperature in winter compared to a smaller Liwan area
- In the vaulted roof systems, the decrease in the area of Liwan opening through the increase in depth but decrease in height, will result in high thermal performance in summer and winter seasons, especially with the limited wind flow and direct sun exposure

This thesis has some limitations. The research was conducted during the pandemic, COVID-19, and the analyzed case studies required site visits during which there was a lockdown. This delayed my measuring, picturing and meeting with the owners that were old and needed strict precautions before their interviews. Other challenges are related to the software applicability during simulations.

As mentioned before, this thesis aimed to assess the thermal performance and comfort of the Liwan space of six case studies in the mid-mountainous region. Meanwhile, the envelope systems were studied to draw a better understanding on the passive strategies that can be implemented in modern constructions. The analysis can be expanded to discuss the thermal performance and comfort in high mountainous, coastal, and inland regions, to reduce the reliance on energy and implement passive strategies instead. Validation is also needed for adding the impact of other factors such as clothing, expanded sun analysis, and human physiological response to the thermal environment. Additionally, the heat losses and heat gains associated with the vernacular envelope systems can be further assessed to know whether retrofitting structures are needed to improve the building performance. With the emergence of renewable energies, it is important to identify, as well, the energy savings accompanied with the design of Liwan spaces in old and modern buildings.

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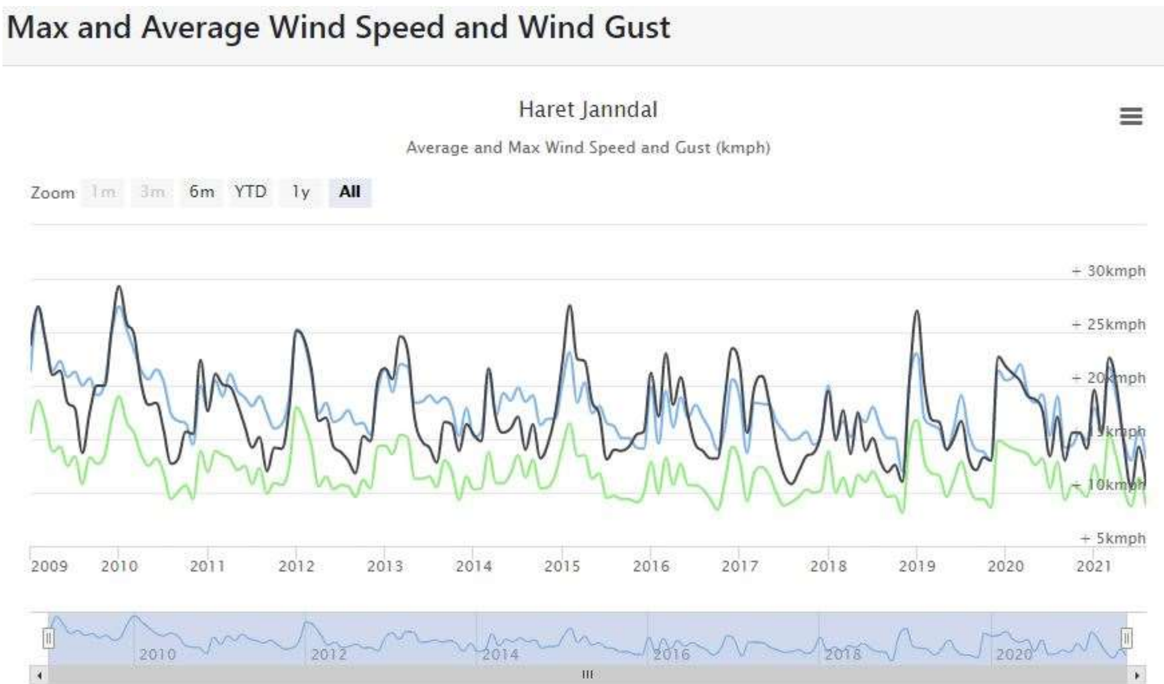
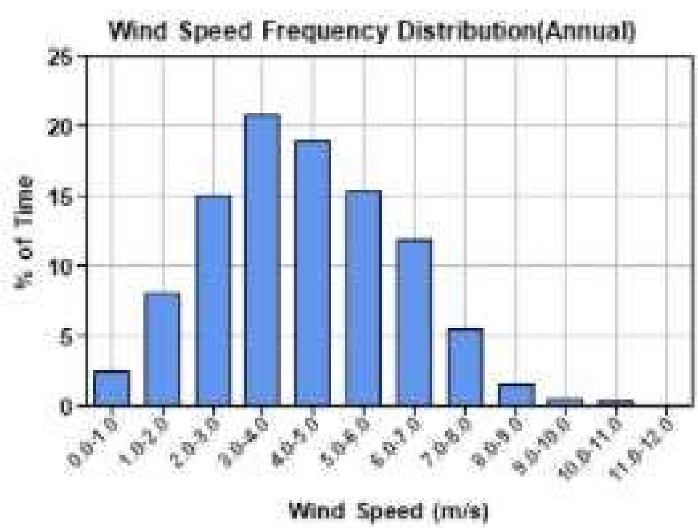
APPENDICES

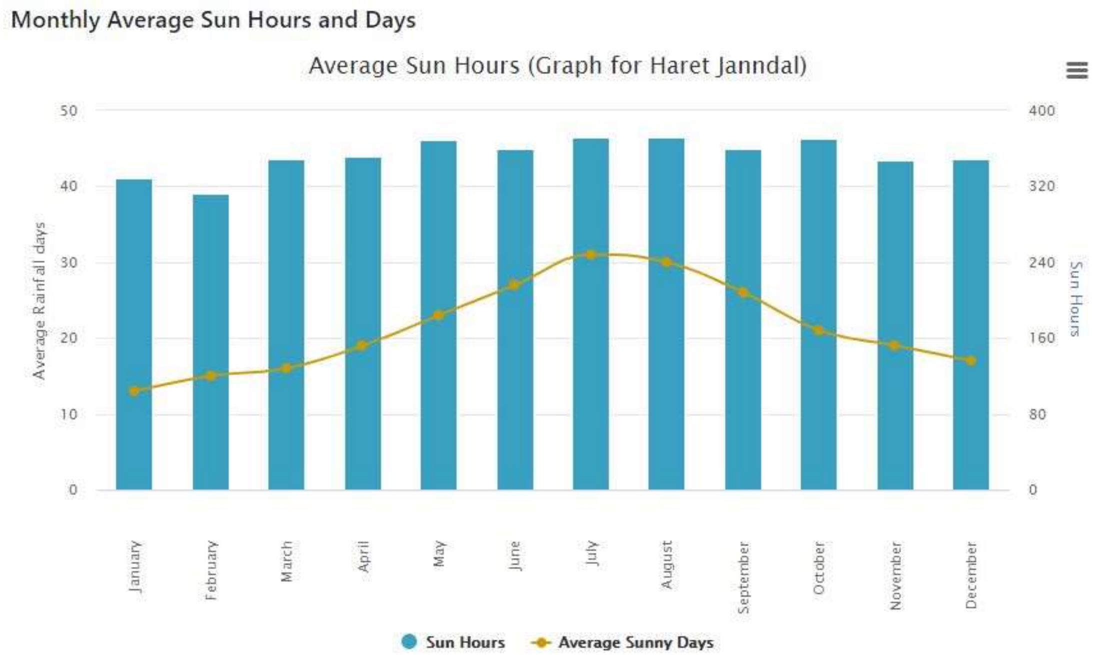
Appendix 1: Graph of average wind speed in Haret Jandal. Source: www.worldweatheronline.com .



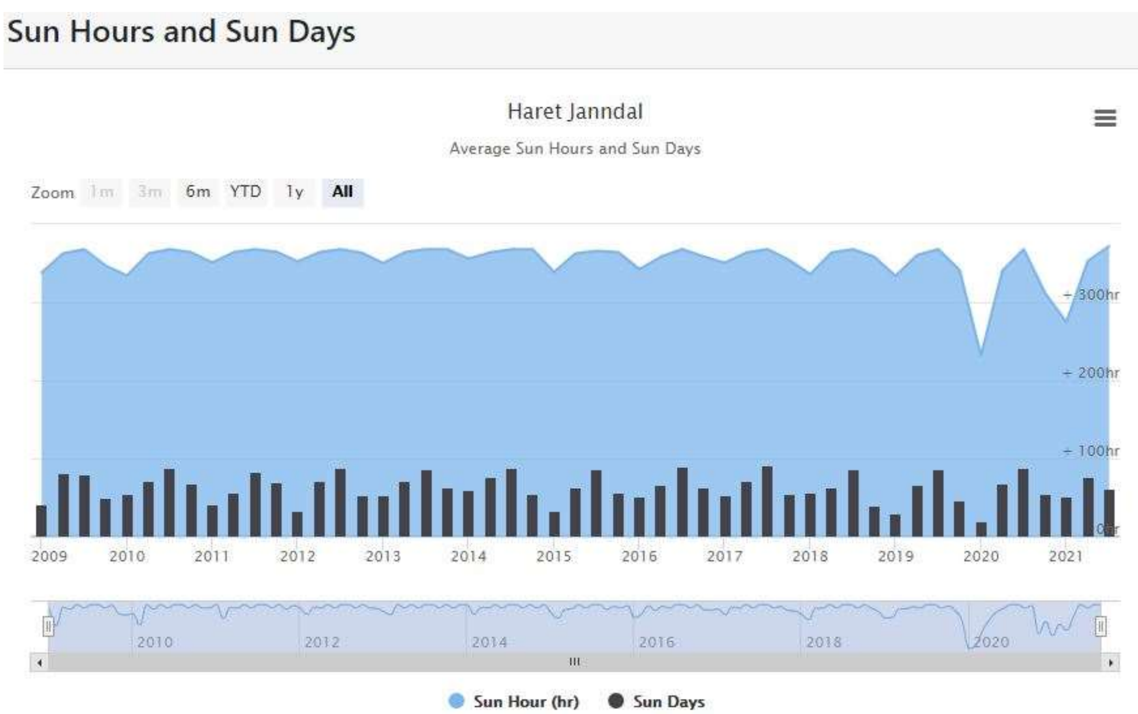
Appendix 2: Graph of annual wind speed frequency in Haret Jandal. Source: www.worldweatheronline.com .



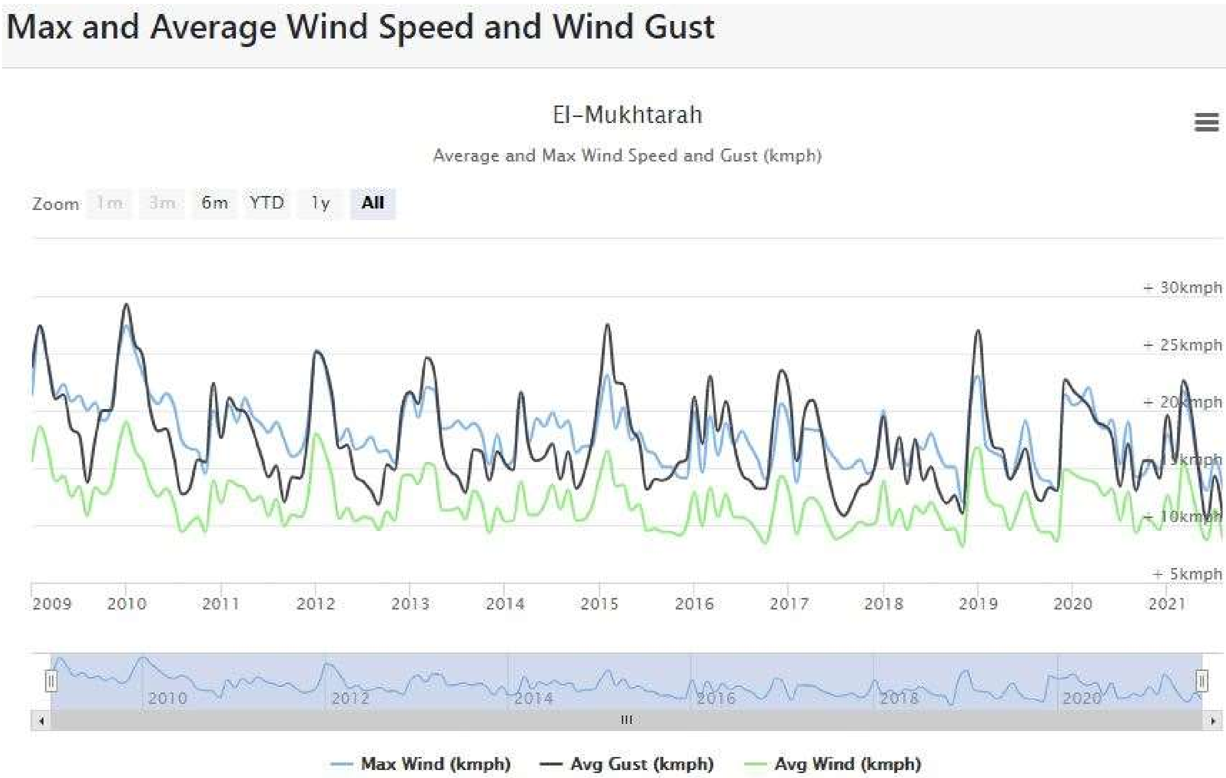
Appendix 3: Graph of monthly average sun hours in Haret Jandal. Source: www.worldweatheronline.com



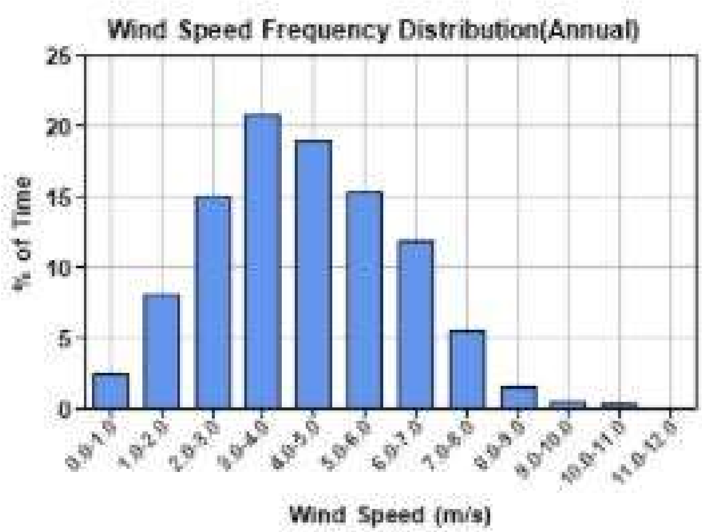
Appendix 4: Graph of sun hours and sun days in Haret Jandal. Source: www.worldweatheronline.com



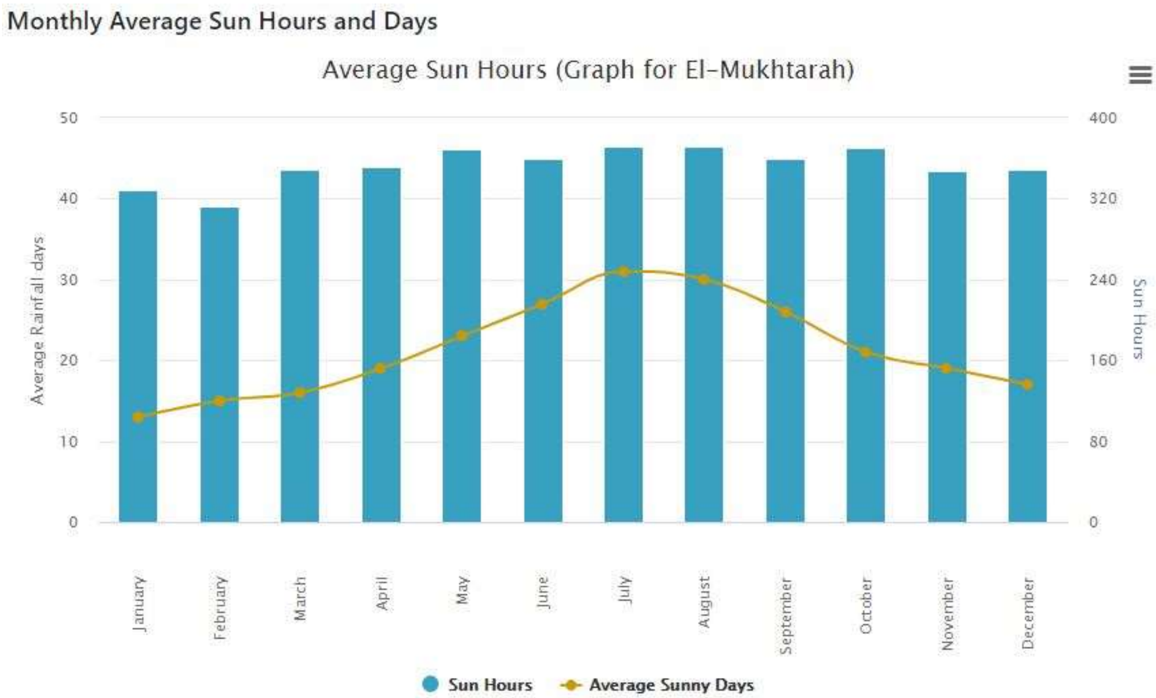
Appendix 5: Graph of average wind speed in Mkhtara. Source: www.worldweatheronline.com .



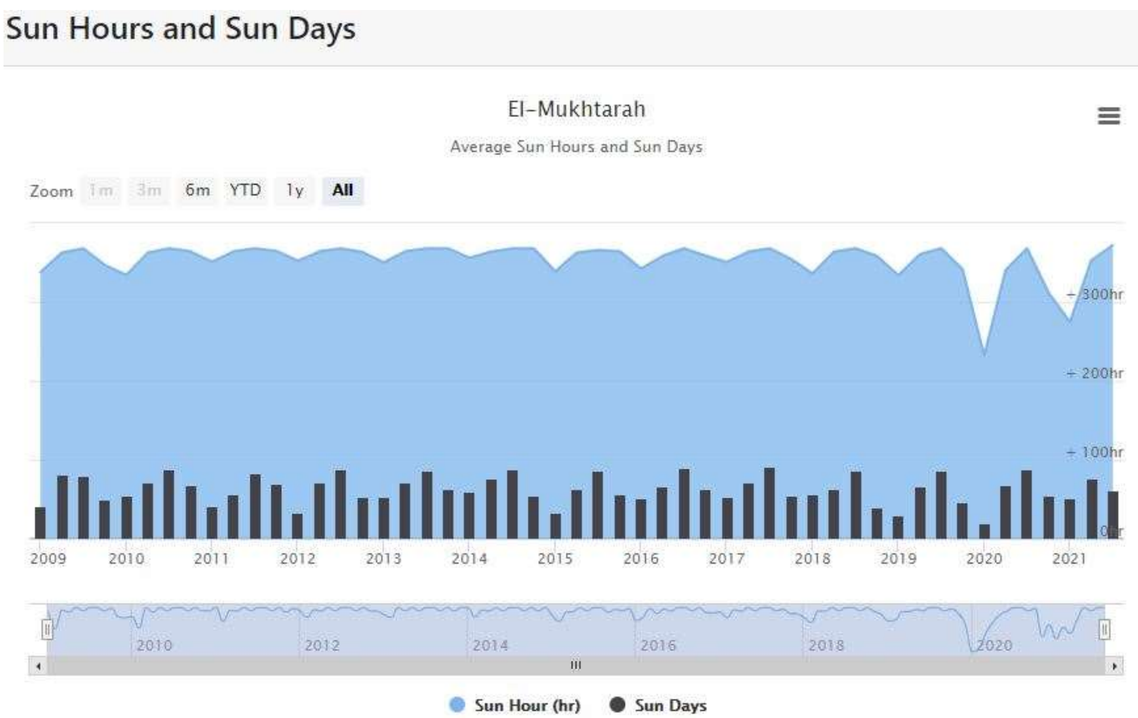
Appendix 6: Graph of annual wind speed frequency in Mokhtara. Source: www.worldweatheronline.com .



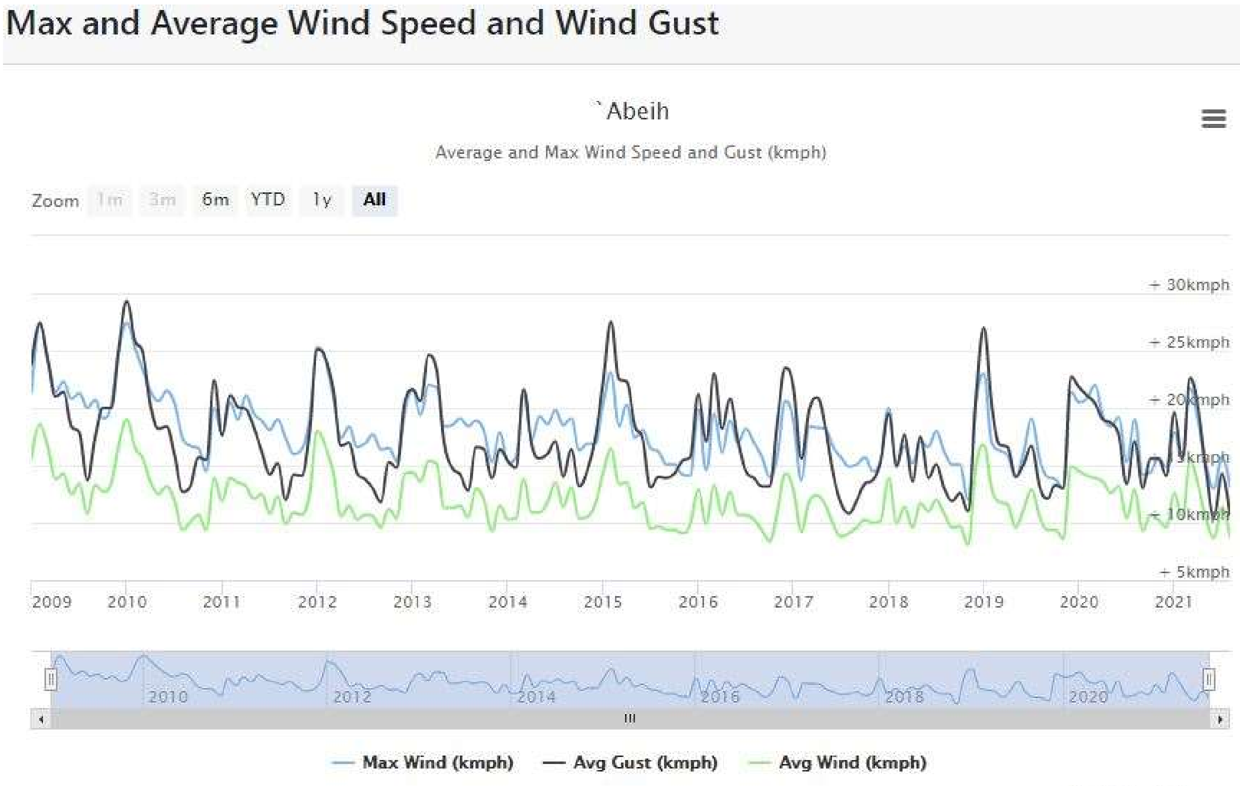
Appendix 7: Graph of monthly average sun hours in Mukhtara. Source: www.worldweatheronline.com .



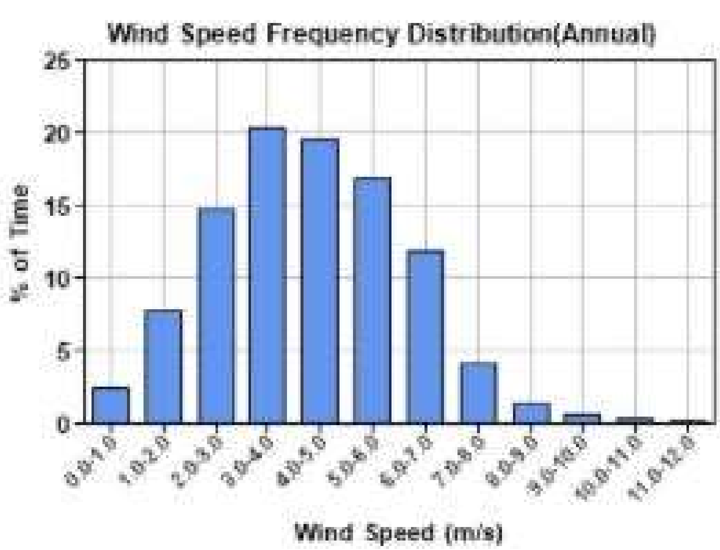
Appendix 8: Graph of sun hours and sun days in Mukhtara. Source: www.worldweatheronline.com .



Appendix 9: Graph of average wind speed in Abieh. Source: www.worldweatheronline.com .



Appendix 10: Graph of annual wind speed frequency in Abey. Source: www.worldweatheronline.com .



Appendix 11: Graph of annual wind speed frequency in Kafarkatra. Source: www.worldweatheronline.com.