People Space: Courtyard as a Spatial Microclimate Adjuster in Hot-arid Climate

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Abstract:

Architectural identity reflects the features of a country's people, society, and environment. Recently, Countries' unique architectural identities have been faded due to globalization, making it difficult to determine each country's regional and local identities. One of the significant architectural elements which characterize the Arab heritage urbanism is the courtyard residence. It is the most important element that characterizes the heart of all the Islamic-Arab houses. The building design usually begins from the courtyard it had been used by Arabs and Muslims in architecture for its compatibility within the environmental, cultural, and social requirements. In traditional residences, Courtyard was considered the focal point of the house, it had functioned as the essential ventilation and daylight for the adjacent built-up spaces. Despite there have been different studies of historical, social, cultural, and environmental aspects of courtyard architecture, but there was not much focusing on its spatial impact. In most traditional Cairene houses, the courtyard was used not only to obtain privacy, which in Arab society is a requirement but also to improve the thermal comfort inside a residence. This paper investigates the climatic and social benefits of the courtyard houses and studies the courtyard's effect as a natural design technique and a microclimate adjustor in a hot arid climate. The paper is illustrating spatial locations, composition, and thermal performance of courtyards, in addition, it analyses the contemporary courtyards house application in the hot-arid regions. Two selected case studies were chosen to be discussed in accordance with the theoretical studies. Finally, the paper proposing a guideline in design process to improve a courtyard's thermal performance.

Keywords:

People space; Courtyard houses; spatial microclimate; Thermal performance; Hot-arid Climate.

ملخص البحث:

تعكس الهوية المعمارية للبلدان خصائص المجتمع والبيئة المحيطة بها، وقد لوحظ بالاونة الاخيرة ان تلاشت الهوية المعمارية الفريدة لها ويرجع السبب الرئيسى فى ذلك الى العولمة، وهو ما يشكل صعوبة فى تحديد الهوية الاقليمية والمحلية لكل بلد. ولعل من أكثر العناصر المعمارية التى تميز النسيج العمرانى التراثى العربى هو الفناء الداخلى، وهو يعد من أهم المكونات

المعمارية التي تميز قلب البيوت العربية الاسلامية، فتصميم المنازل القديمة يبدأ في أغلب الأحوال من الفناء. والفناء تم استخدامه من العرب والمسلمين قديما لأهميته في توافقه مع البيئة المحيطة، الثقافة السائدة والاحتياجات الاجتماعية في ذلك الوقت. في مصر، تتميز العمارة السكنية التقليدية في العصر الإسلامي بهوية محلية فريدة ويمثل الفناء الداخلى النقطة المحورية للمسكن التقليدى، حيث كان بمثابة مصدر للتهوية والاضاءة الطبيعية للفراغات المحيطة به. بالرغم من وجود دراسات مختلفة لتاريخ الأفنية في العمارة الاسلامية، والنواحي الاجتماعية والثقافية لوجود الفناء في التصميم المعماري، ولكن لا يوجد تركيز كاف على الخصائص والتأثير الفراغي والحراري له. ففي معظم البيوت الاسلامية التقليدية الموجودة بالقاهرة القديمة، الفناء لم يكن يستخدم فقط للحصول على الخصوصية والتي تعد من أهم المتطلبات في المجتمع الاسلامي انذاك، ولكن كذلك للحصول على الراحة الحرارية داخل المسكن. تستعرض الورقة البحثية الفوائد المناخية والاجتماعية للفناء الداخلى وتوضح تاثيره كاسلوب تصميم طبيعى ومدى كفاءته فى خفض درجات الحرارة بالمدن ذات المناخ الحار الجاف. كذلك، تتضمن الورقة دراسة الموقع، التشكيل الفراغى والاداء الحراري للافنية الداخلية، ويهدف البحث بشكل رئيسى الى القاء الضوء على التجارب المعاصرة للمنشات ذات الافنية الداخلية التى تم تطبيقها فى مصر ومنطقة الشرق الاوسط وشمال افريقيا. واخيرا، يقترح البحث مجموعة من الارشادات التصميمية لتحسين الاداء الحراري للفناء اثناء مرحلة تصميم المشروعات الحديثة.

الكلمات المفتاحية:
فراغ الاشخاص، البيوت ذات الأفنية، المناخ المكاني، الأداء الحراري، مناطق المناخ الحار.

The Research Problem:

It has been essential to provide thermal comfort and social space within residential buildings. One of the solutions is the usage of internal Courtyards, they are included in some contemporary designs, however they are not beneficial due to improper design. Courtyards designed in an appropriate way protect against high temperatures, sandstorms, and mitigate the thermal load on the envelopes of the buildings, mainly houses and provide an adequate space.

The Research Hypothesis:

The research hypothesis states that using well designed courtyard in buildings especially contemporary houses is an efficient method for saving energy, Courtyard can be a spatial microclimate adjuster through achieving thermal comfort, where air movement is produced through courtyards by convection. In addition to its contribution to the social life of the community.

The Research Objectives:

The aim of the study is to contribute to an approach for energy design and planning at community scale, with the application of the traditional tools that benefit the idea of using the courtyard as a spatial microclimate adjuster and improve its performance.

Research Methodology:

The research follows the conductive approach in highlighting courtyard social and climatic benefits, also studying the spatial location, composition, and thermal performance. In addition,

it follows the analytical approach through the analysis of contemporary courtyard houses cases in Egypt and the MENA region. Finally, the research paper then presents a guideline approach in the design process to improve courtyard's thermal performance.

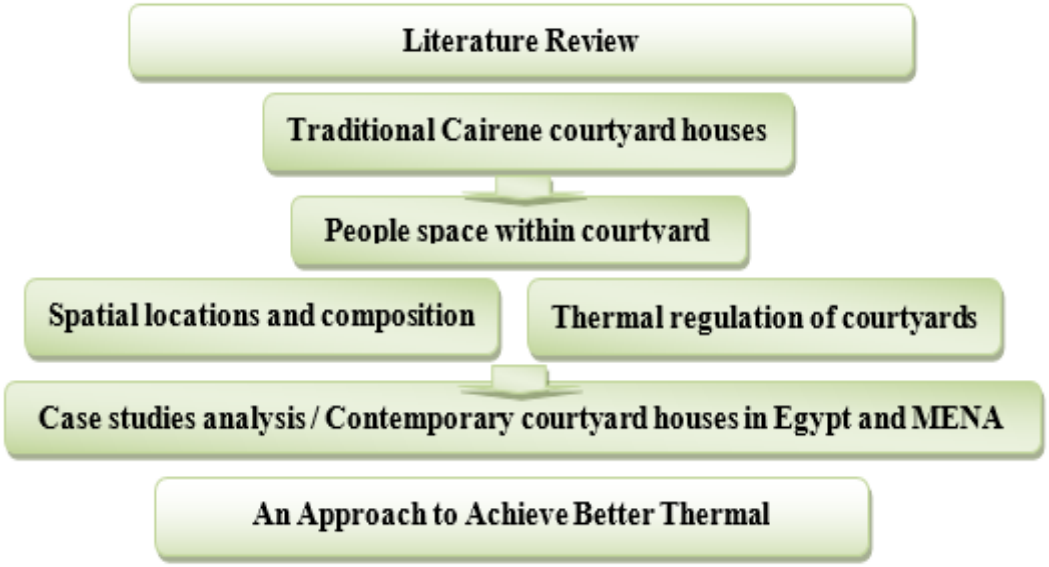

Figure 1: The Research Methodology Diagram (Source: Authors)

Introduction:

Courtyard is the most important element that characterizes the heart of all the Islamic-Arab houses. the building design usually begins from the courtyard; it is mainly open to the sky. The principle of the courtyard is frequently used throughout the traditional rural and urban architecture of hot arid areas from Iran in the East to the Atlantic coast in the West. The courtyard goes back to the Graeco-Roman tradition (c. 1900 BC) of Arabia. Muslims adopted the courtyard's concept with the advent of Islam (632 H) as it suited their social and religious needs, particularly the level of privacy required. The traditional Arab city's urban fabric is compact, and the buildings are incorporated into a single complex structure where it is difficult to differentiate the private houses to prevent sharp sunlight mostly during summer.

Cairo, the capital of Egypt has a rich architecture with a long history, it is still informing knowledge in all fields of science and Islamic architecture that are considered the essential part of this history. Egyptian traditional architecture aims to harmonize buildings with the surrounding environment conditions using local materials, and traditional Cairene courtyard houses best represent the traditional styles and unique values in Egypt. Despite there have been different studies of historical, social, cultural, and environmental aspects of courtyard architecture, but there was not much focusing on its spatial impact.

Within traditional cities, the urban fabric was organic; therefore, most of the buildings were irregular. The geometric courtyard is the first architecture element to be designed to get the inner courtyard that's the core design for traditional residence. It was then appropriate to arrange passageways and rooms across the courtyard. By adjusting the depth of the wall that could be used as cabinets, service areas, niches, or fixed furniture, the irregular sections and inappropriate angles have been changed. In most traditional Cairene houses, the courtyard was used not only to obtain privacy, which in Arab society is a requirement but also to improve the thermal comfort inside a residence.

The paper focuses on the effect of the courtyard on hot-arid climate environments and assessing its thermal performance, with the analysing of the contemporary courtyard houses application in both Egypt and MENA regions.

Importance of Courtyards:

Courtyard is a traditional architectural element that is used, especially in houses, for decades in many regions of the world. Courtyards were also the main meeting areas for specific uses, like working, playing, resting, cooking, or planting (Edwards, B., Sibley, M., Hakmi, M., & Land, P. 2006). The courtyard performs different purposes, social, cultural, and microclimate, like an open area within an urban fabric. The significance of this space was to be situated in central locations inside the building, surrounded by arcades and facades, paved places, landscaped with fountains and pools, shade, screening of light, and different plants, they all have played a major role in our social life. The courtyard is an adaptor of space elements with different functions. Courtyards as spaces could provide climatic, acoustic, and visual protection, for achieving the maximum levels of thermal performance, Courtyard's geometry and its material composition should be taken into consideration within the design phase (Meir, I. A. 2000). Furthermore, Courtyard was created to be climate-responsive, it could be used as a suitable place to foster a natural, healing climate.

Traditional Cariene Courtyard Houses

Traditional courtyard houses in Cairo city, which are recognized as Cairene houses, are regarded as iconic styles of the city's architectural heritage. These houses are considered as the Islamic residential architecture since the late Mameluke period (1255-1517) and throughout the Ottman period (1517-1805) (Mohamed, N. & Ali, W. 2014). The residence architecture heritage in Egypt consists of different forms which developed in response to social, religious, and cultural aspects. These aspects influenced the house's layout, spatial relations, and architectural details. In addition, the spatial planning of Cairene houses is affected by Islamic principles. Moreover, Architectural elements are derived as a response to the climatic conditions of Egypt, Cairene houses form a new Islamic architecture style different from the other Islamic-Arab countries in scale and type. Courtyard is considered the major compositional core of Cairene houses providing privacy and protection and surrounded by different rooms. The courtyard's shape is generally designed from inside to outside. Cairene courtyards are mostly having a rectangular shape and, in a few cases, have an irregular shape, it provides natural lighting, natural ventilation and mitigate the hot climate by absorbing cool air at nighttime to avoid the daytime high temperature, also, it contains landscape and water elements to purify the weather and improve comfort conditions (Reynolds, J. S. 2002). The courtyard is accessed from the entry through indirect corridors called *Magaz* that leads to the internal court and form turning to provide privacy for inhabitants (Abdelkader, R. and Park, J. 2018).

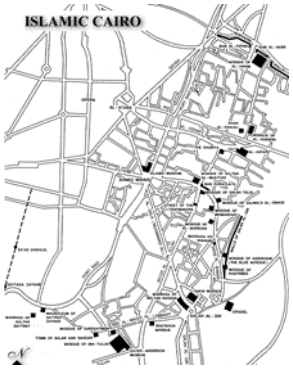

Figure 2: Tthe Urban fabric of Islamic Cairo, (source: www.touregypt.net)

Figure 3: Gamal Al-Din Al-Dahabi House, Cairo, Egypt (Source: Abdelkader, R. and Park, J. 2018)

Figure 4: Zeinab Khatoun House, Cairo, Egypt. (Source: Abdelkader, R. and Park, J.

Egypt Climatical Data:

Egypt is characterized by a hot-arid climate, high sunlight, and low rainfall, due to its geographical location in the north African wide desert hot region. The Northern region of Egypt falls into the warm temperate zone and a Mediterranean climate. Egypt's climate in winter is cold, rainy, and moist from December to February, but it is hot, arid, and rainless in summer from June to August and it is moderate in autumn from September to November. The average daytime temperature in January is between 20 °C to 24 °C, and the average daytime temperature in August is between 37 °C to 42 °C, winds generally blow in the Northwest and Northeast directions. Humidity is below 40 % most of the year and is very high in the North of Egypt than in the South. Hot winds with dust (*Khamaseen wind*) come from the Southwest of Egypt (between the end of March and middle of May) (Mohamed, N. & Ali, W. 2014).

Peaple Space Within Courtyard:

The main benefit of the courtyard is the effect of its inner form, it gives the occupants of the house a degree of privacy and enclosure. Courtyard is indeed the heart of the residence whereby, at various times of the day, various functions will take place. The outdoor space can be used mostly during mornings as an extent of the kitchen during the evenings as an extend of the living room to entertain guests, for all family members, the courtyard often functions as a space for interaction. All the rooms usually face the courtyard, providing a clear relationship between the inside and the outside. This agreement promotes members of the family using courtyard as just a group. In Cairene traditional houses, courtyards are considered as a semiprivate place for inhabitants. The privacy of courtyard housing is one of the major concerns Das, N. 2006). Consequently, in most of the courtyard buildings, screened or walled entrances visually seclude the courtyard. It also offers acoustical privacy in addition to the visual privacy offered by courtyard's shape. Moreover, it can absorb the noise of a residence inside itself. The surrounding spaces can produce a barrier between both the residence's heart and the external street. This allows getting a quieter and more private outdoor area to entertain (Sthapak, S., & Bandyopadhyay, A. 2014).

Courtyard's acoustic factors could be studied according to location and countries culture, in traditional Cairene courtyard houses, the entrance usually opens onto secondary streets to avoid

noise and direct interaction with the main street and its activities. Furthermore, it always preferred that courtyard's wall should not face another neighbor courtyard. If the distance between two courtyard houses increases, it will reduce the level of noise. The length and width of the courtyard preferred to be twice or more than the maximum height for noise control (Gangwar, G. and Kaur, P. 2016).

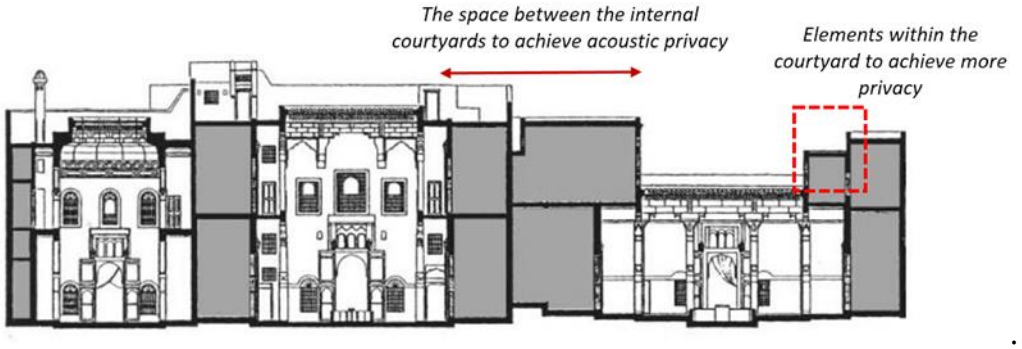

Figure 5: Wall-to-wall built courtyard houses in Fez, Morocco (Source: Analysis by Authors from [10])

Analysis of Spatial Locations and Composition in Cairene Courtyard Houses:

In Cairene houses, courtyard represents the key element of their spatial composition, rooms are organized around courtyard, and the other rooms are positioned around courtyard according to their function. The design method appears to be a result of accommodating social and cultural issues. This concept was influenced by an Islamic principle that promotes monotheism asserting that everything had a start point and refers to God as the creator of the world. In the same way, it reflects another Islamic idea that leads a person to his own feelings. These principles are reflected in architectural features, patterns, and geometric structures in traditional courtyard houses.

Configuration:

Courtyard can be formed in square, rectangular, or circular forms. Reynolds (Reynolds, J. 2002) indicated that most of the courtyards through history were designed as square or rectangular shapes. According to Hude (Hude, R. 2000) as he listed that the Main 3 types of courtyards are Closed, Semi-closed, and Semi-opened courtyards (fig. 6). The closed courtyard is common because it offers the highest degree of privacy, lighting, and good ventilation, from the other side, the semi-closed courtyard is typically created among buildings and is a semi-private area with a shaded region. Finally, the semi-opened courtyard offers the smallest degree of privacy, and at the same time offers direct access, ventilation, and vision (Hyde., R. 2000).

There have been several studies on the courtyard's design form. They stated that its design type could be used as an urban microclimate modifier. In hot-arid climates, several studies have suggested the traditional rectangular courtyard shape and its impact on environmental efficiency. According to analytical research, long and deep courtyard designs reduce energy consumption due to the shading effect of their configuration (Muhaisen, A. and Gadi, M. 2006). Studies suggested the protection of the surface and its environment against extreme solar radiation and hot dusty wind, which directly affects thermal comfort (Aldawoud, A. 2008) (Tablada, A. et *als* 2005).

Position:

Egypt's climatic conditions impact the spatial organization of Cairene courtyard houses. The sun is considered an essential factor concerning orientation, wind direction is considered the second standard. Moreover, the geometrical form of the courtyard and its relationship to its position is an essential factor in improving the microclimate, the position of the rectangular courtyard has more advantages than the square courtyard as its climatic efficiency increases, by forming more shadows in summer, with ease of directing it to bring the preferred winds better (Yousef, W. H. 2017).

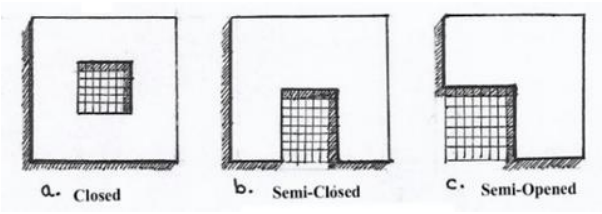

Figure 6: Courtyard Types, (source: The Authors)

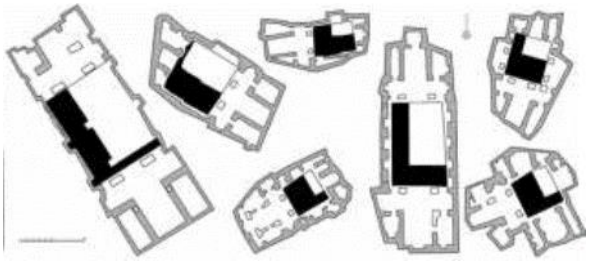

Figure 7: Various examples of traditional courtyards houses illustrate the difference between the quantities of shadows.

Elements:

The principal elements of Cairene houses	Definitions
Courtyard	A square or rectangular unroofed open space, often located in the heart of the house.
Magaz	A bent walkway into the inside of the house (Refracted entrance) which served to shield the house from the view of passers, often open to the courtyard.
Qa'a	A reception hall in Cairene houses, it consists of *Durqa'a* and two *Iwans*.
Takhtabush	A covered outdoor sitting area at the ground floor level located between two courtyards and in the nearest area to the entrance.
Maka'ad	An arcaded loggia with a square or regular shape that overlooks the courtyard, usually facing north to achieve maximum cooling.
Dorqaa	It's the central part of the Q*a'a* with a high ceiling covered by the *Shukhshakhah*, it's another type of courtyard that is not in the center of daily life but could be a secondary social space which plays the role of a lounge.

Table 1, Definitions of principal elements of Cairene houses (source: Dictionary of Islamic Architecture: www.archnet.org.)

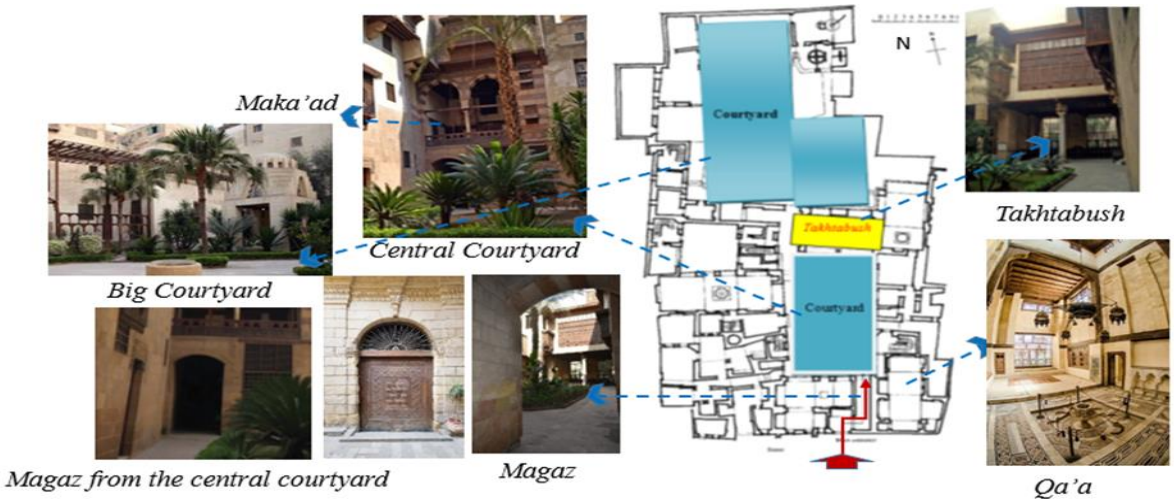

Figure 8: Al-Suhaymi House, Cairo, Egypt (1648) (source: analysis by Authors)

Distinguished Features:

There are other unique features in Cairene courtyard houses such as Shokhshekha, Mashrabiya, and Malqaf (windcatcher). The *Shokhshekha* (wind tower) is a skylight design that is generally used to cover the *Durqaa*, it works on inducing negative pressure and provides a suction effect to pull the hot air out. It's composed of various shapes such as octagon, square, dome, etc. (Abdelkader, R. and Park, J. 2018).

The *Mashrabiya* is considered the most remarkable shading device in the house which is used to cover openings as well as to achieve thermal control, ventilation, daylight, and social privacy. It's a cantilevered space covered with wooden lattice with a prominent geometric pattern. It has a narrow opening that allows airflow into the building, controlling the light's passage, reducing air temperature, and increasing air humidity (Mohamed, N. and Ali, W. 2014).

The *Malqaf* (windcatcher) is an inclined ending tower that has an open side oriented to the north direction to face the preferable wind so that it captures the cool air inside the building. It exists behind the main Iwan's wall to achieve thermal comfort inside the Qa'ah. Also. It has different advantages over the other ventilation elements; reducing the high temperature of rooms, the air passing through it is dust-free because of its unique design, and it contributes to ventilating the internal spaces which do not have windows to outside (El-Borombaly, H. and Fernando, L. 2015).

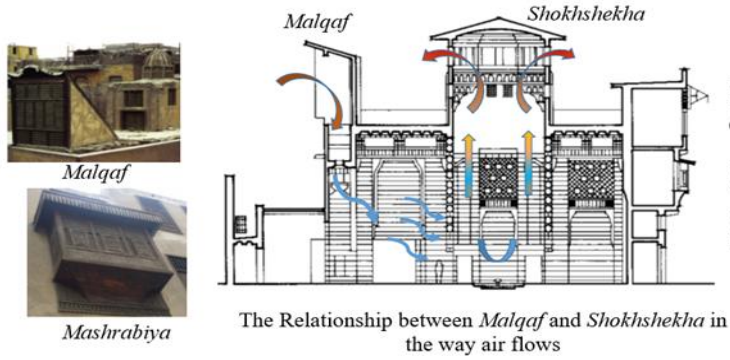

Figure 9: Section in Muhibb Al Din Muqqawi's Qa'aa, Cairo, Egypt, (Source: analysis by the Authors)

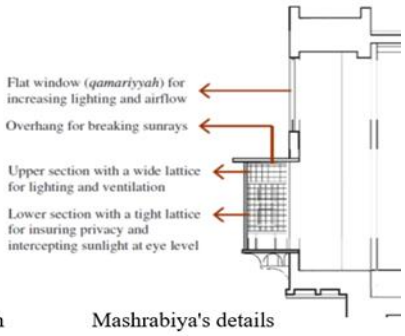

Figure 10: Mashrabiya's main components (source: Mohamed, N. and Ali, W. 2014).

The Thermal Regulation Analysis of Courtyards:

Courtyard Orientation

The courtyard's orientation plays an important role in the thermal performance of the building, it depends on building layout, sun location, wind direction, shading performance, and solar gain are all variables that have a positive impact on the microclimate condition within the courtyard (Bagneid, A. 2006). In most cases, the orientation of the courtyard's walls depends upon that of the street outside. At least on the wall it will usually be roughly parallel to the street (Reynolds, J. S. 2002). The courtyard's orientation has a direct impact on ventilation and wind speed. Different studies discussed that the best orientation of the courtyard in a hot-arid climate is the east-west axis to avoid sun overheating and an inclination by angle 15 ° to 45 ° which is more adequate for ventilation (Mossad, G., Ezzat, H. and Tallat, N. 2016). While the best orientation regarding prevailing winds is north-south. As per Meir et al. (1995), he found that positioning courtyards correctly might improve their thermal comfort, nevertheless orienting them regardless of solar angles, and wind direction may cause thermal discomfort (Meir, I. A., Pearlmutter, D., & Etzion, Y. 1995).

Ventilation Techniques

Courtyards are a very efficient solution to create comfortable temperatures in hot-arid areas where the difference in temperature between day and night becomes larger (Gangwar, G. and Kaur, P. 2016). The ventilation and airflow through the courtyard are dictated by prevailing wind direction.

Air circulation inside this confined space probably depends on the ratios of surrounding walls as well as the placing of the window openings in the surrounding rooms. The appropriate composition of the building in relation to the courtyard enables for a cool breeze in the courtyard. Breeze and shading throughout the courtyard help to develop comfortable living conditions throughout the day and sleeping conditions at night. The courtyard could even regulate the temperature, daylight, and movement of air in the rooms around it. Orientation, depth, height are all essential elements to obtain the same (Sthapak, S., & Bandyopadhyay, A. 2014). The air from the courtyard, which has been heated by the sun during the day rises in hot arid zones and is replaced by cooler night air coming from above. Throughout the courtyard, the collected cold air seeps into and cools the surrounding rooms. The courtyard becomes shaded by its 4 walls throughout the day, and this causes the air to heat slowly and keep cool till late throughout the day.

The passive cooling approach is reflected by the central courtyard, as the air within the courtyard becomes warmer as the day progresses towards nighttime. Cold air is contained in laminar layers throughout the courtyard and flows into the rooms surrounding the central courtyard and then slowly increasing in the morning the temperature within it, allowing the courtyard to stay cool before solar radiation falls directly on it. During the day, warm wind moves over the house and does not reach the courtyard, and merely produces eddies within it, unless baffles are built to deflect airflow (Soflaee, F. 2004).

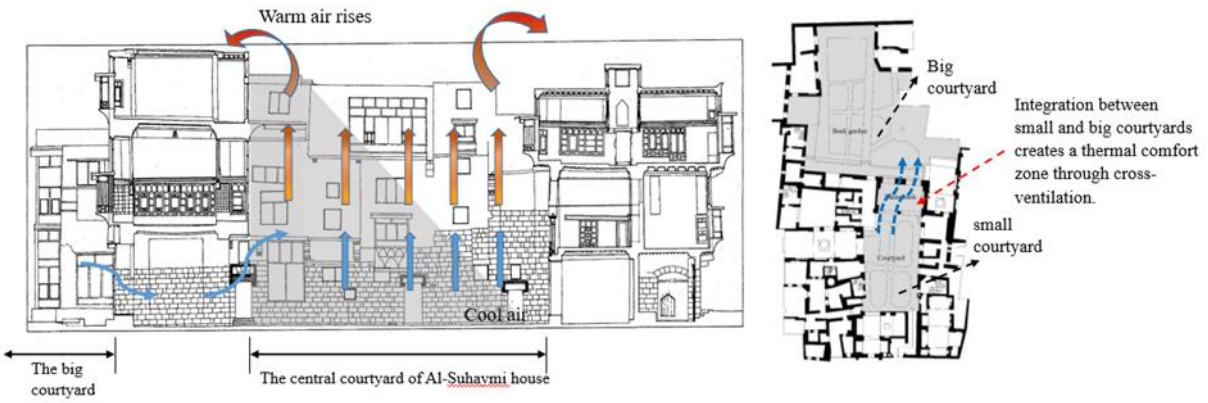

Figure 11: Cross Ventilation study in Al-Suhaymi house, Source: Analysis by the Authors

Thermal mass of the courtyard

High resistance and heat capacity of the envelope elements are required in the hot arid climate. Throughout the day, high resistance reduces conductive heat flow into the building mass. In fact, this can decrease the degree of cooling the building mass throughout the night, but this can be achieved by implementing the night-purge ventilation strategy. High thermal mass has been achieved through thick walls made of heavy materials such as bricks and stones. Moreover, small high windows reduce heat gain and make the interior spaces cool. The vertical surface exposure to the sun is reduced by sharing the exterior walls with the neighboring buildings, in addition, the courtyard's plan is preferred to be small and overshadowed by high walls which contribute to increasing shading ratios and enhancing thermal performance (Mossad, G., Ezzat, H. and Tallat, N. 2016) (Mohamed, M. 2019).

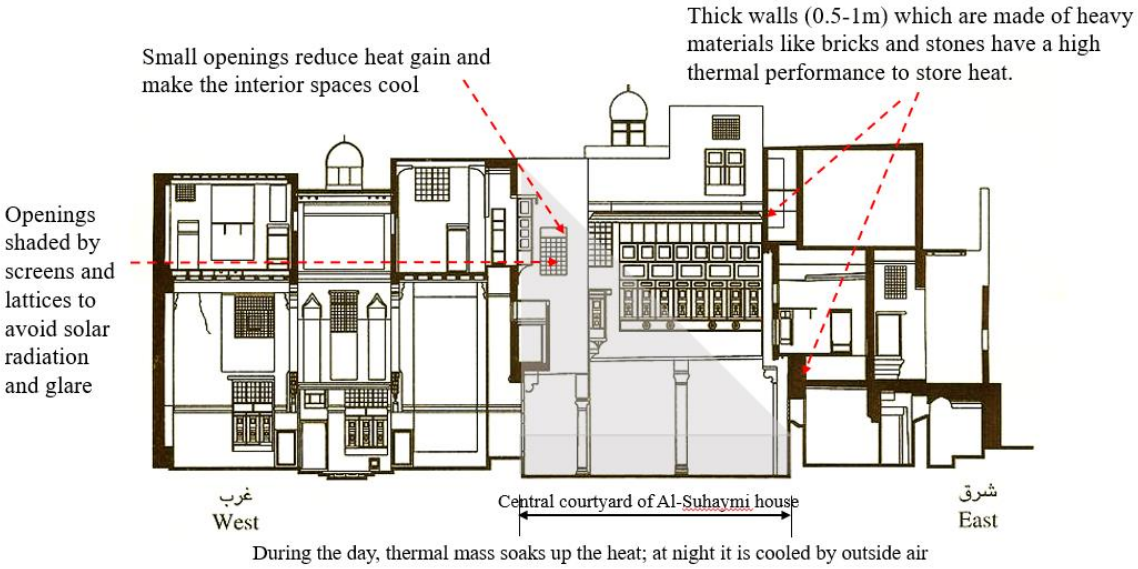

Figure 12: the courtyard has a high thermal mass achieved by thick walls and small openings, Source: Analysis by the Authors

Courtyard Envelope

The design of the opening elements must be studied to attain the desired ventilation rate, the selection of the proper elements (doors, windows, screens, etc.), and identifying their capability are so essential for the application of the appropriate ventilation techniques. For instance, the

position of the windows on the courtyard envelope (vertical or horizontal) has an important impact on ventilation rate, solar gain, and daylight. Screens could also be used for sun protection, shading, and ventilation by selecting the size, and material. Doors are primarily used in the connection between various indoor zones, but also have an important impact on airflow control and solar transmittance (Ahmed, M. A. 2012). There are numerous aspects for designing openings throughout courtyards in hot-arid regions. Some of these basic aspects are first, orienting windows to the north and sizing them to match the amount of thermal mass within the courtyard, second, enhancing winter heat gain and reducing summer heat gain by using external shading devices. Proper orientation with the awareness of the time of the year helps to receive the appropriate amount of radiation from windows. In summer, windows facing eastern and western receive a heat gain. The main openings are usually facing northern and southern within courtyard design; the southern openings must be shaded with any shading device or through deciduous trees. The heat gain within the house could be decreased by reducing the opening's size on the eastern and western sides. Openings should be located in an ideal position to the wind direction to permit the highest airflow that attains evaporative cooling as well as an air exchange thru the building [18]. Building envelope generally in traditional courtyard houses was constructed of indigenous building materials like bricks and stones which were appropriate to the surrounding environment and the climatic conditions.

Wall enclosure applies to all components inside the building that form the courtyard and separate it from semi-enclosed conditioned space and completely closed space. Throughout the design process, wall enclosure elements of the courtyard like windows, doors, and walls must be considered. Via natural ventilation methods, wall enclosures may play a significant role in the courtyard microclimate by opening or closing openings and adjusting their ratio.

Shading

A large part of a building's heat gain is related to solar radiation. This radiation is produced by high air temperature, radiant heat, and glare. Appropriate shading significantly minimizes these impacts. The further north direction or south direction from the equator, the larger the variation among winter and summer sun angles. This seasonal cycle along with shorter and longer days is responsible for the seasons. At the time when warmth is required, the winter sun penetrates deeper south-oriented spaces. However, shading against the direct sun is needed from April to October in most parts of the Arab Region (Ragette, F. 2003).

As per Al-Tamimi choosing good shading devices increase the comfortable house by 26% for unventilated buildings and 4.7% for ventilated conditions in hot climates, using cornices and protrusion, whether on external facades or on the central courtyard, is the most significant shading device. The roof garden is used by traditional houses as a way to minimize direct exposure to the sun, also using the covered walkway to shield the exterior walls from direct sunlight (Al-Tamimi, N. A. & Fadzil, S. F. 2014). The building's shape and size decide the amount of shadow, with the degree of complexity of the residence, the area of shade increases. Traditional houses have wide areas of shade, especially if more than one story rises from sections of the house. If the roof is not at one level, the volume of shade would be greater than if it is at one level (Ajaj, A. & Pugnaloni, F. 2014).

Figure 13: horizontal shading devices (Protrusions, Cornices, Mashrabeya) within the courtyard of Zeinab khatoun house (source: Mossad, G., Ezzat, H. and Tallat, N. 2016, analysis by the Authors).

Landscape features and components

Islamic architecture was using the landscape as the main component for courtyard design throughout centuries. Placing the landscape in the courtyard will provide environmental benefits. Shrubs, shading trees, and flower beds can significantly influence thermal comfort as they are creating shades on walls including ground to create microclimate conditions (Safarzadeh, H. and Bahadori, M. 2005). Water is mostly used in the hot-arid climate courtyards especially in the middle east countries, where is the level of humidity in the air is lower, so using water bodies such as ponds, fountains, and water falls add more moisture to provide comfort temperature for users within the residence (Gangwar, G. and Kaur, P. 2016). The influence of using water bodies inside the courtyard on thermal efficiency with a control tent above the courtyard was studied during daytime (Al-Hemiddi, N. & Megren, A. 2001), it was noticed that the internal courtyard with even a pool, shelter, and water spray had a high cooling influence for inner areas adjacent to the courtyard. In a desert environment, the courtyards will act with another role which is a dust controller. To prevent dust storms outside, the opening of the rooms of the house may be open in the courtyard. Consequently, vegetation, water bodies, paving materials all used for improving the microclimate in buildings (Gangwar, G. and Kaur, P. 2016) (Al-Hemiddi, N. A., & Megren, A.S. 2001).

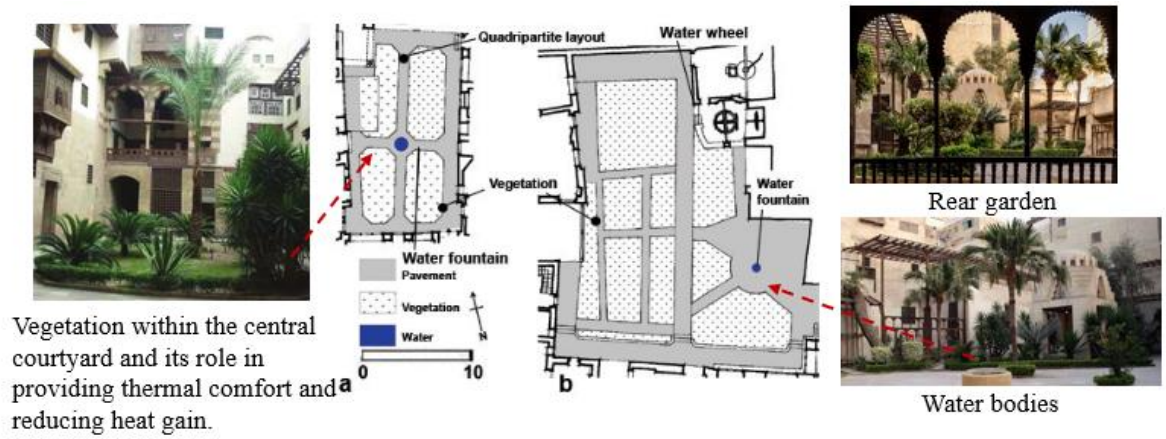

Figure 14: Landscape Design elements in Al-Suhaymi house, Cairo, 1648, (source: analysis by Authors and [27])

CASE STUDIES:

Two case studies of contemporary courtyard houses in UAE and Egypt, since they are similar in the same climatic conditions, research reviews the role of the internal courtyard and its impact on improving the climatic efficiency within houses.

A. Masdar City (Abu Dhabi, UAE)

Masdar City is in Abu-Dhabi; UAE is considered one of the world's most sustainable urban communities. It was created in 2006 by Abu Dhabi's government emirates. The city of Abu-Dhabi is characterized by high temperature, high humidity, and sunshine. Daytime temperature in summer ranges between 33 °C to 45 °C. Masdar city is focused on sustainable development through the reduction of water and energy demand, in addition to waste recycling and reuse. It was designed by Foster and Partners, (a British architectural firm), and has been awarded by the Golden International Green Building Certification.

Masdar City is a sustainable mixed-use project that is planned to be pedestrian-friendly City. Solar energy and renewable energy sources are used in the city. The design is inspired by Arab-Islamic architecture, and Foster's Architectural team began by exploring old cities like Muscat and Cairo to understand how they were kept cool. Internal courtyards, shorter, narrow streets, and wind catchers helped these cities cope with the hot-arid conditions. Buildings at the end of these streets provide enough wind disturbance to move air upwards, resulting cooling streets. Moreover, design focused on internal areas and the residential unit was the most essential element in Masdar city. The design team took advantage of rising the site of Masdar city from the surrounding area to create a slight cooling effect. Buildings are clustered close together to create streets and walkways shielded from the sun. Streets' temperature is within 15 °C to 20 °C which is cooler than the surrounding area. (Masdar city www.masdarcity.ae)

Figure 15: Urban fabric of Masdar city (source: analysis by Authors)

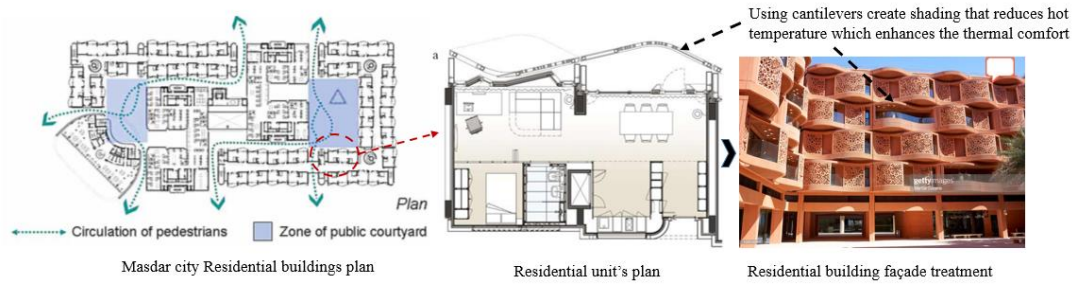

Figure 16: Masdar city's residential plan, (source: analysis by Authors)

Courtyards play a significant role in Masdar City's urban fabric. Most of the buildings include internal courtyards. The urban syntax is also based on the courtyards' configuration. Moreover, it's essential in outdoor activities and facilitating social interaction, which is an important aspect of modern life. Using shading tools has a positive impact on a building's thermal performance especially in the adjacent spaces of the central courtyard.

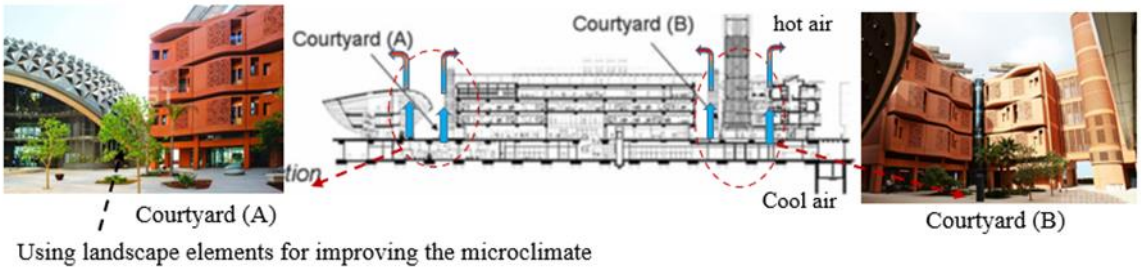

Figure 17: Section in Residential zone. (Source: analysis by the Authors)

Masdar city's streets appear to be large and straight on the ground, yet when viewed from bird's eye streets appear to be narrow due to noticeable cantilevers and undulating facades. Photovoltaic solar panels are placed over the roof to provide shade. The *Mashrabiya* also inspired the design of the residential building's shading devices. the design of the shades was both to filter the sun as well as create beautiful light and shade patterns.

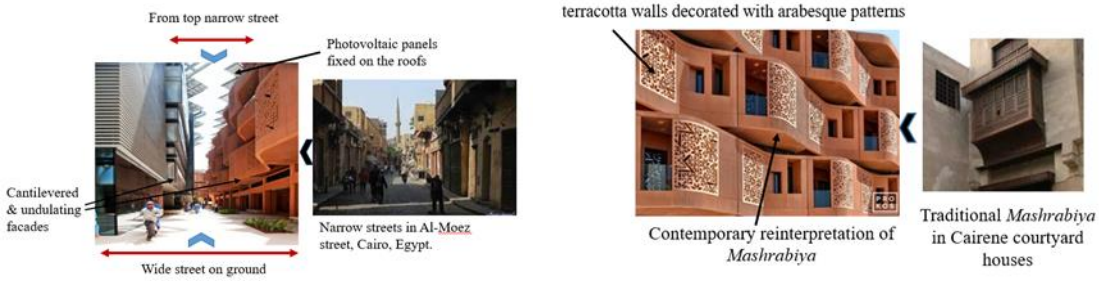

Figure 18: Contemporary reinterpretation of Narrow streets and Mashrabiya. (Source: analysis by the Authors)

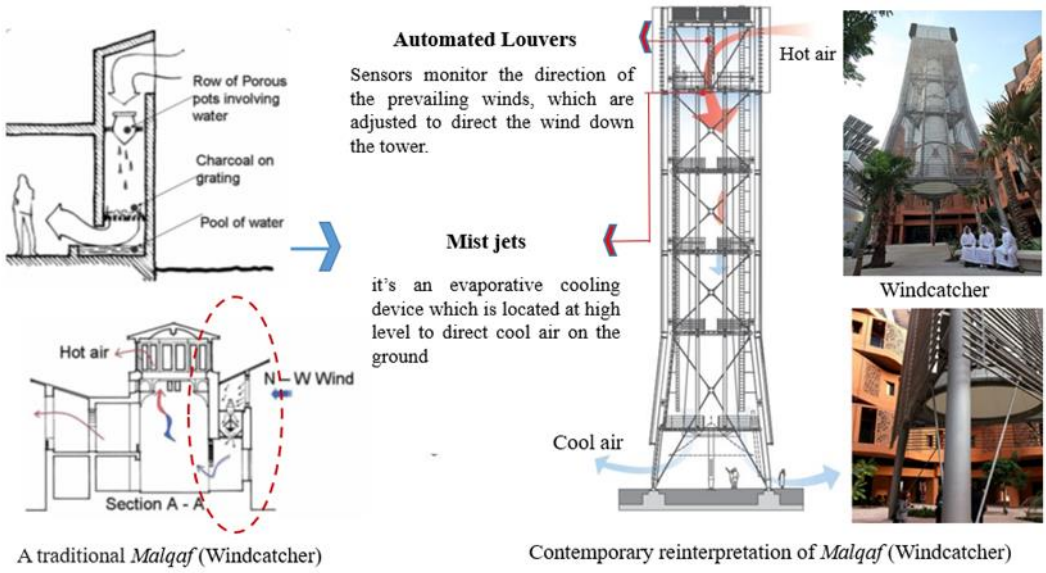

Figure 19: Contemporary reinterpretation of Malqaf (windcatcher). (Source: analysis by the Authors)

Windcatcher is used as well, it uses advanced technology to control wind direction and air quality, windcatchers are applied in public locations beside buildings to provide comfortable thermal zones, hence setting the stage for external social activities.

In summary, the design approach of Masdar city focused on certain points in the urban design process to accommodate the desert climate which influenced by Arab-Islamic architecture; Compact urban form, provision of social spaces within neighborhood, using climatic methods and modern technologies to improve the thermal comfort, and the important aspect is preserving the architectural identity of the Arab-traditional city and connecting communities with their heritage. Masdar City's sustainable design, which is known as one of the eco-friendliest cities in the world, has been proved to have included the main features of traditional Islamic city's form, and details. This provides a rich mixture of the cultural heritage and the modern techniques.

B. Courtyard Housing Urban Planning (New Cairo, Egypt)

Courtyard Housing is an Urban Planning project designed by Al-khawaji Architects in with area about 21 hectares. It has a unique site plan along the petrified forest protectorate which located about 30 km away from Cairo city near Maadi. Most of its area belong to the Oligocene geologic time period since 35 million years ago at least. The geologic history of this place makes it very important, the natural fortune present at this place has given it an essential reputation as a scientific, cultural and touristic destination.

Cairo city is described by hot arid climate. Daytime temperature in summer range between 37 °C to 40 °C, the temperature reaches its maximum in August 42 °C, and humidity is below 40 % most of the year. The site plan has a triangular shaped border, its design is divided into 30 different urban plots, the main idea of Courtyard housing urban planning was distributing three typologies which are; Apartment’s housing, Dorms (Student residence) and the single-family houses according to its function. The architectural plan is inspired by the traditional courtyard house where as the Courtyard is considered the major compositional core of project buildings.

The project design contributes providing both private and semi-private green courtyards for improving the climatic efficiency of residential spaces, providing natural ventilation and lighting. Courtyards are oriented to the east-west axis to avoid sun overheating and to improve the thermal comfort. Courtyard house is considered as a valuable new element to the new urban communities around Cairo which present a compact and sustainable urban design model for rapidly growing cities (alkhwajiarchitects.com).

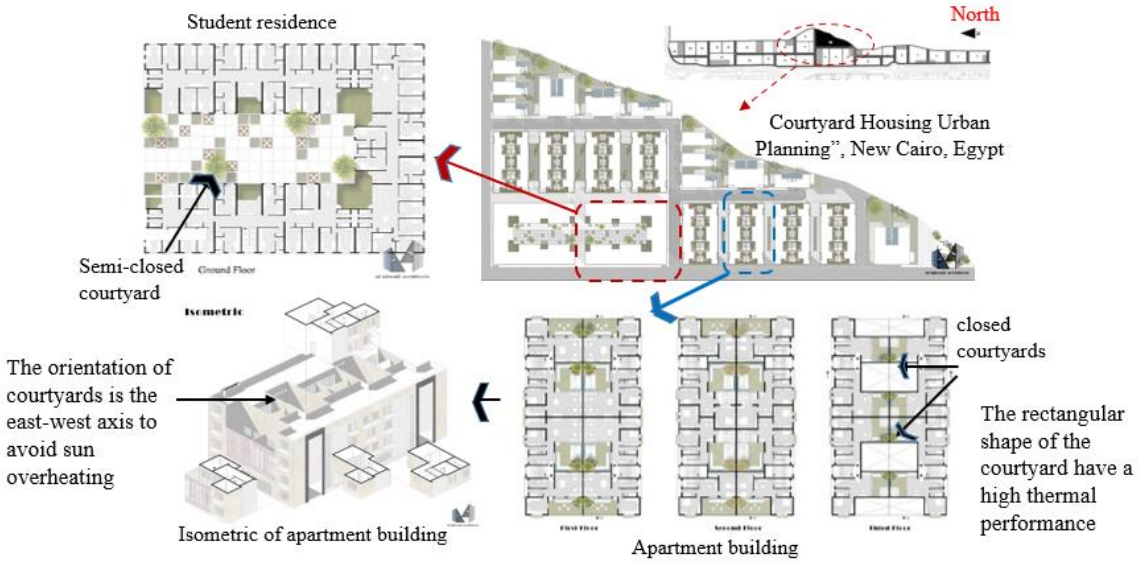

Figure 20: courtyard housing urban planning project, New Cairo, Egypt. (Source: analysis by the Authors)

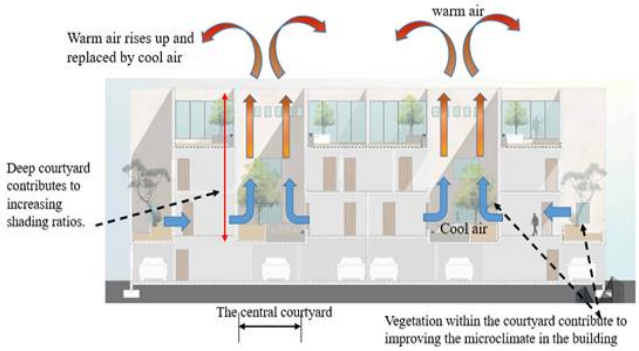

Figure 22: Air flow and Ventilation in courtyards of the apartment building. (Source: analysis by the Authors)

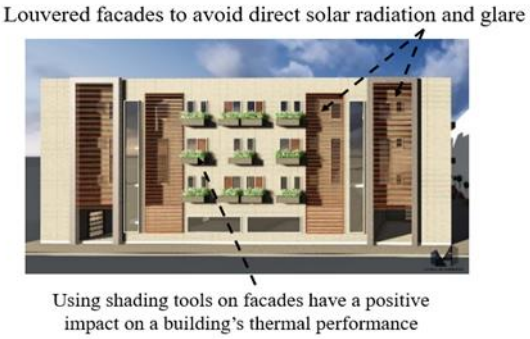

Figure 23: Elevation of the apartment building. (Source: analysis by the Authors)

The success of courtyard design largely depends on its configuration and orientation. In this project courtyards are designed long and overshadowed by high walls which helps to increase shading ratio, mitigate heat gain, and improving air quality and thermal building performance. This supports that the courtyard design could be very innovative solution to meet the current needs of people due to its various benefits.

Discussion of Results:

It is essential to consider the courtyard as a significant dominant element in residential building design in the present time. As discussed, though courtyard is a traditional architectural part, it performs several different purposes such as social and cultural ones. The results showed that it is possible to apply the use of courtyard as a spatial microclimate adjuster in contemporary architecture. This would be an advantage since nowadays, the world is focusing upon using clean energy and how to minimize the usage of our depleted resources. Through the interpretation of the paper to the answer to a major question; how could an old traditional element of architecture get to have an influence on adjusting the microclimate? And how could it provide a space for people? The findings revealed the effectiveness of this distinguished

element, that is achieved through the analysis of spatial location, composition, and thermal regulation of it. At the same time, as spaces, courtyards succeeded in providing space for people, offering social comfort, acoustic and visual protection.

Conclusion:

The research paper highlighted the major effect of courtyard on the thermal performance of buildings in hot-arid climates especially when applied on residential ones. Through the analysis of all the architectural, social, and climatic aspects of the courtyard houses, it is revealed that the orientation, composition, vegetation and shading devices of courtyard have an impact on its thermal performance, which could be a beneficial attitude towards achieving an environmentally friendly building. The paper concludes several guidelines to the Design Process of contemporary projects to achieve better thermal performance in hot-arid climates, in addition to an important aspect that is preserving the unique local identity of Egyptian traditional architecture and connecting communities with their heritage. These Design Guidelines are as follows:

1.Courtyard's shape is considered an important phase in the Design Process, the rectangular shape has better performance than the square shape as its climatic efficiency increases by forming more shadows in summer, with ease of directing it to bring the preferred winds.

2.The fully Closed courtyard is considered the best type since it offers the highest degree of privacy, lighting, ventilation, reduces solar radiation, and enhances comfort conditions.

3.The optimum orientation of the courtyard is the East-West axis in a hot-arid climate due to the high shading obtained and reducing the exposed area to the direct solar radiation, and an inclination by angle 15° to 45° is more adequate for ventilation.

4.Increasing Shading of buildings and building's elements by Cantilevered construction, arcades, loggias, high building parts, and placing buildings close together. Also, using horizontal shading devices on the internal courtyard envelope such as (Protrusions, Cornices, Mashrabeya) can all enhance thermal comfort especially in the adjacent spaces of the courtyard.

5.Increasing the height of courtyard walls (Deep courtyards) will cause a reduction in the degree of air temperature in the courtyard as well as the spaces in a nearby location to the courtyard.

6.Maximizing Shaded Trees, Vegetation composition, and Water bodies within courtyard have a significant impact on the airflow and high cooling influence for the inner spaces surrounding the courtyard.

7.Openings should be placed according to the prevailing winds and allow cross-ventilation, Louvered and screens openings are preferable to increase the wind speed and to direct the wind to the desired internal space, and to avoid direct solar radiation and glare.

8.Minimizing the opening's size especially on the southern sides contributes to reduce heat gain.

9.It is preferred to maximize the size of the inlet and outlet for increasing the cross-ventilation effectiveness within the courtyard.

10. The ventilation inducer (windcatchers and wind towers) is highly recommended to catch the wind and redirect it into various interior spaces.

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