JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 3, Issue No. 1 (June-2017)

ISSN: 2413-5267

Compact Residential Design and Ventilation Efficiency: Indoor Environmental Quality in Hot-Arid Zones, Ghadames, Libya

Hadi Shateh*, Lutfi Sinan, and Tarek El-Zabet

Department of Architecture & Urban Planning, Faculty of Engineering, El-Mergib University, Khoms, Libya.
***Corresponding author:** hasshateh@gmail.com

التصميم السكني المتضام وكفاءة التهوية: جودة البيئة الداخلية في المناطق الحارة الجافة، غدامس، ليبيا

الهادي علي الشطيح*، لطفي سنان و طارق الزابط

قسم الهندسة المعمارية والتخطيط العمراني، كلية الهندسة، جامعة المرقب، الخمس، ليبيا

Abstract

This study examined the ventilation system of the old city of Ghadames, a UNESCO World Heritage site located in the hot and arid Libyan Sahara. Specifically, the study working mechanism of the ventilation system without using technical machines and the rules that helped generate airflow effectively. The study is an important step towards understanding how we may develop architectural patterns using natural ventilation to provide thermal comfort within building complexes in a hot and arid climate zone. The study was based on personal observations, thermal measurements, and maps. Two key findings resulted from this study which can simplify the spatial and urban integrity, and social corroboration are the most important keys that created air-flow processes in the inherited urban complex of old Ghadames.

Keywords: *Ghadames, Urban heritage, Hot-arid zones, Ventilation system.*

الملخص

الدراسة تدرس نظام التهوية لمدينة غدامس القديمة والتي تقع ضمن المناخ الحار الجاف بالصحراء الليبية والمسجلة كموقع تراث عالمي بمنظمة اليونسكو. البحث يركز تحديدا على طريقة عمل التهوية بدون استخدام ميكنة صناعية والعوامل التي ساعدت على استمرار تدفق التهوية بشكل منظم وفعال. تأتي أهمية الدراسة في سياق محاولة تطوير نمط معماري يستخدم التهوية الطبيعية لتوفير راحة حرارية ضمن المجمعات السكنية في المناطق الحارة الجافة. تستخدم الدراسة منهج المشاهدة الشخصية و التحليل للقياسات الحرارية و الخرائط المتوفرة. خلصت الدراسة الى العديد من النقط اهمها، توظيف العناصر الفراغية والوظيفية في تصميم منظومة التهوية والاعتماد على التعاون الاجتماعي في إنشاء وصيانة نظام التهوية للمركب السمني كانت اهم عوامل نجاحه.

الكلمات الدالة: غدامس، نظام التهوية، المناطق الحارة الجافة.

1. Introduction

The wind is a renewable energy and a positive element in achieving thermal comfort economically which is also suitable for residential settlements in the desert natural areas if a

ISSN: 2413-5267

proper system is used to ventilate the buildings. Understandably, characterized by the use of air flow, ventilation in buildings is ubiquitous in traditional architecture, especially in the hot and humid zones. Moreover, the elements of wind direction -wind catchers- have been known for centuries, and wind energy has been harnessed in providing ventilation for the purpose of air conditioning depending on the dynamic movement of air. One of the unique practical examples that still exists today as witness to the use of natural ventilation for cooling buildings in the vernacular architecture is the Old Ghadames City, (OGC). In this city, the method adopted reduces the wind speed to the levels which allow it to enter into the vertical channels or ducts from the highest of the shaded buildings then into horizontal channels-streets- to cool down the air through the various spaces of residential units. In this phase, which is from the entry of air from specific points in the streets till its exit from the top of the internal courtyards of the housing units, the air passes through a set of well-designed elements that control air pressure to be used as a natural air conditioning system.

Architecturally, the system that is discussed here depends on the importance of providing a workable design depending upon the optimal and proper use of this energy to achieve factors that are suitable for the Built Environment. The system based on use of natural ventilation, natural cooling, air condition, and indirect factors such as access to differences in pressure and differences in temperature. Consequently, this system, however, is built on the collective construction and distribution of the elements of the ventilation system. The pattern of the ventilation system is considered to be not only a healthy method but also an economic way because it works to achieve a great deal of thermal comfort for the whole group of housing through a single system which is to a great extent like a central air-conditioning.

Particularly, the thermal comfort is a result of gathering the physical and social patterns that work as one. However, the questions that are raised here are what are the ideas and/or elements that could be used to achieve the thermal comfort by using the wind energy, and it; what are the organization and features that could be used to get advantages of natural ventilation. In this study, the focus is mainly on the system of ventilation which affects the thermal comfort. The other aspects which involve creating the thermal comfort will be mentioned when it has a strong relation to the discussion.

The study aims to investigate the validity of the ventilation system as an important part of the thermal comfort systems and presented the phenomena of the proper use of natural ventilation in dry, arid climate.

2. Methodology

The methodology of this study consists of four phases;

Phase one; a general description to introduce the geography, history, and the climate information of Ghadames.

ISSN: 2413-5267

Phase two includes specific research and collection of data, drawings, photographs, measurements which helps better describe of the ventilation system phenomena in the residential complex of OGC in order to formulate conclusion with respect to the problem of use of the ventilation to enhance the thermal comfort.

Phase three is an analysis of the elements and ideas of the ventilation system based on the observations and data offered in phase two. This phase shows in details the elements that are used to control the air movement and its circulation into the building to increase or decrease its temperature.

Phase four -quantitative investigation- is an investigation of the features of the traditional ventilation system using measured climatic data of the OGC. These physical measurements based on several different studies were conducted at different points in the time line to show the act and sustainability of the system. (Chojnacki, 2003; Shateh *et al.*, 2002; and Shawesh, 1993) however, all these studies that are microclimatic comparative studies between the traditional and the contemporary houses outside OGC focused on the thermal condition. Even these studies may not be the only studies that done on OGC, they chosen to investigate the act of the ventilation system during the longest possible period of time. Yet these studies did not focus on the ventilation system. Their measured data of the outside and inside temperatures are direct evidence on the capability of the system since the temperature affected directly by the air.

3. Phase I: A Pictorial Explanation of Old Town of Ghadames' Characteristics and Configuration System

3.1. The General Characteristics of the Old Ghadames City (OGC)

Although the OGC is a settlement like many others in the Sahara that are located in difficult environmental circumstances, which is the natural typical environment of such a big desert, it uses simple and scientific methods to achieve sustainability. The methods they applied were smart- they were based on changing the building's design in accord and to the desert climate. This idea wasn't the case only for achieving a suitable and required level of lighting and thermal isolation but also it was the case of achieving fresh air for health and an inhabitant building's conditioning purposes. The following points explain briefly the geographic and climatic conditions, which are considered as the natural sources of the ventilation system, and the spatial configuration.

3.2. Location of Ghadames

On the intersection of the longitude of 30.08 N and latitude of 09.30 E Ghadames city has its position. This position is on the northern part Sahara on the northern part of Africa. It is about 600 *km* to the south from the Mediterranean Sea coast. It is located about 300 *m* above sea level and it has many sand-hills surrounding as a crescent from north and west side.

ISSN: 2413-5267

Ghadames is at the intersection of Libya's border with Tunisia and Algeria. Ghadames is about 10 *hectors* surrounded by oasis of 215 *hectors* (531 *acres*) which includes farms and more than 30,000 Palm trees (El-Agouri, 2004; and Shateh, 2002).

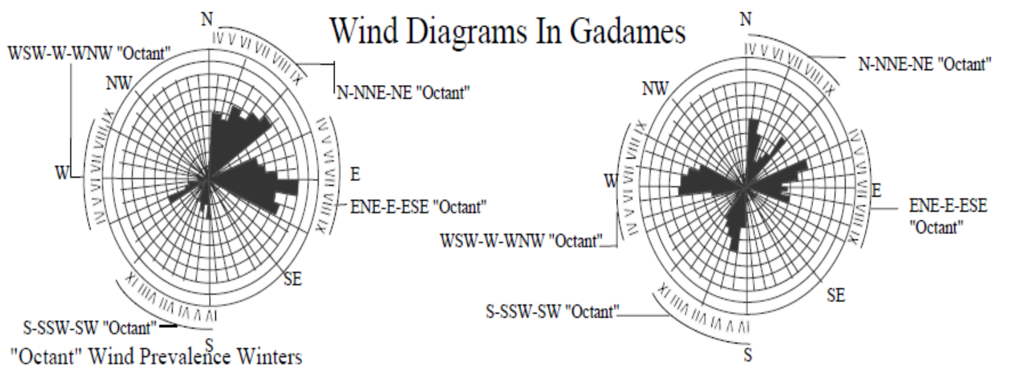
3.3. History of Old Ghadames City

Several references mentioned that the settlement of Ghadames was founded since several thousand years ago. “Historians record that Ghadames was habited (4,000) years ago.” (El-Agouri, 2004). However, there is no strong evidence mentioned that the settlement was built completely before Romans time.

3.4. Climate

3.4.1. Winds

The local wind in Libyan Desert called “Geipli” come in the summer season; moreover, it generally is very hot and comes with dust. The East winds are the most dominant with 14% prevalence. In general, the average wind speeds are 8 to 12 *knots/hr* and the wind speeds 50 to 75 *knots/hr*. As desert climate, in OGC it rarely rains. “The prevalent winds are from north-east, but there is frequent local turbulence. Strongly heated air directly above ground results in the inversion of temperature, which in turn results in the formation of local whirlwinds” (Chojnacki, 2003). The features of the winds’ speed and orientations that are detailed in Figure (1) is a natural energy source which is adapted to generate the ventilation mechanism.



Monthly "Octant" prevalence	Yearly prevalence
1- ENE-E-ESE Octant	25.7%
2- N-NNE-NE Octant	24.8%
3- WSW-W-WNW Octant	18.5%
4- S-SSW-SW Octant	15.2%

Figure 1. Chart of the wind analysis (Shateh, 2002)

3.4.2. Temperature

The temperature is more than 35°C (95^oF)and up to 41.7°C (108^oF) from April to November (Shateh, 2002). The biggest temperature span was from –8.0°C (18^oF) (in Ghadames and all of Libya) to 50.0°C (122^oF).” (Chojnacki, 2003).

3.4.3. Humidity

The relative humidity (which is the percentage of human comfort) averages annually at 34%; it ranges from 72% in winter to 17% in summer, so it is very low during the summer period (Chojnacki, 2003; and Shateh, 2002).

3.4.4. Inclination of The Sun

The maximum inclination of the sun is 82°, and the minimum inclination is 35°.

4. Phase Two: Architectural Compilation of OGC

The architectural configuration of Ghadames buildings as shown in Figure (2) is unique due to its compact architecture pattern that satisfies the social behavior and suitable for adapting of the microclimate at the same time. Crowded buildings together not only reduces to great extent the surface areas exposed to the sun directly and increases shading, but also preserves valuable land, to provide defense needs (Rapoport, 1969). Ghadames, which applied this approach, it is generally a circular plan enclosed by the reinforced back-walls of the houses at the periphery. The walled city of Ghadames consists of ground floor as male domain and upper floor as female domain.(El-Agouri, 2004). For the social privacy purposes women circulate at the level of the rooftops where they can move freely from one terrace to another and visit each other. In Ghadames’ case, at day time when men in the farmers, there are places that specialized for children and teenagers for learning and playing purposes but those places are located in the shaded streets closer to the public places under the observation of old men. (El-Agouri, 2004). This pattern of design provides, especially in the hot arid climate, several advantages. This phase provides several observations that describe the city with focus on the issues that affect the use of the ventilation outside or inside the residential complex. In order to clarify those planning and architectural points, the phase dived into five sub-titles.

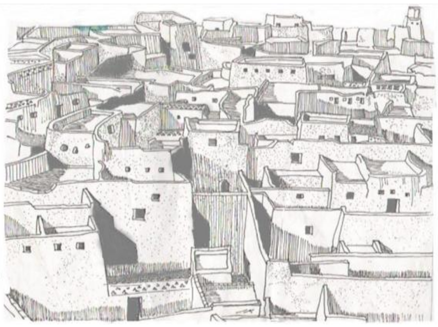


Figure 2. General view of the OGC settlement (Rapoport, 1969)

ISSN: 2413-5267

The emphasis of the use of the planning pattern of the town as a first stage of obtaining the interior thermal comfort is that the added houses were still keeping organic proportion of the general residential plan. The residential complexes were not a single mass, but they have the shape of adjacent masses and integrated within the green cover as shown in Figure (3), and that –as it seems to be guarantees the reach of humidity from the green cover to all residential units easily and also to allow fresh humid air with relatively low temperature to enter through streets that end with green areas.

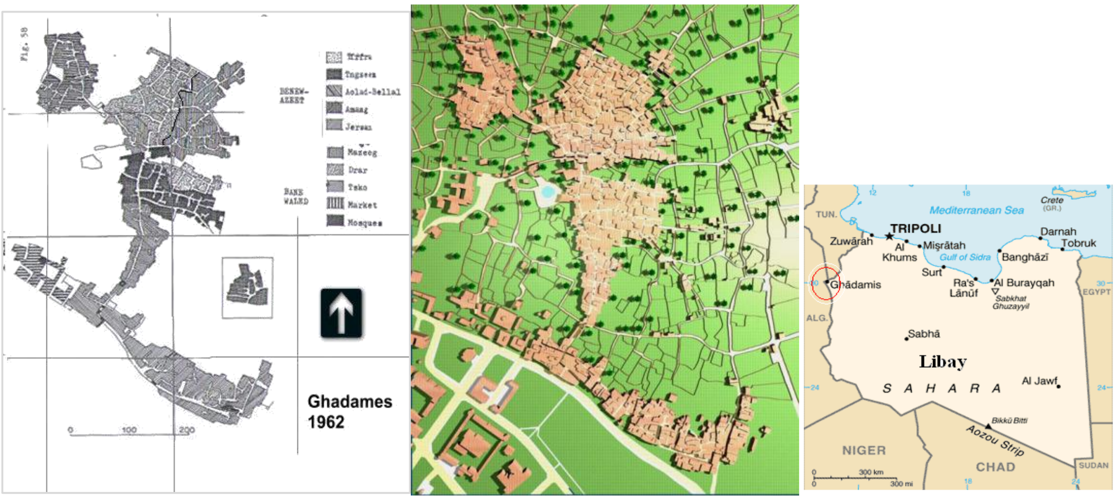


Figure 3. Old Ghadames city, top eye view for the whole settlement presented in 3-D. (El-Agouri, 2004). This figure shows the compacting idea that integrated the houses spaces to one space to reduce the exposed surfaces to the sun heat, and to protect the interior spaces from the reflected and direct sun.

One of the obstacles that appear in modern societies and which make it difficult to generate one system for the whole neighborhood is the variation of the ethnics, however, Figure (4) show the difference in the ethnics, and area of each tribe or groups into the complex. Even though the number of tribes mainly was two but they lived, use, and share all of the sensitive facilities of OGC such as ventilation and lighting systems.

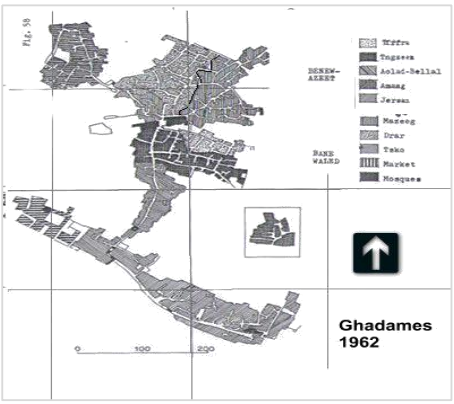


Figure 4. Show the social distribution of the tribes into the OGC (Daza, 1982).

4.1. Site Plan

There are two important features that characterizing the site of OGC. First the complex sited under the hill to be protected from the heavy wind as shown in Figure (5). The residential complex is sited to avoid harmful winds (Rapoport, 1969), and allow useful portion that important to ventilate such complex. The second; in GOC area there are two types of vegetation. The first are cover plants: gardens of vegetables and some types of fruits which in turn contribute also for producing the humidity. The second: the palm trees surrounding the city. The settlement has two artesian wells. The residents of this settlement accommodated the surrounding environment by utilizing palms and mud brick to build architectural complexes that form this unique structure. The local people have been able to use all the limited local resources in a poor environment to create a suited architectural pattern to the harsh climate.

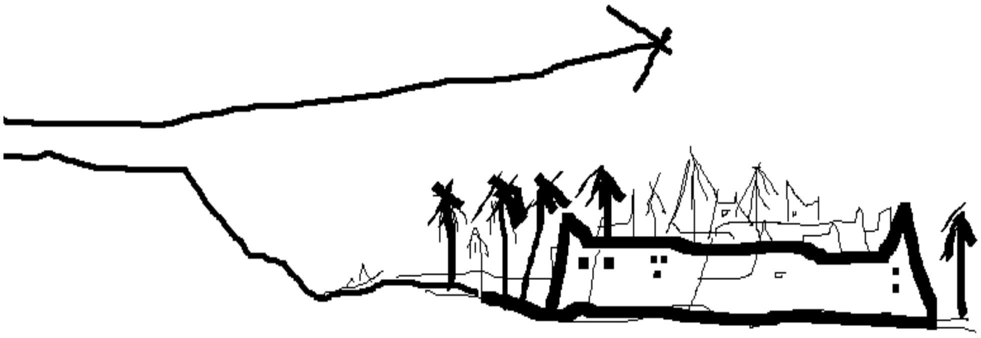
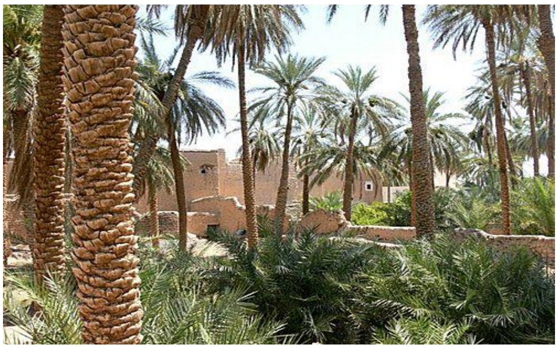


Figure 5. Site of the old Ghadames complex under the southern hill to avoid the undesirable wind.



Picture 1. Show the use of palms around the complex.

Picture 2. A view of one of the streets shows the coverage plant around the OGC.

Pictures 1 and 2 show the palms not only provide the important materials to create the roofs and furniture, but also provide a great natural net to filter the air form the dust during dusty winds. On other hand the high of the palms is working as wind catchers to decline the winds speed. According to this characteristic considered an important step towards adapt a practical mechanism for ventilating the complex.

ISSN: 2413-5267

4.2. Wind Coachers

Architecturally, the windbreaks (Malqaf) that exist in the upper parts of houses corners breaks the wind and reduces its relative high speed until it flows through the ventilation shafts of streets and the opening in the roofs of houses.

Picture 3. Side view shows the use of Malqaf in upper the houses

Picture 4. A view from the roofs shows the wind-catchers on the kitchens' roofs

On the other hand, the triangle has several shapes in the Ghadamesians house. It is the main shape in their sculpture in both outside as small openings and inside the house in all the decoration of the furniture. The triangle has valuable value for the ancient Ghadames people, some they were use it to Exorcism.

4.3. Streets Shafts

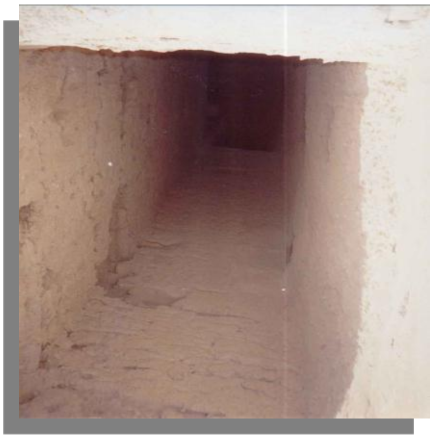
The shafts ate vertical ducts that connect the streets with the atmosphere to provide them light and air. These shafts as show in Figure (6) they are diffused on the streets but there is exact destine between them. Form the fields' observations; it can be notes they are varying in sectional area. Practical job of these shafts is refreshing the air in the shaded streets to obtain sufficient for thermal comfort. The ventilation system in the streets is an advantageous system consisting of vertical shafts in smaller section areas than the illumination shafts, which appear in the picture (5), to create an air current between the inside of streets and the outside. The picture (6) shows an outside view of a shaft from the street and picture (7) shows the interior view of a shaft. "Both houses and streets are admirably adapted for the climate, protecting the inhabitants alike from the fiery glow of the summer's sun and the keen blasts of the winter's cold." (Shateh, 2002).

4.3.1. Street Pattern

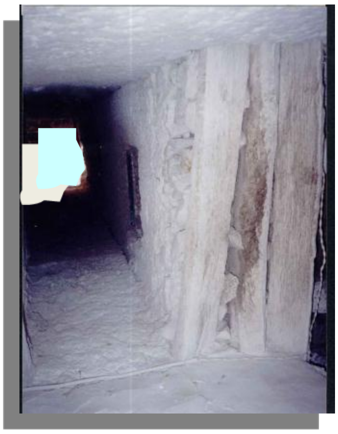
The street pattern consists of narrow and obscure corridors, which are integrated into the architecture of the dwellings at the ground floor level and are mainly used by men and children. Ghadames region is integrated with vegetation and cultivable land within the residential part of the town" (El-Agouri, 2004).

ISSN: 2413-5267

Picture 5. An interior view of a lighting shaft from the street



Picture 6. An interior view of the ventilation shaft from the street



Picture 7. An outside view of the ventilation shaft.

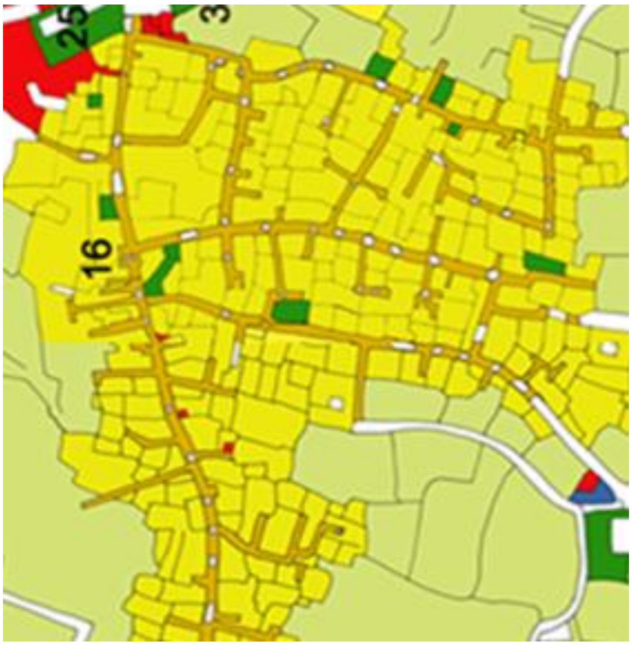


Figure 6. Shows the diffuse of the shafts opening along part of city's streets (Shateh, 2002).

4.3.2. Street Design

The main streets are wider and connect most of the secondary streets, and contain the general public courtyards. The pictures 8 and 9 shown the main streets which were designed in curve-linear forms for environmental aims. On the other hand, the secondary streets narrow down to two meters (6.5 *ft.*), and are specialized for a certain groups of houses, the residents of which are related with a social relation. Moreover, both secondary and main streets are not opened directly to the exterior atmosphere being covered by interference of houses at the first and second floors as shown in Figure (7).

ISSN: 2413-5267

Picture 8. An interior view of a street shows the lighting the streets by the lighting and ventilation shafts

Picture 9. An interior view of a street shows the setting places and the narrow streets intersections

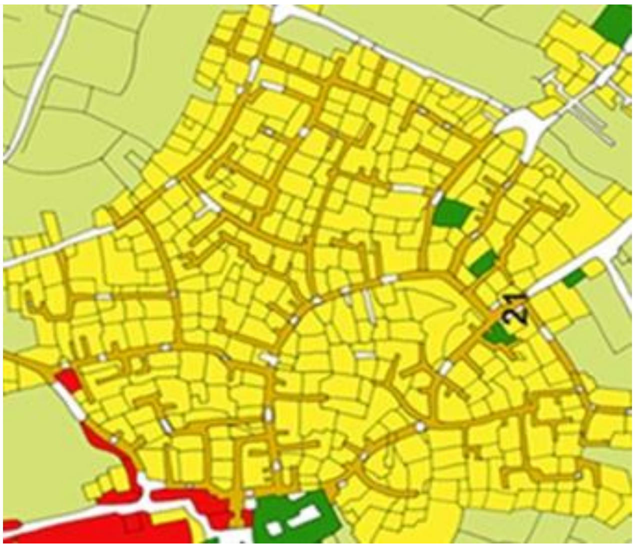


Figure 7. Part of the city streets network which shows the curvature and abundant closed-end (Shateh, 2002)

4.4. Courtyards System

The courtyard is considering the core space of the social behavior in the houses as well as the main thermal mass that control the microenvironment of the other spaces in the house. The use of courtyard provides protection from sandstorm and also useful in coping with the dry heat and has climatic implications as well as psychological once (Rapoport, 1969). For a short time, as shown in the figures 9, a house with plot 26.50 m^2 (285 ft^2) and 15 a house with a plot about 25 m^2 (269 ft^2) (Shawesh, 1993). The houses often are three floors and in fourth floor the often the kitchen and usually there is a storage room. Locating the kitchen on the roof helps to a great extant not only to transfer the heat directly outside old, shaded area, but also made the roves a women movement domain in which is an essential social required. When it is cool, people in hot, dry areas sleep on the roof, when it is cold, they sleep inside (Rapoport,

ISSN: 2413-5267

1969). The house and this activities made people use different facilities on the roof in which helps more shadow on the area that exposed directly to the sun. The ground floor, which is the coldest space in the house, and where the house entrance is, there is a space usually used as storage for the farm products and facilities. The bathroom is located in between the entrance and the courtyard spaces (*i.e.* There is water system that used to supply all houses, farmers and public spaces. This system and sewage system will be discussed in more details in the next study which will focus on the courtyard house in Old Ghadames City). The bedrooms' spaces are relatively small and usually there are one for boys and other for girls. The courtyard, which the main space for the relatives and women visitors, is a shaded and the most lighting space in which where the small windows of the rooms usually open. "Both houses and streets are admirably adapted for the climate, protecting the inhabitants alike from the fiery glow of the summer's sun, and the keen blasts of the winter's cold." (Stowell, 1848).

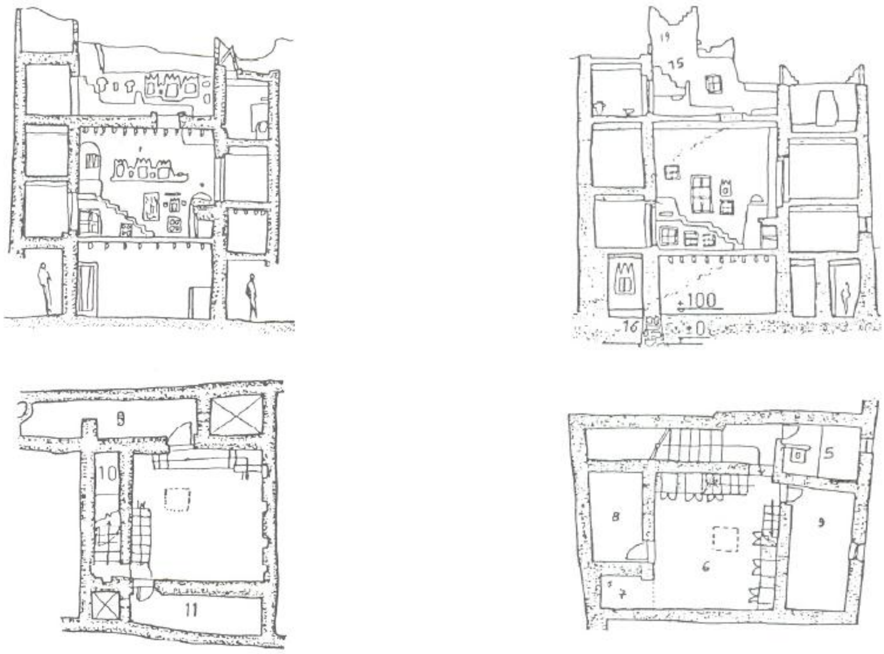


Figure 8. Show two houses in OGC, each column represents a section and plan of a house, (Shawesh, 1993)

For controlling the air flaw between the streets and the atmosphere there are upper and below opening of the courtyard as shown in pictures (10 and 11). They are very small, about 50×50 *cm* (1.64×1.64 *ft.*). The ceiling openings allow the air to escape from the lower streets and the interior courtyard openings channel the air back to the outside. The distance between both opening usually about 6 *m*, (6.56 *yard*), which is the courtyard height. Even though not all the houses, but the majority, have a courtyard, all of them have been linked to the atmosphere by the staircase.

Picture 10. An interior view of the courtyard opening. The picture was taken from the courtyard space. It shows also the roof structure which made from palms logs

Picture 11. A view of the ventilation opening between the ground floor and the courtyard where the view was taken

5. Phase Three: An Analysis of Ventilation System in The Traditional Old City of OGC

To discuss the ventilation in OGC the analysis breaks up into two steps. (i) The ideas and elements which are used for the ventilation, and (ii) the ventilation system's working mechanism of the. In arid zones reducing the speed of the winds is not an easy task. This suggests that choosing the appropriate method is an important step. Using natural features of the landscape abate the lack of the technology processes. Moreover, in Ghadames case, the first builders designed their complex based on the features of the natural resources -wind, sun, local materials- to adapt their microclimate. In other words, the entablatures of Ghadames used the southern hill to void the southern winds. The palms are used to reduce the speed of the winds and to protect the buildings from the undesired winds. Based on the observations that I made during several visits to the city buildings from 1992 to 2006. It found that the ventilation system in general depends mainly on five planning ideas and architectural elements as shown the Figure (9).

ISSN: 2413-5267

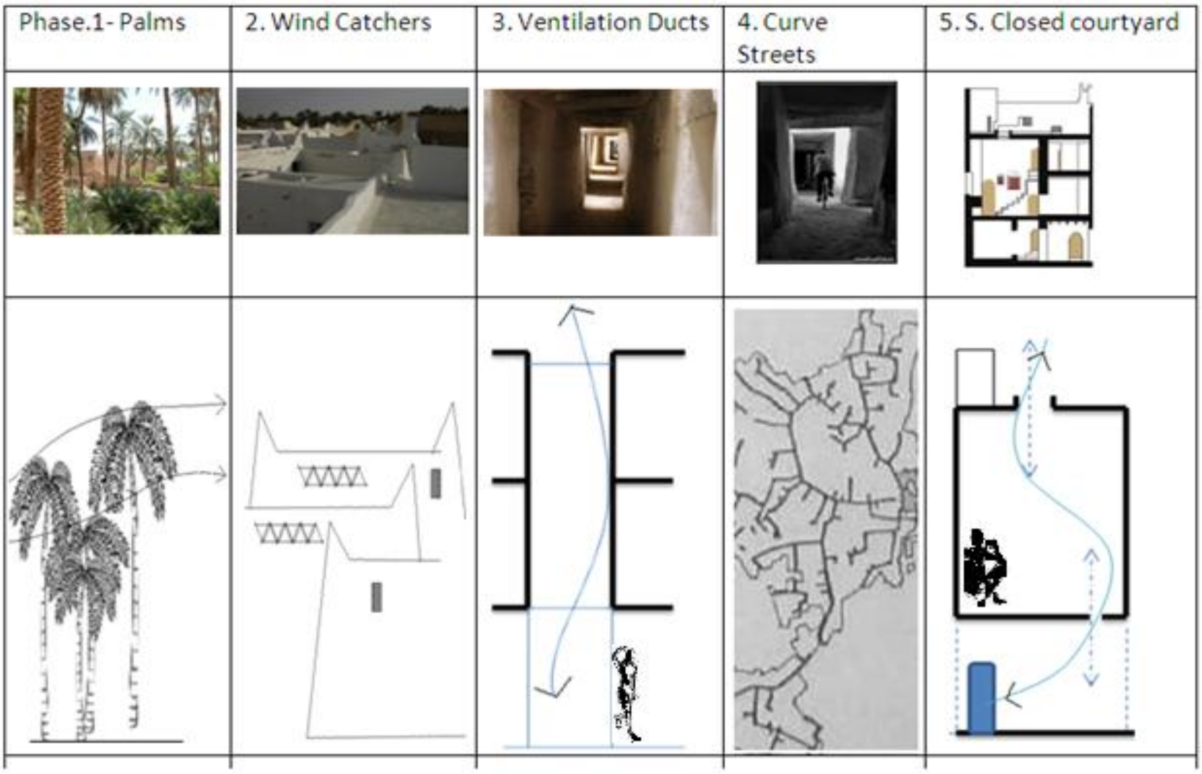


Figure 9. Show the general steps that used in OGC to adept and use the wind to enhance the thermal comfort of the complex spaces.

The first step is the site location, which provides a natural protection to a certain level, and the use of palms to abate the surrounding environment and to support the site features. The palms around the complex mostly have a significant role as a wind-catcher to slow down the faster winds at the higher wind level above the ground. This step for the most part is planning strategy of the chosen location of the city which is protected by a hill from the west and is surrounded by high palms from other sides.

The second step, the windbreaks (Malqaf) that exist in the upper parts of houses corners to change the direction of the lower level winds above the buildings. In addition, they break the winds and reduce its relative high speed allowing some of it to flow through the ventilation shafts of streets and roof openings of houses. The different heights of housing units are another factor that functions as a wind breaker.

The third step, the ventilation shafts, which are a vertical ducts located above the streets to connect them to the atmosphere, to give a space to the air to move between the two different pressure spaces – between the shaded and isolated space into the complex and the natural climate outside it.

ISSN: 2413-5267

Fourth step, the curved and covered streets clear the wind from the dust and help to slow down the initial high speeds of the wind. The length of the covered streets serves to cool the air temperature.

Fifth step, courtyard systems; locating the courtyard in the upper level of the house, the small opening in the courtyard roof, the opening between the courtyard and the ground level and the one between the house and the streets altogether pose the courtyard system. The houses and its courtyards which are connected directly to atmosphere do not affect or disrupt the temperature degree of the whole complex because the volume of the street system is larger than can be affected by a number of houses. Thermally, the houses are in need of the streets more than the streets are in need of the houses. This may be a strong reason that forced all the owners to accept the idea of living in an integrated complex.

5.1. System Mechanism

Architecturally, the ventilation system of OGC in the initial phases depends on using the difference of air pressure between the inside and the outside of the building complex. The height of the multi-storied buildings and the partially closed streets create suited difference of temperature degrees between the inside and the outside of the complex. The interior lower air of the buildings is denser than the exterior hot air. The relatively narrow ventilation shafts of the streets cause a natural air current, due to the pressure difference. And so, the air starts to flow continuously through the streets as cool breezes.

In addition, this interior interaction of the design properties is used to save the balancing of the thermal mass between the houses. Figure (10) shows the interaction of two house spaces. Each micro-space has two connected surfaces with the next-door neighbor's spaces. This helps increase the conductivity between them to achieve nearly the same temperature in the houses. From the same figure note that the street which is at the ground floor shares in the process of thermal interchange, the thermal storage of the total mass will have its thermal balance even when the insulation of some houses is poor.

The current air gets cooler while passing through the shaded curvilinear streets, which had possibly been designed for this purpose. The ventilation shafts are designed to be narrower than the lighting shafts and supplied by wind catchers to direct the air into them. These shafts were distributed on proper distances along the streets. The fresh air coming from the ventilation shafts gets cooler while passing through the shaded streets. It penetrates the houses and then gets out through the small vents of the houses' ceilings.

The ceiling vents of houses are smaller than street openings (shafts), so, the main current is caused by passage of the cooled air of streets to the houses through the doors. The flowing air current is controlled by the relative closing of the ceiling vents. This process happens oppositely during the night hours as depicted in Figures (11 and 12).

ISSN: 2413-5267

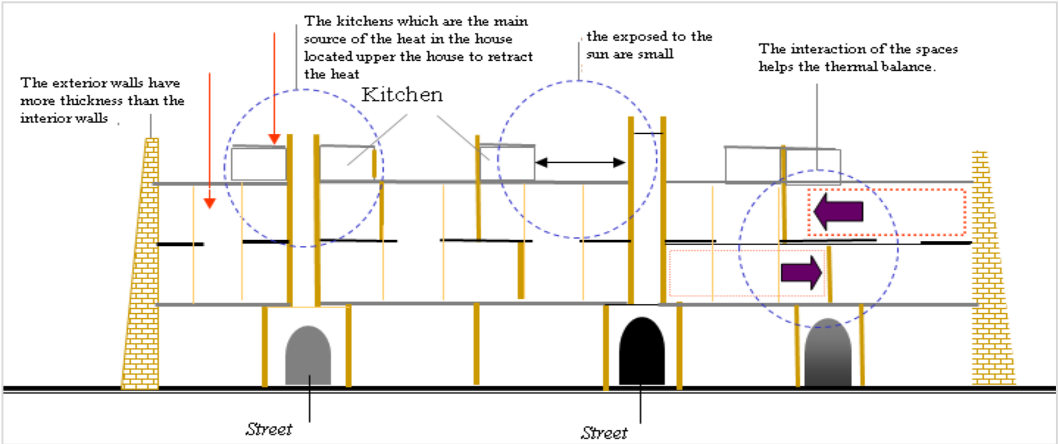


Figure 10. Sketch shows the design pattern of the vertical and horizontal relations between the houses and the streets (Shateh, 2002).

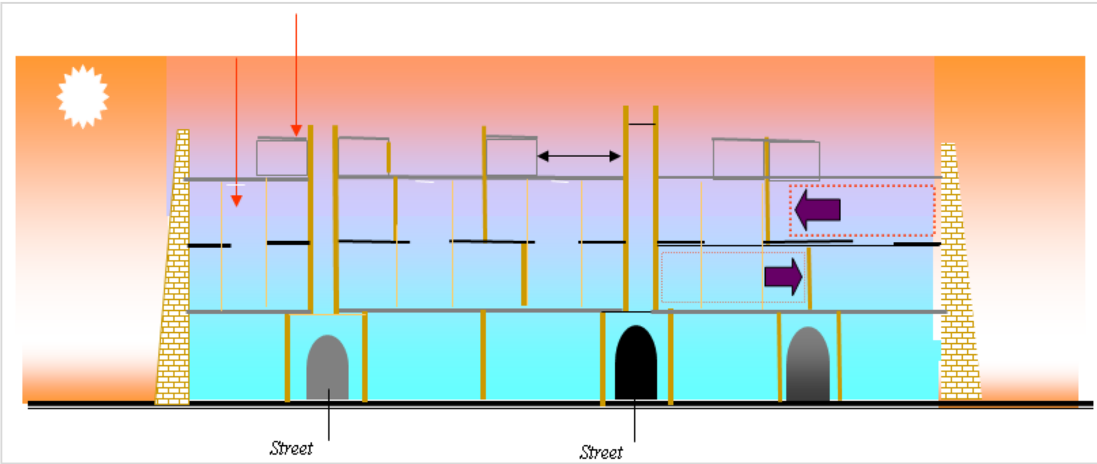


Figure 11. Shows how the method of heat exchange which isolates the day heat of the main living area, bedrooms and ground floor (Shateh, 2002).

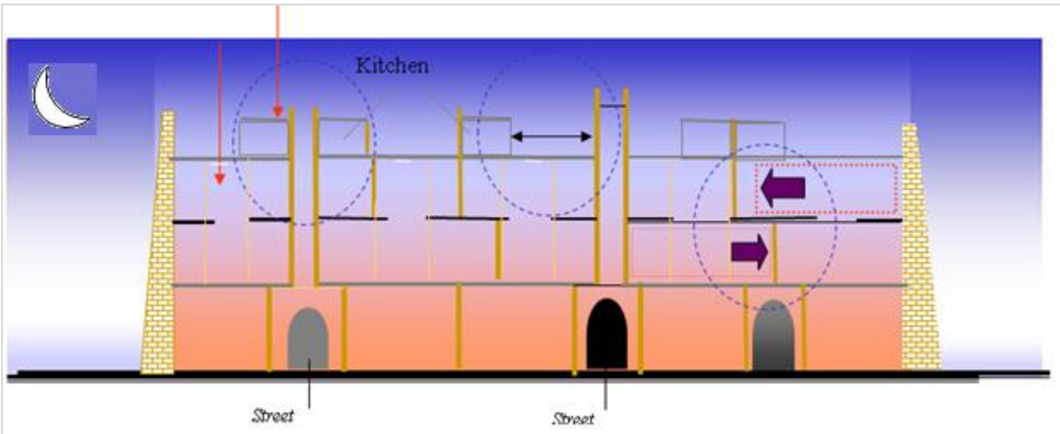


Figure 12. The opposite process of the heat exchange which is happening during at night to save the thermal balance (Shateh, 2002)

ISSN: 2413-5267

The air in lower spaces of the complex has higher density than the hot air outside the buildings and the vertical ventilation shifts or ducts in the streets are built relatively smaller in terms of the area than those which are built for lighting purposes. In this case the ventilation shafts turn into natural canals by the difference of the pressure and which results in generating breezes of cold air. When the air enters the buildings it becomes cool naturally and is one of the reasons for building the streets in curved lines.

The mechanism of an integrated system to regulate the movement of ventilation inside the compound is a key point which relies on pumping air through the spaces of the residential complex and out through the stable mechanism by exploiting the differences in air pressure between inside and outside (Natural Convention) as shown in Figure (13). Moreover, the multistory - three story building height- has enabled it to make a difference in temperature precisely because all of the streets are covered.

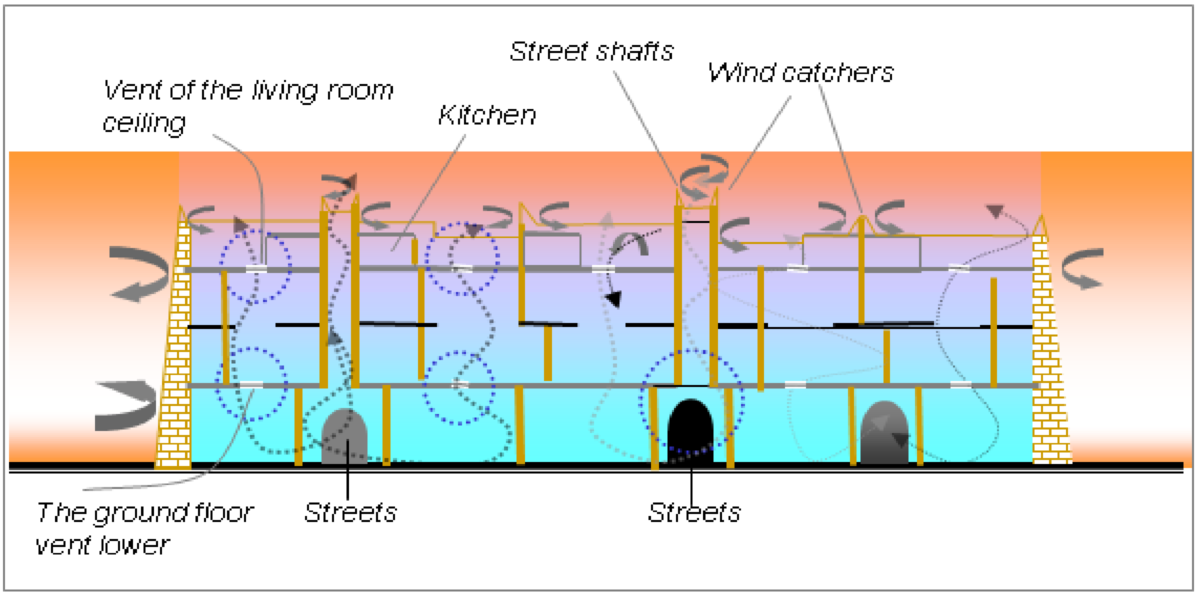


Figure 13. Section illustrates the process of air circulation, and the main elements that control the air circulation in the complex (Shateh, 2002).

Designing wind catchers at the top of the building corners, which work on reducing the wind speed and increasing the air pressure above the shafts and vents to lead it down through them and motivate the air circulation, and then to reduce the inner temperature. Figure (14) shows the air circulation process (Shateh, 2002).

ISSN: 2413-5267

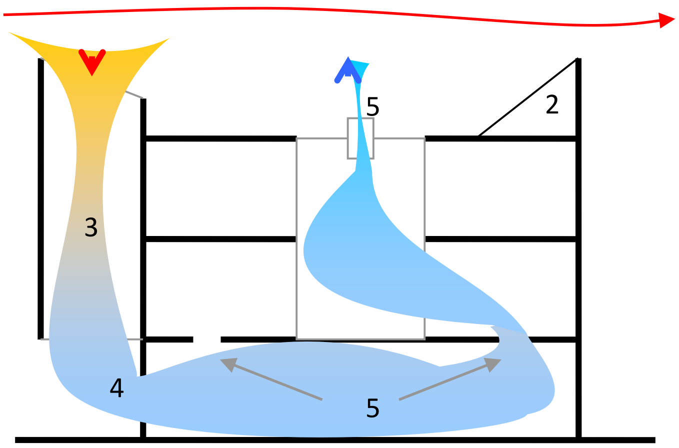


Figure 14. Sketch that shows the steps of the journey of the air movement from interring the ventilation shaft to exiting from courtyard (Shateh, 2002).

Physically, applying a single-system mechanism to ventilate the whole complex not only limits and slows down the heat penetration through the building floors and openings but also makes and keeps the thermal balance between the buildings spaces. Hence, the interior temperature becomes cold and even colder wherever we go deeper down in the covered streets. None of the residential streets remain uncovered. Still, but relatively, the temperature in each house can be regulated by its courtyard opening. According to Rapoport (1969) “hot, dry areas are characterized by high daytime temperature and uncomfortable low nighttime temperature, a fluctuation best met by delaying the entry of heat as long as possible so that it will reach the interior late, when it is needed. This is achieved by use of high heat capacity materials, such as adobe or pisé, mud, stone, and various combinations of these which provide a “heat sink” absorbing heat during the day and reradiating it during the night; by as compact a geometry as possible, which provides maximum volume with minimum surface area exposed to the outside heat: by mutual crowding, which provides shading, and reduces the exposed to the sun while increasing the mass of the whole building group, thus increasing the time lag.” There are several places where the shaded streets are linked with the open public spaces. These public spaces are covered and diffused in the city plan. This situation may help to arise the cool air as Roppoart (1969) was mentioned; “When a shady court is used in conjunction with a sunny court, in which the heated air will rise, cool air may flow from the shady into the sunny one through the rooms”. However, in Ghadames case the public open areas which exposed directly to the sun are more useful in the winter season when they cutting the long shaded streets by sunny paces. In the summer, these open spaces are not affecting the low temperature of the covered streets due to its small size.

The hot air inside interior spaces (houses and streets) goes up due to the stack effect depending on the difference in temperature and the air current which passes through the streets due to the air pressure. This current is caused by the relatively narrow vertical shafts along the height of the buildings, and also by the open-ended streets. Besides that, the big height of the ventilation shafts reduces the entering air temperature. Thus, the ventilation system of the streets works in one composition with the houses' ventilation vents to obtain a thermal balance inside the built mass in a general manner.

6. Phase Four Evaluation of the Passive Cooling Design System in Ghadames

For the purpose of this study, and due to the distance between the U.S.A, where developed this study, and Libya, in this phase I tried to depend on my personal visits to the OGC from 1993 to 2006 and other two other studies that measured temperatures of the same city. This investigation phase is not only important to indicate quantitative date, which is considering more scientific evidences, but also to observe the change of the thermal comfort ability into its built environment during eighteen years.

The first quantity study to include here, Figure (15) was taken by Ahmed Salem in 1985 (Shateh & Rabah, 2002) and represented in Table (1). These measurements are showing the big difference of the average temperature between the outside and inside the complex in which most of them falling in the thermal comfort zone of the human. On the first side, these differences explain to which extent that through the best organization of the architectural systems and the appropriate use of local materials and natural resources can create buildings spaces with thermal comfort. This measurement illustrates indirectly the time lag of the building materials as well as the continuously change of the air temperature between day and night.

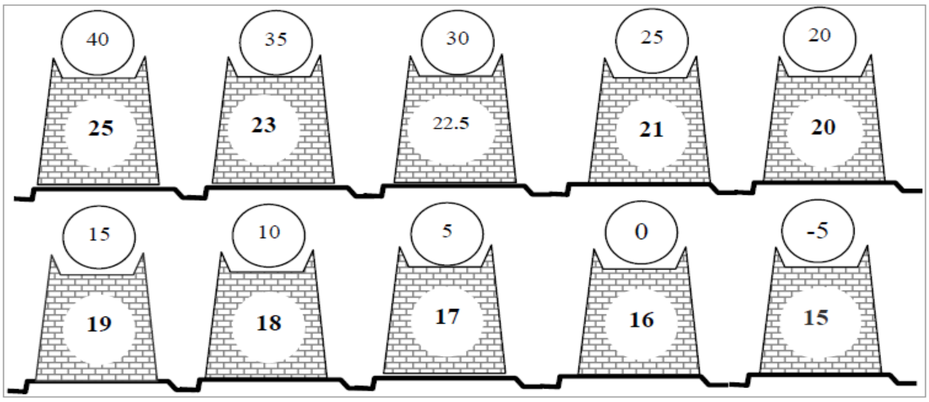


Figure 15. Shows the exterior and interior temperature degrees in Celsius (Shateh & Rabah, 2002)

Table 1. Show the temperature degrees which in Figure (15) in Fahrenheit degrees.

Outside	104	95	86	77	68	59	50	41	32	23
Inside	77	73	73	70	68	66	64	63	61	59

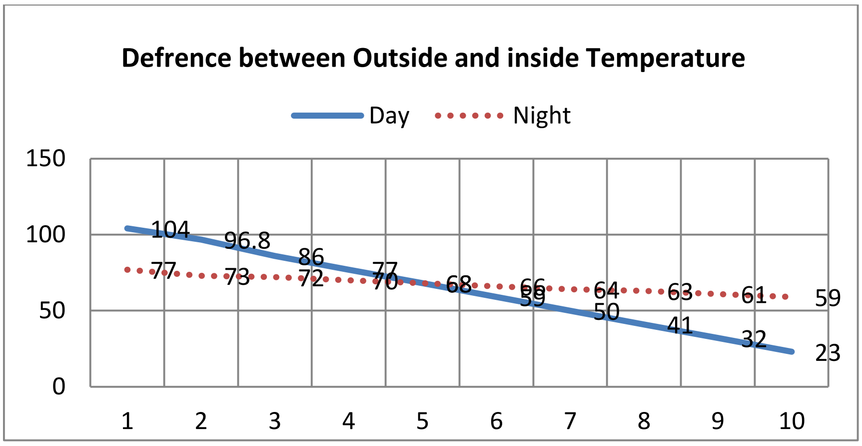


Figure 16. Chart of the liner relation between the outside and inside temperatures.

The survey study that was published by Ealiwa *et al.* (2001), which is based on the application of ISO 7730 and the physical measurements that they did for 11 traditional and contemporary house in Ghadames, one of the results that they reported was that "…the overall feeling of the occupants in OGC in the summer seasons, reported that they are more the study are more satisfied and thermally natural in old naturally ventilated buildings that in new air-conditioned buildings."(Ealiwa *et al.*, 2001). Moreover, the field study mentioned that 96% of the Ghadamesinas were satisfied with the interior environment of old buildings compared with 77% of residents of the new buildings, who relied more on air-conditioning as shown in Table (2).

Table 2. Temperature results of old and new buildings in Ghadames, 1997 (Ealiwa *et al.*, 2001)

Buildings No.– Type	t_{out}		t_a		tg		v_a	Rh (%)	t_{mr}		Activity[a]	Rcl^a (clo)	PMV	AMV
	ºC	ºF	ºC	ºF	ºC	ºF	ºC		ºC	ºF				
3 – Old	43	109	33.6	92	34	93	0.04	45.9	34.1	93.4	1.1	0.6	2.9	0
5 – Old	40	104	33.8	93	34	93	0.05	35.3	34.1	93.4	1.1	0.6	2.7	1
7 – New	36.2	97	28	82	29	84	0.20	20.0	30.0	86	1.1	0.6	0.7	0
10 – New	39.1	102	33	91	32	90	0.19	29.0	33.6	92.5	1.1	0.6	1.8	1

[a] *Values were taken from ISO 7730 standard to represent the thermal insulation and the activity. t_a, inside air temperature; tg, inside globe temperature; v_a, air velocity; Rh, relative humidity; t_{mr}, mean radiant temperature; t_{out}, outside air temperature; Rcl, thermal resistance of the clothing.*

Shawesh (1993) chooses six houses to assess the comfort climate in depth investigation and the houses his chosen were in different areas from the OGC. "The residents' responses survey

ISSN: 2413-5267

indicates that 97% of the population in the old city were satisfied with the climatic conditions in the town compared with 95% of new city population were dissatisfied with their climatic condition both indoors and outdoors- streets.". Not only are the houses built in a compact form to provide shade and protection from undesirable heat and winds, but they also have heavy and thick external and internal walls and roofs that involve a time-lag of several hours. Due to extreme heat of the desert, it is important to note that the pattern design and the ventilation system themselves could not provide thermal comfort without the coved streets. The narrow, covered, shaded, and winding of the streets are the most important properties that pattern the street to work as cooler of the air. These characteristics of the streets in the whole system of the city make the task easier for the courtyards to control the interior thermal condition. This is one of the cases, for the most part, that made mainly the thermal measurements in any house of the OGC to give satisfactory results. The microclimatic pattern in Ghadames traditional houses show in different stages in a climatic adaptation (Shawesh, 1993).

As a conclusion this comparison study reported that, design pattern, use of local materials in proper measurements, however, these aspects helps with social system pattern to create a sustainable bio-climatic in indoor and in-between spaces. When the light as well as ventilation are brought in to the streets and houses through shafts, and through limited openings between the covered streets and the interior of the house, this transition of the air movement helps heat up more slowly during the daytime. In numbers, for indoor air temperature and relative humidity, (Shawesh, 1993) reported the average of three reading taken inside –indoor- each house, and the measurements were taken at 8 am, 2 pm, and 8 pm; while the in OGC the air temperature in the *morning, afternoon, and evening* are *between* (23 and 28 ^{o}C) (74 and 82 ^{o}F), (27 and 30 ^{o}C), (81 and 85 ^{o}F), and (20 and 28 ^{o}C), (68 and 82 ^{o}F) respectively, in new city are between (23 and 30 ^{o}C), (74 and 85 ^{o}F), (33 to 39 ^{o}C), (91 to 102 ^{o}F), and (26 and 34 ^{o}C), (79 and 90 ^{o}F). The relative humidity shows slowly decrease in the old city comparing to the new city.

In the old city the relative humidity has slowly disease; from (23-29%) at morning, (17-23%) at afternoon, and (20-26%) at evening. However, it shows high decrease in the same periods of time in the new city, (20 and 25%), (10 to 18%), and (16-22%) respectively (Shawesh, 1993). This slight change is due to the use of air-conditioning in which made the closer to indoor air-temperature and relative humidity in the OGC were the natural ventilation balance the indoor temperature and relative humidity. On the other side, according to these readings, it can be inferred that the ventilation system is not only provides the proper temperature and the suited relative humidity but also provides better air quality since it cooling the air naturally and separate the cooled air equally to all spaces.

On the other hand, for outside each house the average shows sharpen differences. While in OGC, temperature is between 24 and 30 ^{o}C (75 and 86 ^{o}F), in the new city it is between 25 and 31 ^{o}C (77 and 88 ^{o}F) in the morning, in the afternoon period, in OGC is

ISSN: 2413-5267

between 33 and 38 ^oC (91 and 100 ^oF) and in new city is between 39 and 47 ^oC (102 and 117 ^oF). However, in the evening it becomes between 28 and 33 ^oC in OGC and it is between 41and 43 ^oC in the new city. The humidity also shows important different when it reduced from (22-27%) at morning to be (17 -22%) in the OGC compared to new city where it show great decline from (21-27%) in the morning and (12-16%) in the evening (Shawesh, 1993)

7. Conclusion

When this system had worked in a steady way for the last 20 years, which the time that the city was mostly empty of people, most houses are closed and the number of houses were collapsed, we expect that the ventilation system as well as the other systems had worked better before the last two decades, when its inhabitants were taking care of its systems. But still how ventilation system was working to provide high quality of indoor ventilation? Simply, looking at the ventilation system we find that it is a part of the whole systems that complained the residential complex. However, the manuscript fused on three important points:

- First, the level of indoor environmental quality and ventilation efficiency depends on the spatial connectivity and configuration between the private and public spaces, specifically within the individual house and between the houses making up the multi-housing complexes.
- Second, the compatibility between the planning and architectural design guarantees the ventilation rights of the homes at both the individual and complex levels.
- Third, as each house is a part of the ventilation system, the inherent required social cooperation serves an important role in the efficiency of the cooling and heating processes of the system.

References

Chojnacki M. (2003). Traditional and Modern Housing Architecture and Their Effect on the Built Environment in North Africa: A Comparison of Traditional and Contemporary Housing Architecture as a Method of Assessing the Microclimatic Conditions of Housing Development in the Desert Zone: (Ghadames case study), In: The *International Conference Methodology of Housing Research*, 22-24 September, Stockholm, Sweden, 1- 22.

Daza M.H. (1982). *Understanding the traditional built environment: Crisis change and the issue of human needs in the context of habitations and settlements in Libya*. Ph.D. Dissertations, Pennsylvania University, USA.

Ealiwa M.A., Taki A.H., Howarth A.T., and Seden M.R. (2001). An investigation into thermal comfort in the summer season of Ghadames, Libya. *Building and Environment*, 36(2): 231-237.

ISSN: 2413-5267

El-Agouri F.A. (2004). *Privacy and Segregation as a Basis for Analyzing and Modelling the Urban Space Composition of the Libyan Traditional City Case Study: The City Of Ghadames*. Ph.D. Thesis, Middle East Technical University, Ankara, Turkey.

Rapoport A. (1969). *House form and culture*. Englewood Cliffs. Prentice-Hall, NJ, USA.

Shateh H.A. (2002). Development & Use of Traditional Patterns For Design in Hot Aried Zones. Unpublished Thesis.

Shateh H.A., Salim A.H., and Rabah S. (2002). Interior Architecture of Desert Climate: Case Study of Gadames city - Libyan Desert. *Fundation for Science Technology and Civilsation* Available Online at: [http://www.muslimheritage.com/topics/-default.cfm?ArticleID=315].

Shawesh A. (1993). The impact of hot-dry climate on housing: a comparative study between tradition and contemporary houses, with special reference to Ghadames city, Libya. *Forum*, 2: 42-46.

Stowell W.H. (1848). History of the Puritans in England, and the Pilgrim fathers. The Puritans in England. *The Eclectic review*, Kessinger Legacy Reprints, 23:794.