Control of Daylight and Natural Ventilation in Traditional Architecture of Ghadames, Libya

Jamal Alabid[1*], Dr. Ahmad Taki[2] & Dr. Birgit Painter[3]

[1]*Leicester School of Architecture, De Montfort University, Leicester, United Kingdom*

[2]*Leicester School of Architecture, De Montfort University, Leicester, United Kingdom*

[3]*Institute of Energy and Sustainable Development, De Montfort University, Leicester, United Kingdom*

* jamalalabid@email.dmu.ac.uk

ABSTRACT

Housing energy consumption accounts for almost 36% of total primary energy use in Libya of which cooling and lighting are the main source of demand. This study reviews passive control methods employed in traditional dwellings of Ghadames that highly contribute to enhance indoor thermal and visual comfort. Designing for natural ventilation and daylighting in harsh environment poses a greater challenge to building designers. Twenty one traditional dwellings were surveyed to assess building designs and performance in terms of daylight and natural ventilation interoperability. The study conducted field surveys comprising measurements of indoor/outdoor temperatures while concurrently investigating inhabitants' thermal feeling through both direct semi-structured interviews and questionnaire. In addition, drawings were made to demonstrate the design elements and techniques used to minimize extreme outdoor temperatures and best make use of daylight. Findings indicate that skylight openings play an important role in promoting day and night ventilation. The opening's position and size have to be carefully studied to prevent excessive direct solar heat gains and induce air movement across internal spaces. The field surveys showed that occupants were thermally satisfied in naturally ventilated dwellings having considered that fixed ceiling fan is used at late afternoon when indoor temperature starts to rise gradually. Also the use of light color roofs and walls is recommended which is approved to enhance interior lighting and increase the outdoor albedo ratio. Embedding passive design measures in traditional dwellings can be very effective and cheap in reducing the cooling and lighting demand; the impact on future housing development is also discussed.

Keywords: traditional architecture, natural ventilation/lighting, passive design features.

1. INTRODUCTION

The demand in energy has seen an increase of over 26% in the last five years in Libya within the domestic sector, expected to be even higher by 2017 (GECOL, 2012). Cooling loads and lighting are the main energy consumers in buildings in hot regions particularly in summer seasons. Roaf et al. (2009) mentioned that for thousands of years traditional societies have managed to live in comfort dwellings using natural and simple means to cool or heat spaces. The window design plays a major part in controlling the ventilation and lighting of dwellings on which other interrelated aspects (solar heat gain, heat loss, privacy and security) may depend on (Wilson, 1999). Although there is sufficient detailed design guidance on daylight and natural ventilation issues in CIBSE publications and other related sources, there yet especial cases in extreme climatic conditions may require additional revision. Therefore, understanding the general climate and the micro-climate conditions in particular could help building designers offer better control of indoor built environment. The most important element connecting the indoor and outdoor world is openings in terms of thermal and visual interaction. This element plays many roles including the supply of daylight, the view to outside world, control of air exchange, noise and acts as a glare protector and climate moderator, as well as contributing to energy efficiency in buildings (Wilson, 1999). McCluney (2008) believes there are many benefits of good daylighting design in buildings, starting from enhancing the users' visual and thermal comfort to worldwide issues like global warming and dwindling of fossil fuel energy supply. In the US lighting alone accounts for 30% to 50% of all energy consumed in buildings and 20% to 40% saving in lighting and cooling can be achieved by utilizing daylight and natural ventilation system (Boubekri, 2008). A number of studies highlighted the performance of some architectural elements employed in vernacular architecture such as the Arabic *Mashrabiya* and its environmental implication on visual connection, users' privacy and natural ventilation systems (Hansen, 2008). Hansen also stated that only few studies considered integrating such passive strategies into contemporary architecture and these have the potential to synergize buildings, microclimatic conditions and interrelated human activities. Henriques, et al. (2012) focus on developing a responsive skylight system with a mechanism response to indoor and outdoor environmental conditions, synthetically imitating the natural biological system of daylight control.

2. METHODOLOGY

The study conducted field surveys evaluating the traditional dwellings' performance and control of daylight and ventilation investigating how satisfied occupants are within this naturally ventilated (NV) indoor environment. The nature of the study necessitates carrying out qualitative surveys involved semi-structured interviews of 4 professionals and 7 house owners, personal observations and meanwhile a questionnaire was distributed in 16 neighbourhoods to include 85 respondents to quantitatively evaluate the residents' opinion and preference of their thermal and visual indoor environment. In addition, 21 traditional dwellings were visited during summer 2013 and 2014 and simultaneously temperature measurements were taken inside and outside dwellings. The study also used CBE thermal comfort tool to predict the neutral comfort temperature and zones of these investigated dwellings comparing the two models with actual votes of subjects participated in the surveys. *EnergyPlus* is used for daylight analysis and architectural drawings were made to demonstrate design techniques and methods employed in traditional dwellings

3. CLIMATE

It is well known that indoor environmental conditions in buildings depend highly on outdoor climatic conditions. Thus, housing designs should consider climate analysis in a very early stage in order to make buildings responsive, healthy and friendly to the environment. Literature is rich in discussing the implications of climate on the design of homes particularly of those who study vernacular architecture such as Singh, et al. (2009). Climate has an immediate impact in forming old cities and related effects on local community traditions and way of life and the choice of adaptation methods to deal with surrounding environment (Ben-Hamouche, 2008). Libyan climate classified into three main regions; the coastal region "hot and humid", Mountain region "cold zone" and desert region "hot and dry" but also there are subsidiary regions may found within those mainstreams as stated in Bukamur (1983).

Ghadames Oasis lies in the Libyan Sahara desert "hot and arid climatic zone" characterized by high average temperatures and temperature variations, very directional solar radiation, clear sky most of the year, almost no rainfall, very low humidity and hot dusty winds occurs occasionally in summer. It is very extreme climate conditions especially the diurnal swings of temperatures in summer times where temperature may rise over 47˚C during the day and drops down to 20s˚C at night and can drops below 0^0C in winter. It is always important to know the wind shadow and sun patterns of the region throughout the year for effective passive optimization of building designs. However, in Ghadames direct exposure to sun and wind is not desirable especially in summer when scorching sun and high solar radiation rates as well as sandy and hot windstorms are the case.

4. SITE & URBAN STRUCTURE

Old settlements in a wide range of climates have been produced in different architectural styles based upon the local climatic conditions and inhabitants' way of life (Singh et al., 2009). The urban fabric of the old town of Ghadames is highly compact and dense with a clustered type of building design. It has been existed for over 400 years ago and re-erected several times as local builders gained experience over time by trial and error. The discovery of the artesian spring called Eyn El-lfaras (horse's lake) was the impetus of the town existence that built on an Oasis of an area of 310.3 hectares surrounded by massive sand-dunes and mountains according to (Ealiwa, 2000). One can notice that there are underground water-streams passing underneath the urban fabric of the town ending at green fields surrounding the town. On a city scale, the urban plan of the old town indicates a hierarchal structure from public wide scale to private family space concerning every single issue in community life. Elwefati (2007) described the urban structure of the old town as a covered connected city as majority of roofs are interconnected whilst streets and alleyways also covered in order for shade, privacy and security to be ensured.

Yet, natural ventilation and daylight are among the issues concern local builders and users which carefully were employed in accordance with interior space requirements and moreover upon inhabitants' need for protection from undesirable outdoor conditions. Littlefair et al. (2000) underlined the role of urban morphology, building geometry, street patterns and other local features like vegetation play in natural ventilation field. However, local builders have recognized such effect and adopted certain building techniques to maintain sufficient access of fresh air and daylight in dwellings throughout the year. And the only way to ensure this mechanism is to rely on skylight openings. Open courtyard was not ideal due to the sandstorms that hit the area from time to time. Therefore, there is a modified microclimate in the town differs from the regional synoptic climate brought by its urban structure as well as the massive green fields that contribute to mitigate the extreme regional climate by preventing the buildings from direct sandy winds and vegetation helps promoting thermal stability and increasing humidity rates. The urban stratification of the town and its individual dwellings shows a great coherence to the natural world surrounded formed upon social and environmental considerations making the entire city works as a one unit. Figure 1 demonstrates a curved and centralised urban structural design of the old town surrounded by over 36 thousands of palm trees and part of the new town with an open rectangular kind of western style of city urban design.

Figure 1: view of the urban settlements of old and new towns of Ghadames

5. DATA ANALYSIS

5.1 House Design

The visit to the old settlements involved drawings to capture the most common architectural design and features of different dwellings besides the investigation of indoor thermal conditions. Surveys found that traditional dwellings somehow have similarity in form, layout and interior space organization irrespective of the dwelling size. According to Ealiwa (2000) the traditional house plot area ranges from 25m² to 50m² whereas the total floor area of the house may also varies from 70m² to 80m². Figure 2 demonstrates the location of the modelled house within the compound and its space organization. As this drawings of typical traditional house show, the majority of houses consists of three storeys stratified according to social and environmental requirements.

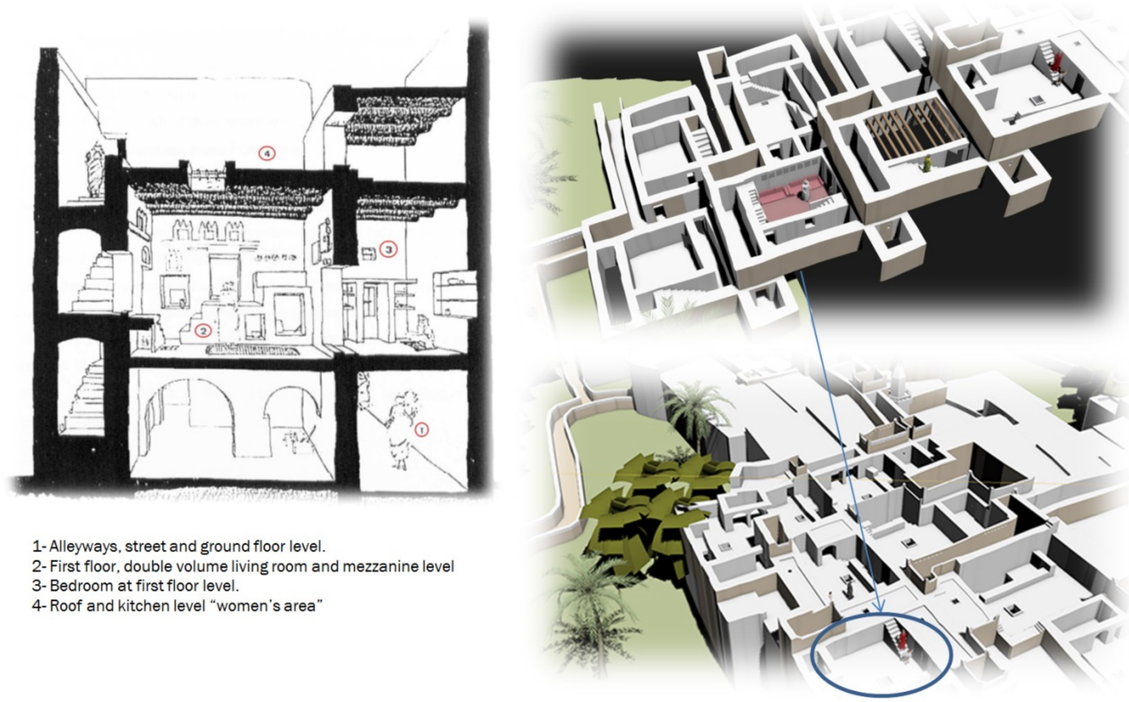


Figure 2: architectural details of typical traditional house

Socially, privacy is very important issue for local community and therefore ground floor allocated for visitors and storage purpose. The first floor is the semi-private space where family may invite someone and also part of it still considered as private area for sleeping and practicing certain cultural affairs. The third floor is only for women use where the kitchen is located and a shed used in summer time at cool nights. Thermally, ground floor found to be cooler and the higher the level the warmer it gets. The living room is built in a double volume with a height of 4.5m to 5.5m. The relatively high ceiling space enhances the air circulation and helps remove the heat gained through the roof structure during the day.

5.2 Comfort & Users' Thermal Sensation

According to a number of studies, thermal comfort requirements may vary from region to region and even between individuals. Therefore, it is important to understand the building users' thermal perception in order to determine the proper indoor conditions that natural or mechanical systems may deliver. Brager & De Dear, (2001) compared The upper limit of comfort zone in ASHRAE Std. 55 which is 26˚C that base on 0.5 cloth rate (clo) and 50% relative humidity (RH) to the new adaptive comfort standards (ACS) which is based on climatic data and 80% acceptability limit of subjects. To some extent Brager and De Dear's study agrees with a number of studies conducted in North African context including current work suggesting that adaptive approach in hot regions so often allows warmer indoor temperatures in naturally ventilated dwellings during summer, which may refer to psychological and physiological adaptation of the human body to surrounding environment. The air movement is a significant parameter in human thermal comfort and how effective may depends on other physical environmental parameters. For example, in warm humid conditions, higher indoor air speed is preferred (Tablada, et al. 2009). On the other hand, in hot dry climates lower air speed and mean radiant temperatures could enhance indoor thermal comfort as Ealiwa, (2000) and Al-Jared, (1991) concluded.

As figure 3 demonstrating the comfort temperature records for naturally ventilated buildings show that neutral comfort temperature for subjects falls within the acceptable band in adaptive model and stepped aside in Predicted Mean Vote (PMV) model. This findings may underpin the study carried out by Honnekeri, et al. (2014) that explains the case users' expectation towards particular thermal environment which sometimes overrides other psychological or physiological factors. The study found that in naturally ventilated dwellings occupants are thermally satisfied preferring to be slightly cooler despite air temperatures of 32˚C and relatively low air speed that ranges between 0.04 m/s to 0.08 m/s. In air conditioned dwellings, the majority wanted no change to the indoor thermal conditions with temperatures recorded at 21˚C to 25.5˚C and air velocity of 0.12m/s to 0.25m/s. According to the equivalent temperature reduction method (ETR) suggested by Lechner (2014) there is only necessity to increase air velocity when relative humidity is higher to maintain the same thermal sensation. This may explain the tolerance for higher air temperatures and relatively low air speed of those who live in naturally ventilated dwellings of Ghadames.

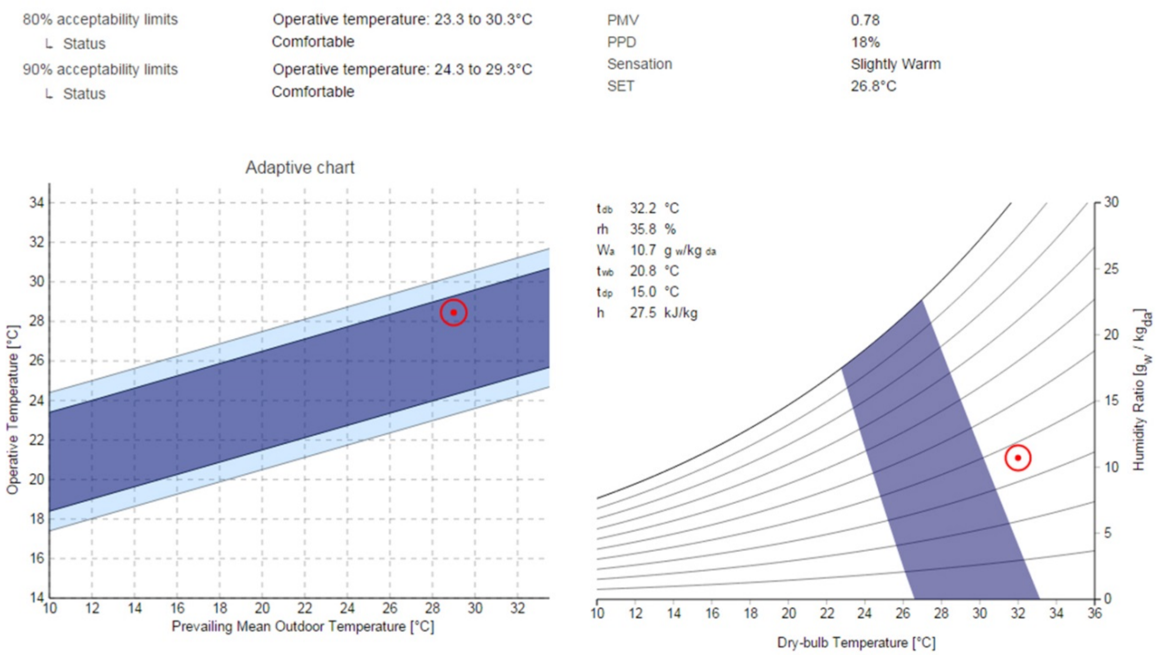


Figure 3: Thermal comfort zone in CBE tool for MPV and adaptive models

5.3 Natural Ventilation

Clancy, (2013) has stated in CIBSE knowledge series – KS17 that ventilation is very important component in human thermal comfort and highlighted certain reasons for which ventilation is mainly needed:

- providing fresh air for metabolism, dilution and removal of pollutants from space
- extracting contaminants at source (e.g. extract systems for kitchens, bathrooms, industrial processes and fume cupboards)
- satisfying combustion needs for appliances such as gas cookers, boilers and unvented heaters
- distributing conditioned air (for heating or cooling)
- space pressurization to inhibit the infiltration of pollutants from outside or from one space to another (e.g. preventing integrated circuits within cleanrooms from being contaminated by dust particles)
- pre-cooling building fabric (e.g. night venting of naturally ventilated spaces).

For naturally ventilated dwellings it may seem quite challenge for designers to ensure all is achieved particularly in extreme conditions. However, Ghadames traditional dwellings show an incredible application of natural ventilation systems in homes considering all mentioned above by Clancy. The house is so often surrounded by adjacent houses from three or four sides with light-wells interposed in between. These light-wells play an important role in ventilation especially during summer. The position of those voids designed mainly according to both the room location and privacy issue. Air speed was measured in different locations within the house and found to be higher the closer to those openings at an average of 0.12 m/s whilst lower in the middle of the living room at an average of 0.06 m/s which may explain why occupants use ceiling fan in this room at that position. Minimum exposure of external facades helps reducing the direct solar heat gain whereas the greater thermal mass structure the more the amount of heat transferred through building fabric is delayed, which means less heat extraction from the space to cool the air down as shown in figure 4.

The skylight aperture is the soul of the building structure acting as an artery for daylight and air movement daily cycle linking inhabitants with the outside natural world. During the day air enters the house through relatively small room voids approximately 15x25cm crossing all other spaces to leave the house via the 1m² roof aperture. Vice-versa at night time as outdoor temperature is getting lower, cool air begins to penetrate through the skylight opening and warm air leaves through the same opening via stack ventilation effect and more recent a fan ceiling is used to enhance the air circulation. Al-Zubaidi, (2002) and others have mentioned how roof is an important component in traditional house of Ghadames for women do home cooking and some other family traditional customs. The main reason that kitchen was placed on the roof is to extract heat and smoke away from the house and therefore there is no heat generated from home appliances and such activities inside the dwelling.

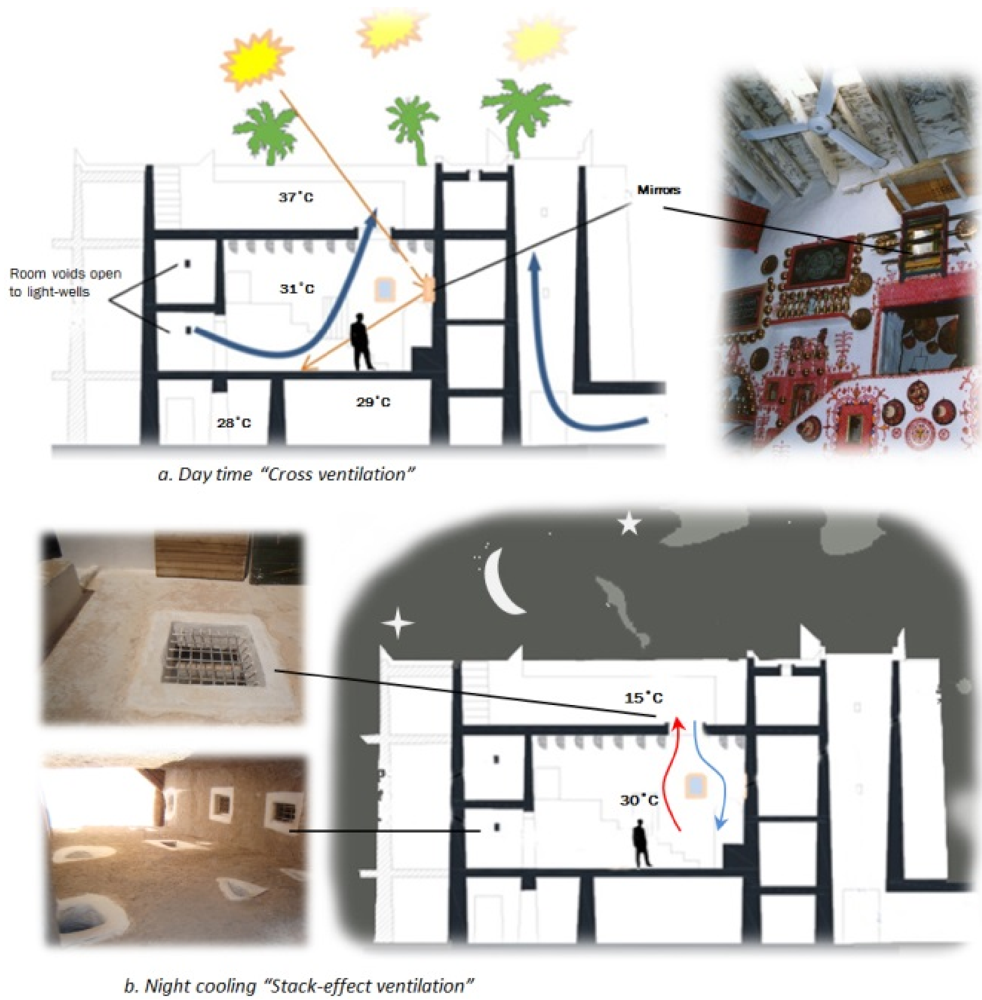


Figure 4: Natural ventilation, design and methods "traditional house"

5.4 Daylight

Boubekri, (2008) defined the daylight or sunlight as a vital component to life that plays fundamental, biological and psychological functions to humans and other creations on earth. Daylight is also known as natural light which is the amount of solar radiation stemmed from either the sun “direct sunlight” or the sky “diffused light”. Scientifically, as figure 5 demonstrates natural light is the visible wavelengths on the earth surface which ranges from 400 to 760 nm (Thomas, 2006). Obviously, considerable factors can affect the availability of natural light such as the geographical location, weather conditions and the time of the day and year, and notwithstanding the spatial design and the particular use of the space has a significant impact on the required amount of daylight.

Recent studies concerning with daylight design in residential buildings have developed possible passive solutions to provide an adequate amount of daylight to buildings in order to optimize its energy efficiency and consequently for human well-being and productivity. Carter, (2014) and some other researchers have studied the use of tubular daylight guidance system (TDGS), that was introduced in the last decade of the last century and became widely used in a wide range of buildings. The polycarbonate collectors are located at roof level to capture direct and indirect sunlight which may enhanced by additional reflective devices such as mirrors where sun conditions may not be predominant. Despite TDGS being 50% more expensive method than electric systems and compared to conventional roof lights and windows, it is still considered as passive tubular daylight system and have capacity to deliver deeper daylight into areas that cannot be covered by conventional means.

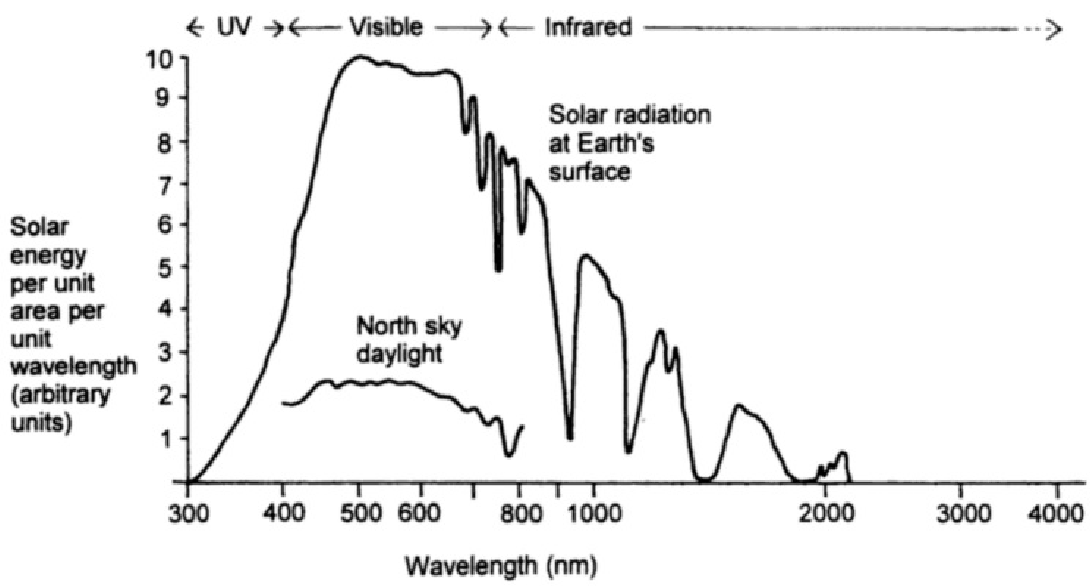
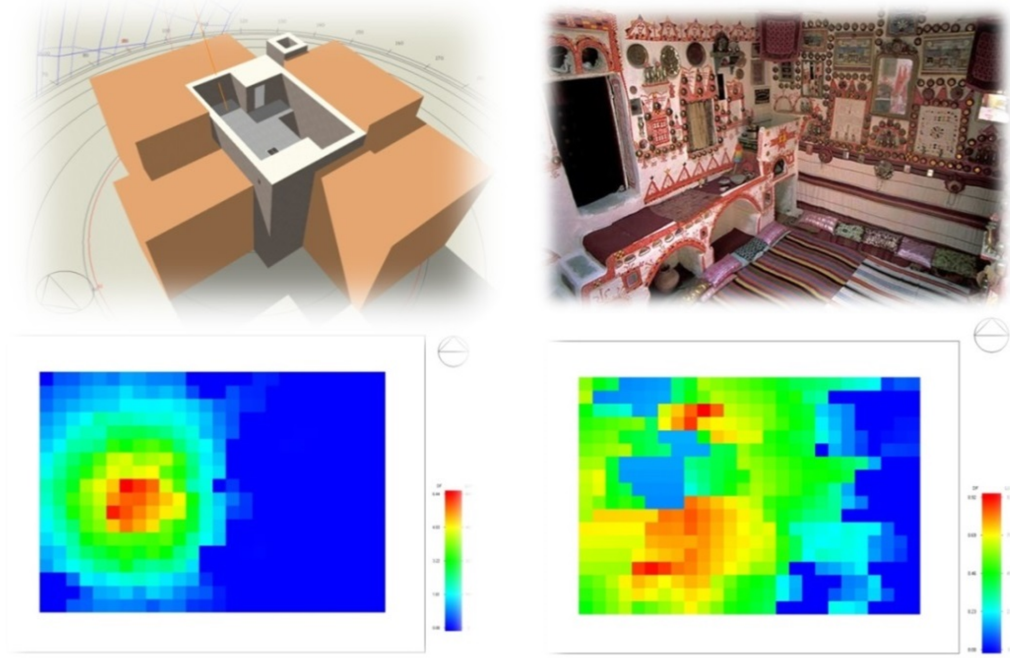


Figure 5: The visible solar radiation on earth surface ... source (Thomas, 2006)

Similarly, but over 200 years ago traditional dwellings of Ghadames employed such passive design technique installing skylight aperture at roof level to lit the interior with the use of reflective mirrors and brass motifs to deliver the daylight into deep areas. Figure 6 shows the use of these reflective devices on internal walls not only for decorative propose but rather to optimize indoor visual environment. The figure also shows dynamic simulation of daylight analysis using EnergyPlus tool to compare the average of daylight inside the living room with and without reflective surface. As may figure 4 illustrated the position and size of external openings and one can notice that roofs and internal walls are painted with white colour to intensify reflected solar radiation, as the lighter the colour and more reflective the surface the less heat will pass through the roof. Due to clear sky in desert regions and high solar radiation which creates extreme brightness that more likely to cause glare, therefore the size of external openings is minimized whilst sky diffused light is optimized to avoid overheating and discomfort occurrence. Sealed and porous plank shutters have been used to cover roof aperture according to weather conditions and another shutter type to prevent from insects invading buildings during some seasons.



a. Without reflective materials b. With reflective materials

Figure 6: Daylight analysis in living room of traditional house

The sunlight's motion incorporated through the design of the old town's streets and alleyways. The repetition of shaded and sun-lit zones resembles a natural phenomenon of day followed by night, which is experienced in sequence as one walks through these alleyways during the day as shown in figure 7. These streets and walk paths were designed for minimum exposure and daylight requirements, inhibit the amount of direct sunlight and diffused reflections. Thus, during the hottest summer days while outdoor air temperature was around 44˚C it was recorded in these shaded paths at 28˚C to 31˚C.

Figure 7: Design methods and distribution of daylight in alleyways

5.5 Ground Water Cooling Strategy

In fact, not only minimum exposure to outdoor environment contributes to alleviate the extreme outdoor conditions but also water systems passing underneath the town alongside those alleyways have a great impact on indoor microclimate. These canals designed to work in gravity fed system starting from the water source "Eyn El-lfaras" passing the town urban structure to end up at fields surrounding the town. The water contributes to humidify the indoor air and brings cool breeze into pedestrian paths and light-wells attached. Figure 8 demonstrates the process of using the water from the domestic use point to the green fields.

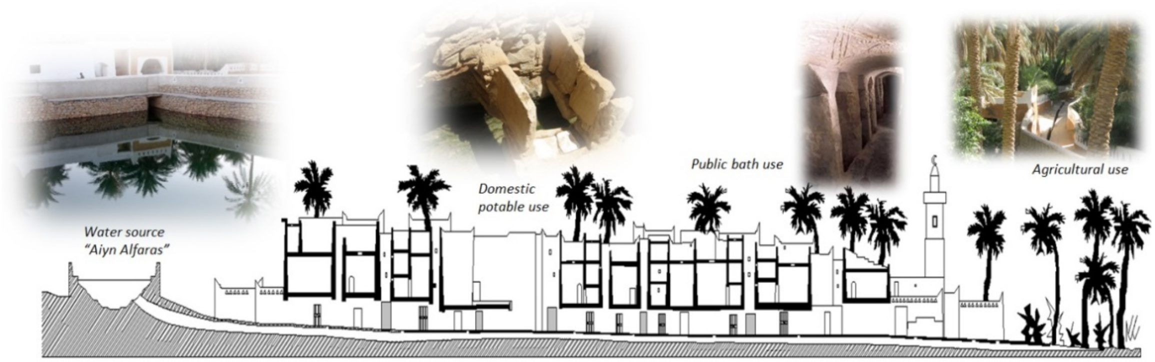


Figure 8: Gravity fed water system and distribution in old town

However, the water flow promotes air circulations and introduces air currents into the indoor atmosphere that can clearly be noticed at the junctions of alleyways and those opened voids to the water streams. The air enters the alleyways through the wider main streets may have been passed over the canals and subsequently cooling it via latent heat exchange and humidity in the air may increase though.

6. CONCLUSION & RECOMMENDATION

Good design of daylight and natural ventilation could result in considerable avoidance of energy consumption in buildings. The benefits of that are not only saving energy operating costs rather than achieving the desirable natural environment in buildings. And to do that building designers should have an understanding of the design methods and techniques found in vernacular architecture that harness the climatic conditions to work to its advantages. The purpose of this work is to shed light on various techniques used in indigenous settlements of Ghadames to naturally control the indoor thermal and visual environment. Obviously, uncountable benefits can be achieved by incorporating various passive design techniques and bioclimatic features into future developments which some may underline here:

- Considering a compact type of settlements in such climate conditions that provide less exposed external surfaces which mean more shadings and less solar heat gain rate.
- Ensuring high thermal mass structure in order to stretch the time lag reducing the heat transfer rate per unit of the surface into internal spaces.
- Paying more attention to external openings and promote the concept of roof and skylights rather than vertical windows to;
    - Promote stack ventilation
    - Minimize direct solar and heat gain through openings
    - Achieve appropriate daylight distribution
    - Prevent from undesirable hot sandy winds during summer
    - Respect cultural norms and preserve local identity
- Applying mutual shadings from adjacent buildings helps reducing solar heat gains.

- As the visible solar radiation is high in the region so that size of openings on external facades can minimized to avoid issues such glare and discomfort.
- Narrow shaded streets and pedestrian paths will act as cooling ducts that vents away hot dusty air which may contribute to enhance the heat loss via winds to the outside environment.
- Light-wells behave as environmental modifier for heat exchange and provision of natural light and adapting such concept in future housing development can solve number issues like heat islands and reduce energy costs for lighting and ventilation.
- Covered public routes and squares ease residents' movement during the day at which car parking locations may be connected to in future developments.
- Having live plants within the dwelling and an enclosure of green belt around settlements helps stabilizing the outdoor microclimate for instance absorbing CO_2, provide more shades and filters out hot dusty air which in turn have an impact on indoor environment.
- Creating wet surface within the building or surroundings cools the air via latent heat extraction that may passes over intermittently-wetted surface and also increasing its humidity rate.
- Introducing double volume space e.g. living room or covered indoor courtyard with roof openings promotes the night ventilation system by trapping cooler air at night and stratifies air presence during the day.
- Reflective external surface by painting it white could help increase albedo rate and reduce the heat gain and transfer through the building structure into interior spaces.

7. REFERENCES

Al-Zubaidi, M. S. (2002). The Efiiciency of Thermal Performance of the Desert Buidings–The Traditional House of Ghadames/Libya. In *Annual Conference of the Canadian Society for Civil Engineering* (pp. 1–8). Montreal: Quebec, Canada.

Ben-Hamouche, M. (2008). Climate, Cities And Sustainability In The Arabian Region: Compactness As A New Paradigm In Urban Design And Planning. *Arch. Net-IJAR: International Journal of Architectural Research*, *2*(2), 196–208. R

Boubekri, M. (2008). *Daylighting, Architecture and Health*. *Construction Research and Innovation* (First edit., Vol. 1). Oxford, UK: Elsevier Ltd.

Brager, G. S., & De Dear, R. (2001). A new adaptive comfort standard for ASHRAE Standard 55. In *Moving Thermal comfort Standards into the 21st Century* (pp. 1–18). Windsor, UK: Centre for the Built Environment UC Berkeley.

Bukamur, S. M. (1983). *Design Guidelines for Housing in Libya Based on Climatic and Social Criteria*. *University Microfilms International*. University of Arizona.

Carter, D. (2014). LRT Digest 2 Tubular daylight guidance systems. *Lighting Research & Technology*, *46*(4), 369–387.

Clancy, E. (2013). *Indoor air quality and ventilation*. London - UK: CIBSE Knowledge Series: KS17.

Ealiwa, A. (2000). *Designing for Thermal Comfort in Naturally Ventilated and Air Conditioned Buildings in Summer Season of Ghadames, Libya*. De Montfort University, Leicester.

Elwefati, N. A. (2007). *Bio-Climate Architecture in Libya: Case Studies from Three Climatic Regions*. Middle East Technical University.

GECOL, *(2012) General Electricity Company of Libya*, Annual report 2012. *Tripoli - Liby. www.GECOL.ly-pdf.*

Hansen, M. (2008). Performance-Oriented Design Precursors and Potentials. *Architectural Journal*, *2*(78), 48–53.

Henriques, G. C., Duarte, J. P., & Leal, V. (2012). Strategies to control daylight in a responsive skylight system. *Automation in Construction*, *28*, 91–105. doi:10.1016/j.autcon.2012.06.002

Honnekeri, A., Brager, G., Dhaka, S., & Mathur, J. (2014). Comfort and adaptation in mixed-mode buildings in a hot-dry climate. In *Counting The Cost of Comfort in a Changing World* (pp. 446–460).

Windsor, UK: NCEUB.

Littlefair, P. J., Santamouris, M., Alvarez, S., Dupagne, A., Hall, D., Teller, J., … Papanikolaou, N. (2000). *Environmantal Site Layout Planning : Solar acess, miroclimate and passive cooling in urban areas*. London - UK.

McCluney, W. R. (2008). Daylighting. *Encyclopedia of Energy Engineering and Technology*, (March 2014), 37–41. doi:10.1081/E-EEE-120041702

Roaf, S., Crichton, D., & Nicol, F. (2009). *Adapting Buildings and Cities for Climate Change - A 21st Century Survival Guide Second Edition*.

Singh, M. K., Mahapatra, S., & Atreya, S. K. (2009). Bioclimatism and vernacular architecture of north-east India. *Building and Environment*, *44*(5), 878–888. doi:10.1016/j.buildenv.2008.06.008

Tablada, A., De Troyer, F., Blocken, B., Carmeliet, J., & Verschure, H. (2009). On natural ventilation and thermal comfort in compact urban environments – the Old Havana case. *Building and Environment*, *44*(9), 1943–1958. doi:10.1016/j.buildenv.2009.01.008

Thomas, R. (Ed.). (2006). *Environmental design: an introduction for architects and engineers*. Taylor & Francis.

Wilson, J. (1999). *Daylighting and window design*. *CIBSE* (Vol. 1). London, UK.