An interface of night ventilation and mass structure for passive cooling design strategy in Ghadames traditional dwellings

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ABSTRACT
The effectiveness of night ventilation strategy for residential buildings in the old town of Ghadames has been investigated in this study. Methods of field surveys including observations, temperature measurements and interviews were conducted to determine the characteristic building parameters and strategies including window patterns and space organisation that mostly contributed to achieve an efficient indoor comfort conditions especially at night summer time. Results showed that skylight openings can be a good window pattern for enhancing night ventilation in hot arid climate. Further findings indicated that majority of occupants tend to feel thermally satisfied with indoor air conditions particularly during daytime Due to high thermal mass structure in traditional dwellings indoor air gets warmer at night and small roof aperture would be not sufficient to readily extract warm air, so that a fixed roof fan is used to enhance air buoyancy. It is also observed that double ceiling height in the central hall plays an important role in balancing air change during day and night keeping interior at acceptable thermal conditions. The lower surface temperature due to standing wall to wall with surrounding buildings apparently has an impact on indoor thermal comfort conditions. However, the study suggested that new courtyard design in residential buildings should be considered taking into account all these passive design strategies in such a way to promote indoor climate conditions. Finally, and based on field surveys and measurements a preliminary design priorities and recommendations for passively ventilated dwellings in hot arid context are suggested.

Keywords: Traditional dwellings, night purge ventilation, thermal mass and hot climate.

BACKGROUND
All vernacular dwellings have perfect building physics especially under extreme weather conditions (Nguyen et al., 2011). It can be so often difficult to maintain thermally comfortable conditions relying on thoroughly passive design strategies. Although it does not contradict the fact that vernacular housing generally does well adapt to local climatic conditions, meanwhile uses low energy design principles to achieve acceptable indoor thermal and health conditions. In hot regions cooling loads can be efficiently improved applying mass structure especially if combined with night ventilation strategy (Ben Cheikh & Bouchair 2004). Stack ventilation occurs in presence of greater pressure differences as the fact that warm air is more buoyant than cool air due to the less density causing air thermal buoyancy (Kleiven, 2003). This type of stack pressure would be applicable for single-sided openings or in the case of placing higher windows. However, IEE (2013) pointed out that placing roof vents along sides would enhance ventilation and relieve any problems of single-sided ventilation whilst a reverse air flow potentially will occur when outside temperature is lower than inside. Not only inside and outside thermal discrepancy and air density affect natural ventilation driven by stack effect but also wind velocity and direction is of importance (Gładyszewska-Fiedoruk & Gajewski 2012). This study investigates the advantage of

having sky-windows in enhancing natural ventilation at night through stack effect and different thermal pressure.

THE METHODOLOGY OF THE RESEARCH

This study has employed methods of field surveys to investigate the efficiency of applying passive cooling techniques in vernacular architecture of Ghadames. Observation of dwellers' behaviour and indoor climate conditions was the first method to carry out this work coupled with temperature measurements and assessment of residents' thermal satisfaction in naturally ventilated houses. The research also documented the work through drawings, sketches and photos to help understanding the way these houses were built to achieve acceptable indoor environment in such hot climate.

GHADAMES LOCATION AND CLIMATE

Ghadames is a town located in the Sahara Desert built over 400 years ago on an Oasis that lies approximately 630 km to the south-west of Tripoli close to the junction between Libya, Tunisia and Algeria with an altitude of 340 to 370m above sea-level (Chojnacki, 2003). Ghadames falls in the most extreme zones within the Libyan climates as located in the Sahara Desert region with almost eight months of hot and dry period and four moderate and partly cold winter period as can be seen in Figure 1.

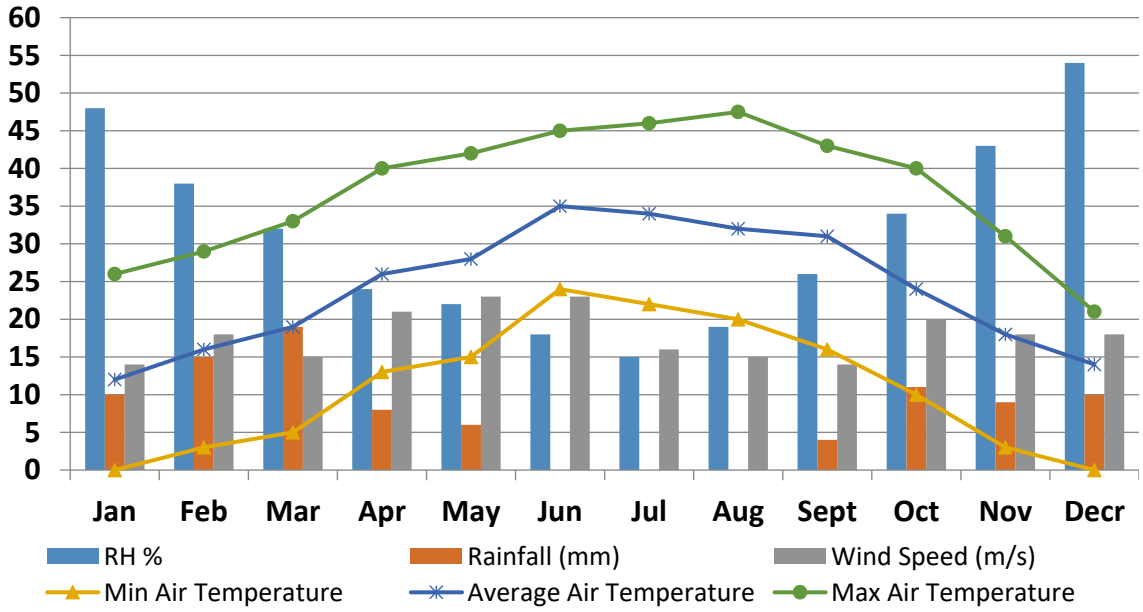


Figure 1.Ghadames climate conditions of the year 2013

THE URBAN STRUCTURE OF THE OLD TOWN

The Oasis is inhabited thousands of years ago as excavation found in the area goes back to 4,000 years but existing buildings are dated back no more than 400 years and majority within 200 years' time. It can be noted that climate simply is the main deriving and dominant force in the solutions used to build old settlements in this Oasis. The building form is highly compact and tightly interwoven built up on an inclined land centralized to the southwest of the Oasis forming a large complex of townhouses.

THE TRADITIONAL HOUSE (FORM AND LAYOUT)

The form of the house combines high degree of compactness with minimum exposure to outdoor and relatively small plot area ranges from 25 to 50 m^2. The space organisation of rooms varies according to the privacy level and functionality though. It therefore constructed in three storey design to accommodate fully-sheltered ground floor consists of usually main entrance with stairs, guest room, storage and cesspit room. The first floor is a semi-private family area centralised by living-room which is surrounded by number of rooms. The central hall is constructed in double-volume height with steps leading to mezzanine level which also consists of other private

bedrooms. Stairs lead up to the roof level where kitchen is found as well as summer shed space used so often at summer nights.

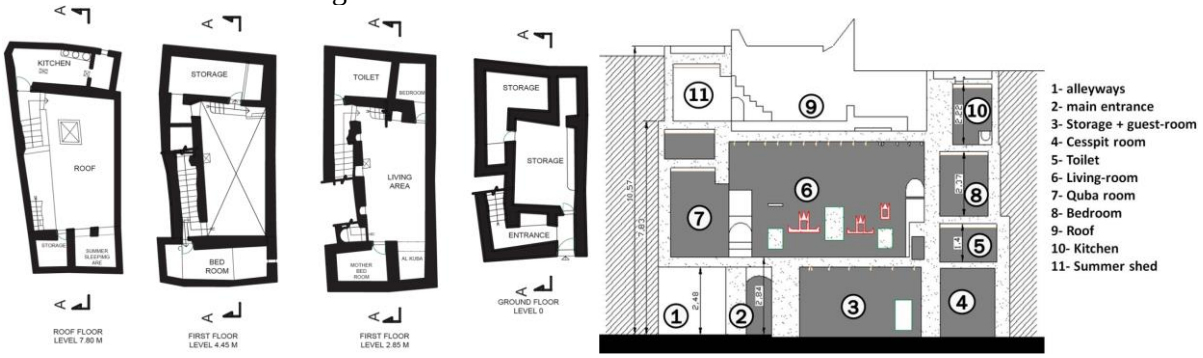
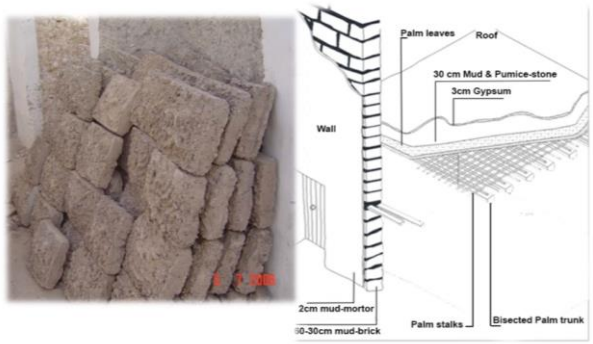


Figure 2. Typical traditional Ghadamesian house
Source © (Gabril 2014, p.49)

DONSTRUCTION MATERIALS

Building material is one of the key aspects characterises the desert architecture which so often called adobe architecture in some literature. The selection of specific material and method of construction was not a choice of people rather influenced by many factors predominantly the ecological land cover especially the abiotic elements such as soil, climate and other geological conditions. Equally importantly, the economic structure of society and inherited experience and knowledge of construction methods and techniques have an impact on the way local dwellings were built. In the case of Ghadames old town it is barely distinguishing individual buildings because of houses stand wall to wall having same constructional materials, façade finishing and similar heights. Al-Zubaidi (2002) stated that rocks and mud are the most common building materials in the old town of Ghadames due to the nature of the desert land.

However, traditional houses constructed not only with sun-dried mud and stone which is mainly used in the bearing walls but also gypsum, limestone and wood are commonly used particularly in roof construction and finishing as Figure 3 shows. The roof is given more attention and care as constructed with many layers to ensure it stands heavy loads and be thermally insulated. In general, all envelope components of the house are heavy in mass and thick walls and roofs which by experience proved to maintain good indoor thermal conditions. Rocks are used in foundations and on ground floor for only the first 1.5m height.



Material	Thick-(mm)	Conductivity (w/m.k)	Resistance(m^2k/w)
Mud-Brick	500	0.17	2.941
Clay-Mortar	20	0.29	2.33

Figure 3. Construction materials in traditional house of Ghadames

The external surface reflectance is a significant issue in hot climates and hence light colours (often white) with increasingly brighter tonalities helps to reflect solar light falling incidentally from the sky. Brighter colours not only reflect light but also absorb less solar heat so it contributes to increase daylight whilst reduces heat gains through building fabric (Ealiwa, 2000 and Elaiab, 2014). Cheng et al. (2005) found that an increase in indoor temperatures about two degrees higher

than outdoor temperature when black test cell was used whereas it was three degrees below in the case of using white test cell. This result and others convey the message that local architecture in hot regions used white finishing materials for the same reason. However, studies showed that envelope optimisation in design could save energy up to 47% at peak cooling demands and around 35% of total energy use (Sadineni et al., 2011).

COMBING THERMAL MASS STRATEGY WITH NIGHT VENTILATION

Heavyweight structure has the ability to soak up a great amount of heat and store it for up to 12 hours with only small increase in internal surface temperature and hence it helps to maintain surface temperature below the ambient air temperature for most of the hot day time (Andjelkovic et al., 2012). The effectiveness of applying thermal mass especially in extreme conditions such as in cold and hot climates has been acknowledged by many research group suggesting to integrated with night purge strategy (Shaviv et al., 2001) and (Krüger et al., 2010). It is also found that the greater the daily and seasonal temperature variations in the region the more effective the thermal mass to reduce cooling loads (Yang and Li, 2008). This aspect is discussed in more details in chapter (2) for further information.

However, traditional wall in old settlements of Ghadames is made out of sun-dried mud bricks with thickness of up to 750mm and in most cases not exposed to sun. Although the roof is the most exposed component in the house envelope but it is also well-insulated with approximately 400mm thickness of five layers. On 03rd of October 2014 temperature measurements were recorded in traditional and modern houses of Ghadames during the day and at night for five days to assess the thermal fabric performance of both dwellings.

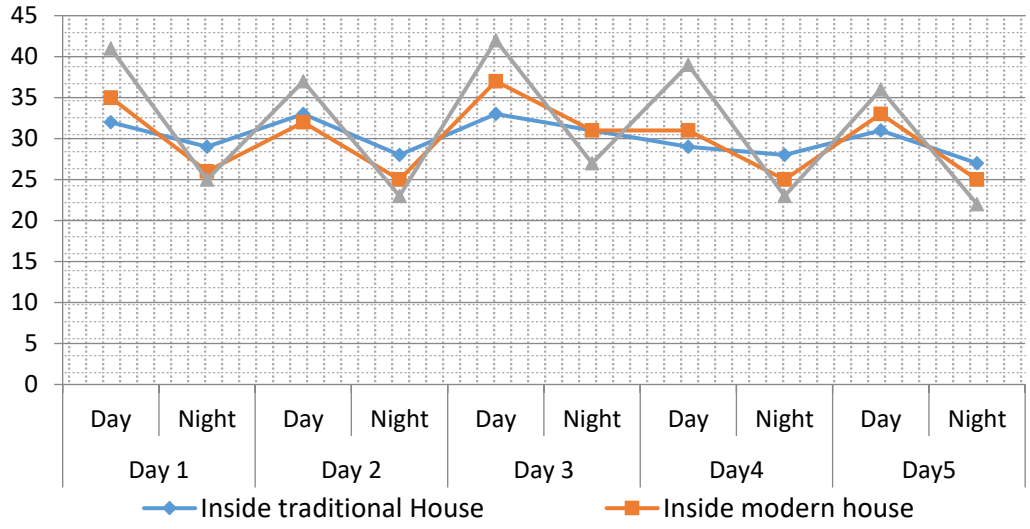


Figure 4. Thermal mass effect on indoor thermal conditions
Source © (Author, 2014)

indicates that the house fabric of old settlements shows more stability in indoor thermal conditions than modern houses despite the fact that temperature variation in October is inconsiderable at daily cycle. Both traditional and modern houses were unoccupied during temperature records and windows were opened day and night in both dwellings including the roof aperture in traditional house. From **Error! Reference source not found.** one can also notice that the temperature trend for both dwellings almost following outdoor air temperature and being within its amplitude throughout. In fact, a previous study by Chojnacki (2003) showed better results indicating that traditional house of Ghadames provided almost a constant indoor air temperature about 28˚C in summer throughout the monitored weeks.

By the current study it is found that there is slight difference between outside air temperature in old and new towns of Ghadames which may refer to the difference in microclimate surrounding the two areas. Summer nights in Sahara Desert is well-known as winter of the

summer where temperature sometimes drops down to less than 10˚C. It therefore very important to strip away indoor warm air stored in by the fabric during the day.

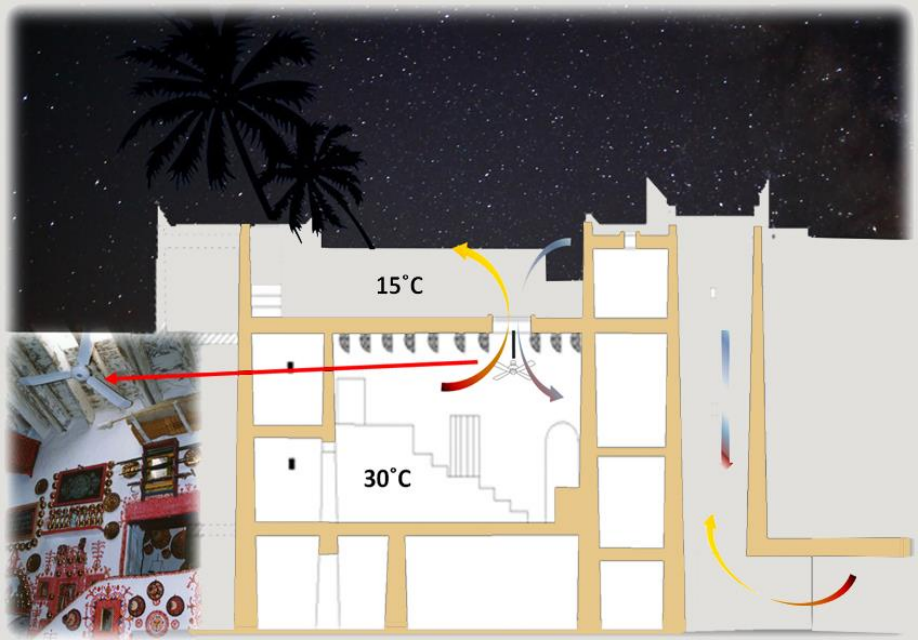


Figure 5. Night time ventilation in traditional house of Ghadames
Source © Author

Figure 5 demonstrates the night purge ventilation and the use of fan to enhance the air circulation. At night when the indoor air gets warmer it becomes lighter in density as less molecules in the air contents and the opposite is true for cold air making it weighs more so it sinks from lower temperature through the roof aperture into the house driving the warm air up with the assistance of the fixed fan.

INDOOR THERMAL ENVIRONMENT AND OCCUPANTS' PERCEPTION

During the visit to the three case studies in the old town interviews were conducted with a number of professionals and meanwhile temperature was recorded and participants' thermal sensation also was assessed. The temperature measurements shown in Table 1 were all taken at the same day (27/09/2014) with different times inside the central hall (living room) during the interviews for every 15 minutes for almost an hour each. All records are an average of five interviews. The table indicated that inhabitants in old town settlements feel happy with such indoor physical environment. It may also confirm the validity of the adaptive model (AMV) for naturally ventilated dwellings. Meanwhile, predicted mean vote (PMV) model shown overestimation values

Table 1. Indoor temperature measurements inside traditional houses

Location	(˚C) T air	T surface (˚C)	air velocity	RH (%)	Activity [a] (Met)	[a] (clo)	AMV	PMV
Living room	32.2	31.7	0.04	40	1.0	0.55	0.71	2.12
Basement	29.2	28.1	0.02	58	1.2	0.55	0.42	1.30
alleyway	30.7	28.3	0.5	49	1.45	0.55	0.285	1.51
Upper-roof	38.6	39.1	0.65	26	1.4	0.55	2.30	4.13

The householders were asked to make a preference according to the scale given in Figure 6. The Figure revealed that 43% wanted no change, whereas 45% prefer to be cooler. However, despite the fact that none of the respondents were using AC there was some preferred to be warmer which indicates that comfort temperature is highly subjective.

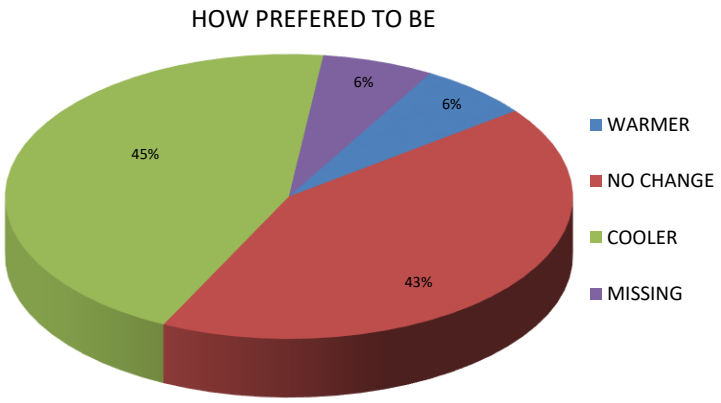


Figure 6. Householders preference of thermal change

CONCLUSION

This study has investigated the impact of applying night ventilation strategy coupled with thermal mass construction on indoor thermal performance of traditional dwellings of Ghadames. Observing daily cycles of climate conditions and building users' behaviour was a powerful research technique to analyse and understand how our buildings behave and be conditioned with less energy demand. Thermal mass structure in the traditional architecture of Ghadames has great impact on passively cooling indoor environment. In addition, the house structure kept cool during the day due to minimum exposure to solar radiation where internal surface temperature so often less than ambient temperature. Heat stored during the day through mainly roof construction is controlled by a number of ways such as creating double ceiling height, thick roof structure with a number of layers and also placement of skylight aperture that helps warm air to be extracted at night via stack effect. It is also observed that occupants uses fixed fan installed beneath the skylight in order to fasten the extraction process of warm air at night time. It can be concluded that simple passive design strategies like all mentioned in this paper successfully controlled thermal indoor conditions in traditional houses which can bring a number of benefits to our today's housing including cutting down energy bills. Finally, this study showed that thermal comfort zone can vary depends on outdoor conditions and personal perception and may be AMV comfort model works better for naturally ventilated buildings. This study suggests that roof openings can replace wall windows especially when solar shadings are provided and thick walls should be considered in hot climate architecture. It can be said that site conditions and microclimate of traditional settlements highly contributed to mitigate extreme outdoor conditions.

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