Renewable Energy Optimisation for Vernacular Settlements

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Abstract

Vernacular architecture is the outcome of accumulative efforts to sustain energy-efficient building traditions, using scarce resources in a strictly sustainable manner. Desert vernacular is not only an example of climatic building performance. It is a model for cost-efficient traditional building practice, intelligence in coping with material availability and for respecting local cultural traditions. This study analyses the energy performance of desert vernacular building and discusses several vernacular building traditions and construction techniques ending in a vernacular building form that is carbon neutral. The analysis also shows that vernacular retrofitting with renewable sources can be one way of preserving vernacular heritage from demolition for the sake of new modern facilities. Existing vernacular buildings still possess climatic solutions that can help move the energy performance of buildings towards a contemporary energy-efficient vernacular building model. The building performance of vernacular buildings can even out-perform the current agreed definitions for zero carbon buildings (ZCBs) when retrofitted with renewable energy sources for building operations.

1. Introduction

In recent years, in the face of the risk of global warming and climate change, reduction in energy consumption along with sustainable design and development have become a priority for many countries (Crawford, 2011). There has been a dependency on energy-consuming technology during the last decade in the form of heating, cooling, ventilation and lighting systems to achieve human comfort in buildings (Hootman, 2013). It is argued that the emerging world's energy and environmental crisis demands a substantial revolt in building design strategies, technologies and construction methods (Wines and Jodidio, 2000). As green building practices become more commonplace in the global building construction industry (Hootman, 2013), the goal of designing zero energy buildings (ZEBs) and zero carbon buildings (ZCBs), or buildings with zero energy consumption and zero carbon emissions annually, has emerged as the future cutting edge of building technology (Allan, 2013; Herring, 2012). Zero-energy designs are becoming more sensible to implement because of the rapid increase of non-renewable fuel prices and their harmful effect on the earth's ecological balance and climate (Heinberg and Lerch (red.), 2010). Many countries in the Middle East and North Africa (MENA) are in an energy crisis (Visser et al., 2013); so reducing energy use, especially during building operations, is becoming an increasingly important issue. Despite this fact, there is still a tendency to disregard energy-saving principles.

The majority of our contemporary buildings in Egypt depend on fossil fuel energy sources over the entire life of the building, due to a reliance on mechanical means to control the indoor comfort. We cannot reject what modern technology provides to ensure a better building climate, especially since we are experiencing a mounting increase in comfort standards. Ver-

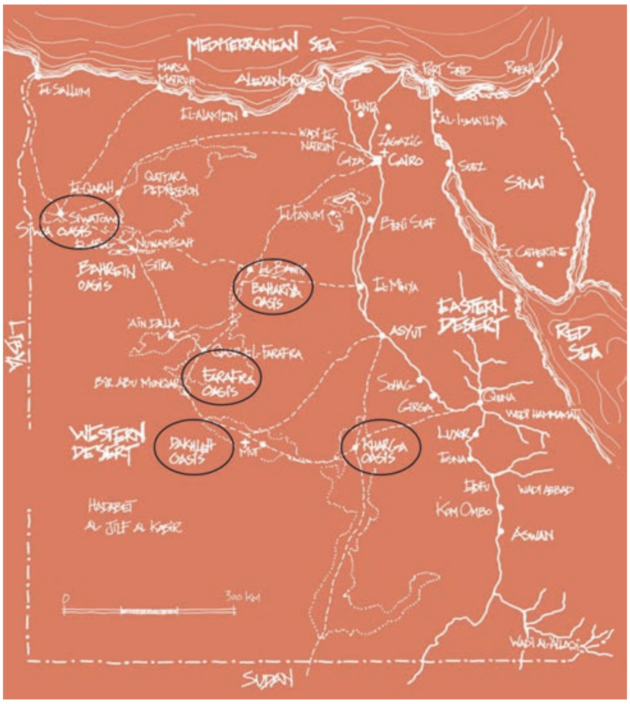

Fig. 1 Edited map showing the location of the five desert oases used as case locations for the purpose of this study

Fig. 2 An overview of earthen building typologies in the Western Desert

nacular architecture in Egypt succeeded in providing energy-efficient solutions by natural means for many hundreds of years (Fathy, 1986). Our understanding of vernacular architectural features to compensate for the current challenges and adverse climatic conditions is now being ignored and is thus in danger of being forgotten, as it is neither being employed nor developed (Dabaieh, 2013a). This has instigated the present study, which looks at a specific type of vernacular building, desert vernacular. It reviews how energy efficiency and thermal comfort were achieved in desert vernacular architecture of the Western Desert of Egypt. It examines how locals have adapted their dwellings to meet their need for comfort and respond to the given climate conditions, merging these elements into a minimalist energy-efficient architectural application. In addition, the study shows how the possibility of retrofitting vernacular buildings with renewable energy can help vernacular structures meet ZCB standards. Retrofitting could also help reduce the rate of abandonment and demolition of existing vernacular heritage buildings which are currently being replaced with ill-adapted industrial buildings.

1.1 Desert vernacular, a sustainable building practice

Desert vernacular architecture is known and recognised for its practical, effective, sustainable, and responsive building outcomes (Supic, 1982; Vefik Alp, 1991). In the past, locals had to depend on a number of creative indigenous techniques to optimise people's comfort in buildings' interior spaces for their desert climate (Vefik Alp, 1991). Desert vernacular architecture and construction designs are based on accumulative experience in responding to human needs within harsh climatic conditions (Al-Hinai et al., 1993). Over the years, desert vernacular architecture in Egypt passed through processes of trial, error, reflection and new trials that took climate, physical landscape and cultural practices into consideration (Fathy, 1986). Through these processes optimal solutions for a sustainable built environment were developed that achieved the lowest levels of energy consumption possible (Fathy, 1986). Dwellers in desert oasis communities could appear to outsiders to have no vision for their life in the future. It might seem that they only consider it important to respond to tradition or to their basic needs and their desire for self-sufficiency. Desert dwellers do in fact often respond to their current needs in traditional ways. However, they are also conscious about the future as they develop logical solutions, especially in regard to their comfort inside their dwellings (Dabaieh and Eybye, 2016).

Inhabitants designing and constructing desert vernacular buildings have for a long time tended to adapt their dwellings to the tough and harsh desert climate conditions. The sustainability of desert vernacular is mainly about managing the balance between preservation and use (Dabaieh, 2015). Desert vernacular dwellers show multiple layers of wisdom in their minimal use of limited local materials, reduced waste of such resources, and an ability to be inspired by forms from nature (Dabaieh, 2013b). In addition, from an economic point of view, such local building materials are almost cost-free, as locals use wood trees and palm trees growing on their farmlands, and cast mud bricks for which earth from their surroundings is used. People build their own dwellings, so there are almost no labour costs involved (Dabaieh, 2011; Schijns et al., 2008). Generally, almost no waste products are produced from the building construction process. Due to the shortage of natural resources and raw materials in the desert, inhabitants tend to appreciate opportunities to develop creative ideas and solutions that maximise the use of the scarce available resources. They tend to use any by-products of building materials in their daily activities (Dabaieh and Eybye, 2016).

1.2 Carbon neutrality in vernacular practice

A net zero carbon or carbon-neutral building is a building that causes no increase in CO_2 emissions (La Roche, 2012). There are considerable carbon emissions involved in the extraction, manufacturing, and transportation of building materials, as well as in the physical construction of the building (Allan, 2013). Considerable amounts of carbon are also emitted during the operation of buildings itself. On the other hand, carbon-neutral buildings operate without fossil fuel GHG emitting energy (Allan, 2013). Building operations include heating, cooling and lighting. Vernacular buildings also used to perform without the use of fossil fuels. Without using electricity, vernacular buildings can be categorised as dark green buildings, meaning that they are self-sufficient buildings in terms of energy, if calculated over an annual cycle, as they are constructed without any harmful substances and there is no harmful waste going to a landfill after demolition. The strategies executed since ancient times to ensure comfortable living spaces in vernacular buildings were simple, affordable, and not fuel-dependant (Chiras, 2002).

Energy saving design strategies and applications in desert vernacular buildings are mainly dependant on passive cooling and heating techniques, together with non-energy-consuming strategies for ventilation and lighting (Fathy, 1986). These strategies consequently create numerous varieties of solutions for applying passive and low-energy sustainable applications. Some key passive strategies are proper solar orientation and thermal mass; e.g. thick mud brick walls, passive cooling through cross ventilation and compact urban structure to provide shade and reduce heat gain (Dabaieh, 2013a). Construction techniques using available local materials decrease the processing energy and transportation costs of building materials (Gado et al., 2010). Thus, the building outcomes are less energy-demanding and more environmentally friendly. In the Western Desert of Egypt some vernacular buildings are still inhabited and there are significant architectural and urban models of environmental lessons for ZCBs that they still can provide. For contemporary vernacular, such targets can be accomplished by implementing innovative sustainable design strategies and generating on-site renewable power for electricity.

2. Methodology

The five main desert oases in Egypt, Siwa, Dakhla, Kharga, Farafrah, and Baharia, were investigated in this research. The field work was carried out in sequence along several visits between 2010 and 2015. This study focused mainly on the cases selected from Siwa and Baharia due to their relevance to Photo Voltaic (PV) retrofitting. Two main procedures were applied: first, an in-situ survey for ten vernacular building samples in the Western Desert of Egypt, two in each oasis, and second, an analysis of the effect of retrofitting with renewable energy. Mainly a roof top PV system was researched in two of the case buildings, one in Siwa and one in Baharia. The aim of the methodology was to discover the underlying climate responsive and zero carbon strategies conceived in desert vernacular architecture and to analyse the building characteristics and environmental passive solutions applied. In addition, it aimed to look at vernacular passive solutions and how they can be combined with PV retrofitting to reach a better building performance for ZCB practice. A qualitative lab test was conducted for the thermal properties of the main earth building material (mud bricks). The outcome of the lab test was used in the analysis of the building performance.

3. Results and Discussion

3.1 Thermal performance and passive adaption in vernacular buildings

The climatic effectiveness of vernacular solutions has always been questioned, as it is also a reflection of cultural specificities (e.g. Givoni, 1994). Site investigations revealed that vernacular buildings show the application of three main climatic adaption strategies: thermal mass, solar radiation control and night ventilation. Such strategies are the key to improving energy efficiency in buildings. It is a fact that thick mud brick walls have thermal inertia; therefore, the building envelope is protected from external temperature peaks both during summer and winter. Lab tests of 30 cm thick brick samples show a low thermal conductivity (~0.5Wm-IK -1), but a high thermal storage capacity (cond. coeff< 0.69 W/InK). According to Al-Hinai et.al's (1993) study on mud brick for desert vernacular settlements in Oman, thick mud brick walls help reduce solar gains and nocturnal heat losses and so stabilise the temperatures within houses, despite the large diurnal-nocturnal temperature fluctuations to which they are exposed. In winter, thick mud brick walls store and transmit some of the solar energy from the day and release it during the night and in the early morning hours in order to heat the internal spaces. Al-Hinai et. al add that this desirable behaviour is due to the long thermal-signal time lag (~ 12 h) produced by the thick mud brick walls. However, this heat absorption phenomenon causes problems in summer. As explained by Givoni (1998) and Meier et al. (2004), the extreme thermal inertia of traditional architecture in hot-dry climates averts the nocturnal cooling of the houses and leads to indoor discomfort at night. From site investigations, it was also observed that dwellers tend to open north-facing windows to get rid of trapped heat that is transmitted and released by the walls to the interior of the house during evenings (see Fig. 3). This cross-ventilation method allows cool air to enter using the summer night flush cooling effect. Locals also use ingenious systems for air traps; for example, having a courtyard or a wind catcher, wind scoops and staircase shafts. Mingozzi et al. (2009) explained the phenomenon that in summer the building mass mitigates the sun-air impact during the hottest hours as it captures and stores heat, which can be dispelled at night using cross ventilation. From site surveys, it was also observed that desert vernacular architecture depends on vegetation to modify the micro-climate. As explained by Al-Hinai et al. (1993), the transpiration processes

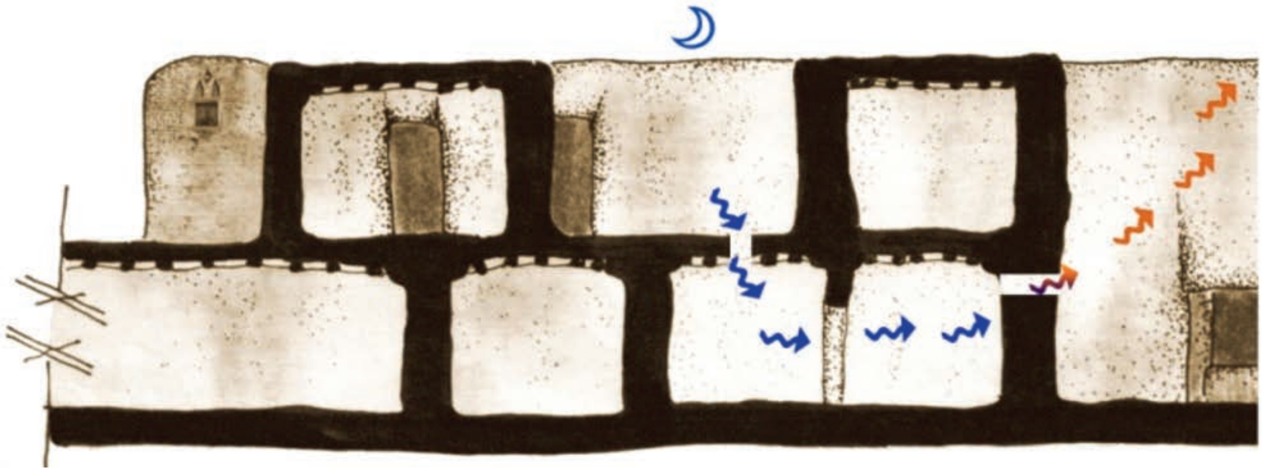

Fig. 3 Cross section of one of the houses explains night cooling using "night flush-out". Cool outdoor air is introduced into the building at night to allow the interior to pre-cool for the next day. Occupants have to open and close windows when needed. It is most effective as thermal mass helps store cool air for the next day.

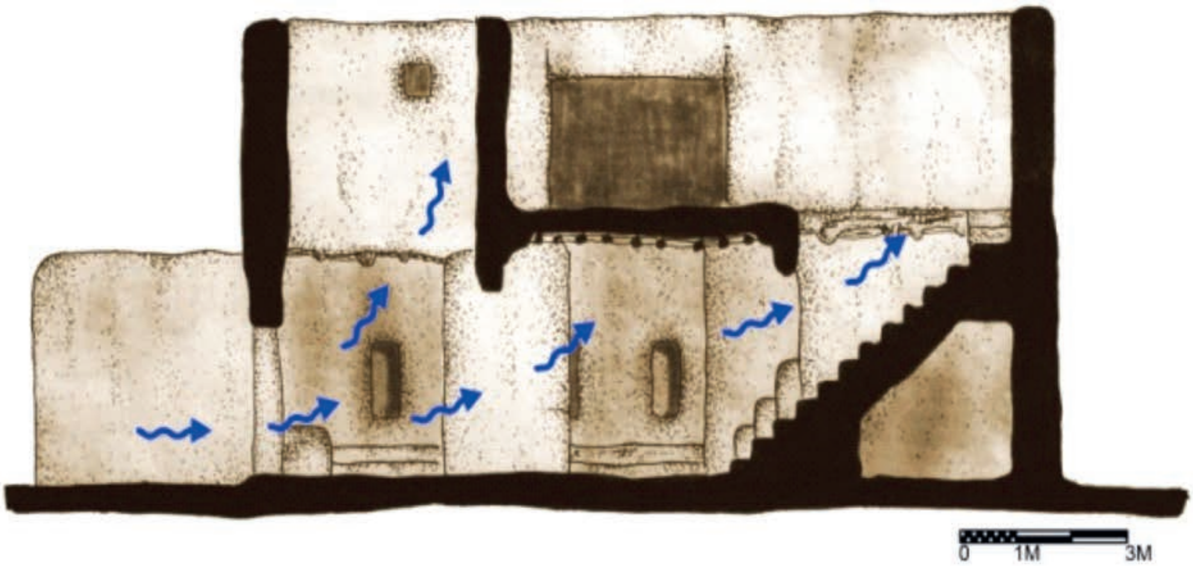

Fig. 4 Cross section explains cross ventilation using high and low openings on opposite facades overlooking courtyards. These openings create stack air flow and differences in air circulation speeds and air movement inside the spaces.

of plants help condition air streams by increasing the moisture content in the air before it reaches houses. Banana trees and palms are planted in small courtyard gardens in between clustered buildings, serving as channels for relatively cool air from the gardens to the houses. They provide shade and reduce the intensity of wind, especially during sandy seasonal windstorms (see Fig. 4).

The main skeleton of the buildings is earth, which is the main building material used in the oases. Inhabitants can recycle earth easily, either re-using old earth blocks as building material or returning them to the soil for use as planting medium. Fathy (1986, 1973) mentions that earth has the ability to conserve energy, provide thermal insulation, store heat, and stabilise indoor temperatures when used as building material. Bourdier and Trinh (2011) state that earthen walls can absorb excess humidity as well. Fathy (1986) explains that vernacular earthen interiors remain cool during the day and release warmth at night, the opposite of concrete, a material that unbearably traps and holds high temperatures in Egypt's hot climates. In a similar study on sun-dried brick used in desert vernacular buildings, mud bricks were shown to have a low heat conductivity and a high-energy storage capacity as they allow as much as 80% of the outside heat to be absorbed and only 20% transmitted inside (Vefik Alp 1991).

3.2 Vernacular buildings and low carbon building practices

In ancient times and even up until recently on a limited basis, animal manure and dry compost from toilets were shaped into pie-like forms and left to dry in the sun. They were used as bio fuel for ovens, for both cooking and heating in wintertime. This was one main source of energy production. To calculate the exact energy consumption, a two-floor 75 square metre sample house representing a typical average house size

Fig. 5 Al Gara village in Siwa after retrofitting one of its vernacular buildings with PV systems for electricity production (photo: Nahla Makhlouf)

in the Western Desert area was selected. Calculations are supported by household consumption recorded in monthly electrical bills. Average energy bills for 2014 and 2015 were used together with the equation below to calculate the total energy consumption and they were compared for accuracy.

(Wattage × Hours Used Per Day) ÷ 1000 = Daily Kilowatt-hour (kWh) consumption (1)

Equation (1) was used to calculate household energy consumption. The result of the calculations was that the house's average energy consumption was 77 kWh/m² per year, which is less than the passive house standard or low-energy house standard. This is due to the fact that the cooling and heating is mainly dependant on passive methods. The electricity needed is mainly for electric devices and for night lighting. Such a small amount of energy can be powered by roof-top domestic PV systems without occupying a large portion of the roof area, which is normally used for grain storage and chicken coops in vernacular buildings. One successful pilot project was implemented at El Gara in Siwa and El Heiz in Baharia. Both are off-grid villages where vernacular buildings were retrofitted with PV systems (see Fig. 5). The pilot trial project showed a direct impact on dwellers' satisfaction and appreciation of having access to electricity. Some of the village dwellers show an interest in leaving the village, especially younger generations. They tend to live in new houses with industrially fired bricks and cement due to a lack of access to electricity. PV retrofitting could be an important factor in reducing the number of deserted vernacular settlements. However, there is still widespread concern about the visual impact of PV panels, especially if applied on listed vernacular buildings, which is the case for the majority of vernacular towns and villages in the Western Desert. Smart interventions are needed to place the panels in discreet locations, for example by hiding them behind roof parapets.

4. Conclusion

The results of this study show that vernacular creative passive strategies combined with active retrofitting solutions using renewables for energy production can act beyond the common standards of zero carbon and passive buildings. Vernacular structures in their current state do not appeal to village dwellers; however, retrofitting old structures could reduce the rate of abandonment for modern facilities or demolition and sometimes vandalism of vernacular buildings. In order to avoid overestimated results, further quantitative research using energy monitoring is needed to verify the passive energy-efficient strategies and vernacular building performance outcomes explained in this study.

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