Ecological Design Principles in Egypt: Case Study Application and Economic Evaluation

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Abstract

Several international systems exist for measuring sustainability compliance such as BREEAM in the UK, LEED in the US and CASBEE in Japan. A recent Egyptian system is termed the Green Pyramid Rating system (GPRS), and is intended to operate as a rating and certification scheme to define and encourage ecological building design and development in Egypt. Both international and local systems are uncertain in terms of their suitability to local technologies and conditions and in terms of their economics. This paper aims to discuss sustainability system elements of existing buildings in rural areas in Egypt in terms of their suitability to local conditions and economics. Ecological design principles were extracted from international systems and model eco-houses. Challenges facing eco-houses in Egypt were reviewed. The ecological design principles were applied to a case study in Wardan, Egypt, where local available technologies were used to apply the principles of indoor environmental quality, energy efficiency, water management, eco-materials. Ecological systems are proposed for natural ventilation, photovoltaic panels, and thermal insulation and their economic viability is compared to typical air conditioning systems. The conclusion of the comparison is that the proposed ecological renovations of the case study are competitive in terms of construction costs and more economical than typical systems considering life cycle costing. It is thus recommended that government agencies and industry institutions take on awareness campaigns and research institutes direct research towards appropriate ecological technologies for new and existing buildings, whether rural or urban.

Keywords: Sustainability; Ecological Systems; Economics; Cost Savings; Local building technologies; Egypt.

Introduction

Ecological houses has been an important enabler of sustainable construction and has been extensively researched. Ecology is defined as the study of the interactions of organisms and their physical and biological environment (Roaf, 2001). An ecological house conserves resource (energy, water, food and materials). It also produces resources or gathers and stores more of them than it uses. In an ideal ecological house, there is no waste because the resource flow is circular (Roaf, 2001). Examples of eco-houses adapting to climate are the Nomadic Tents in the Middle East and Igloos in the North Pole. Many ecologic building design standards/measurement systems have been developed, most of which have developed into more sustainable development systems, such as BREEAM in the UK, LEED in the US, CASBEE in Japan and Green Star in Australia.

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International examples of ecological houses (eco-houses) that have been constructed are the Oxford Eco-House, UK, (Roaf 2001), Berkeley Eco-House, USA, (Berkeley 2007), Lara Calder Eco-House, Sydney, Australia, (Lara Calder 2008), Ramallah Eco-House, West Bank, Palestine, (Med-Enec 2010) and El-Tahrir Passive Solar House, South Tahrir, Egypt, (DDC 2006), and Sharm El-Sheikh Students Residential building, Sharm El-Sheikh, Egypt (Med-Enec 2010) mostly showing major reductions in carbon emissions, energy consumptions, electricity costs and gas costs. However, the design principles of ecological houses have not always used local buildings technologies nor are always economically competitive.

The aim of this paper to extract the main ecological design principles in international sustainable rating systems and international eco-house models and apply the principles to a case study in Wardan, Egypt, using available local building technologies. The construction costs and lifecycle costs of typical construction and ecological design alternative are compared for economic evaluation.

The paper is divided into five further sections discussing international ecological and sustainable building rating systems, eco-houses design principles, eco-houses challenges in Egypt, a case study application, and finally a conclusion and recommendations section.

International Ecological and Sustainable Building Rating Systems

Green buildings provide many benefits including increased return on investment, reduced energy, operating, and maintenance costs, increased sales and leasing potential of buildings, better occupant health and productivity, and reduced natural resource use (LGBC 2011). International Assessment and certification systems for green buildings have emerged throughout the past two decades such as BREEAM in the UK in 1990, LEED in the US in 1998, and Green Star in Australia in 2003 (IBE, 2011). Figure 1 shows the major global rating tools as per the EGBC (2011).

Figure 1. Major Global Rating Tools (EGBC 2011)

A specific version of BREEAM has been developed for the Arabian Gulf Region for assessment of new and existing buildings in 2008. The BREEAM Gulf rating is based on sections addressing management, health & wellbeing, energy, transport, water materials, waste, land use & ecology, and pollution. The weighting of these sections in overall rating is affected by the regional scope of the system, so for example water contributes a 30% of the total weighting (BREEAM, 2008). Although LEED has been criticized for naturally tending to reflect Western building conventions and lifestyles, it is being implemented in some Arab countries. Abu Dhabi in the United Arab Emirates has developed a local answer to LEED designed around its own culture, environment and ideas about sustainability, and in fact is called “Estidama” – the Arabic work for sustainability (ADUPC 2011 and ABN 2011). The rating system corresponds to the Estidama pillars of environment, economy, culture and society and is reflected in the categories of: integrated development process; natural systems; livable communities, buildings and villas; precious water; resourceful energy; stewarding materials; and innovating practice (ADUPC 2010).

Furthermore, the Egyptian Green Building Council (EGBC) developed the Green Pyramid Rating System (GPRS) in January 2009. The system builds upon proven methodologies and techniques used in the United States, Europe, Asia, South America and Middle East. The system uses a whole-building approach to sustainability by focusing on seven key areas: sustainable sites development; water saving; energy efficiency and environment; materials selection and construction system; indoor environmental quality; innovation and design process; and recycling of solid waste (EGBC 2009 and EGBC 2011). A green building rating system in Lebanon was launched in 2011 by the Lebanon Green Building Council (LGBC) with support from the International Finance Corporation (IFC). The system is termed “The ARZ Building Rating System”, whereas the “ARZ” is the Arabic term for the cedar tree that is a symbol of Lebanon and part of its flag. The ARZ system meets minimum international environment requirements while emphasizing Lebanon-specific conditions, such as energy and water conservation and recognition of the county’s existing buildings (CMO 2011 and LGBC 2011).

Eco-Houses Design Principles

A comparison concerning main ecological design principles among the major international rating systems famous international eco-houses was conducted in Farouk (2011), resulting in the main categories of: indoor environmental quality; energy efficiency, water management; eco-materials & waste management; and ecological sites.

Indoor Environmental Quality

This category aims to improve the quality of life through a comfortable and healthy home. It includes indoor materials and gases, such as avoiding the use of asbestos, growth of legionella or molds, low levels or absence of radon radioactive gas, home plantation, use of water-based eco-paints and varnishes, avoidance of wood preservative usage and use of rammed earth plaster. It also includes thermal comfort in terms of temperature, relative humidity, air speeds, sound and lighting.

Energy Efficiency

This category aims to reduce carbon emissions and atmospheric pollution by encouraging local energy generation from renewable sources to supply a significant proportion of energy demand. It include the use of renewable energy sources such as solar and wind energy for electricity and heating, shelter design to provide natural cooling systems, and roof and wall insulations. Opening and windows can be used as outlets to provide a good pattern of air movement. Shading devices can be used to decrease sun exposure.

Water Management

The aim of this category is to reduce the consumption of potable water in homes and encourage the use of recycled water such as grey water. Irrigation systems should use sprinklers or trickle systems to save water. Grey water systems are encouraged in houses, in addition to rain water tanks.

Eco-Materials

The aim of this category is to encourage the use of materials with lower environmental impacts over their lifecycle. Low embodied energy materials are used such as concrete, loam, polyethylene, bitumen and softwood. Recyclable materials are also recommended such as hollow concrete elements and sand-lime bricks.

Ecological Sites

This category aims to encourage the development on suitable land and discourage the development of ecologically valuable sites. Sites should be selected away from contamination with the possibility of soil replacement if necessary. Trees and green areas are encouraged around the house to filter the house air and to create a green belt and encourage wildlife around the house.

Eco-House Challenges in Egypt

Ecological buildings are believed to have long existed in Egypt starting from the great pyramid of Khufu that has a sustainable structural system, natural materials and durability with minimum maintenance, natural ventilation and lighting systems, and harmony with the surrounding environment, as can be seen in Figure 2 (EGBC 2011).

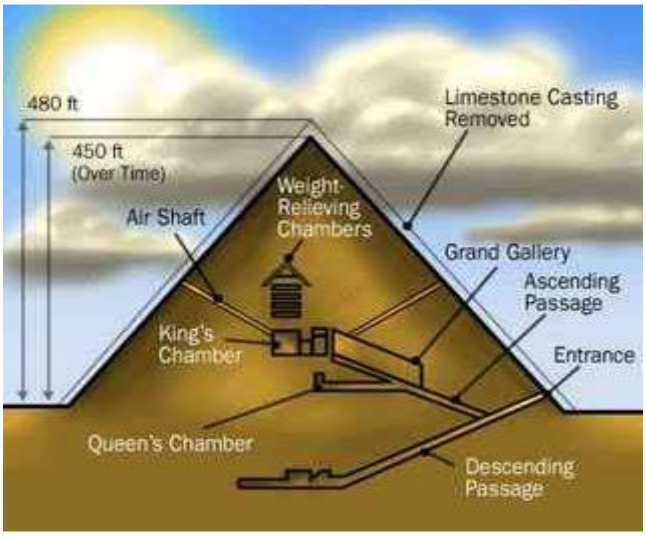

Figure 2. The Great Pyramid of Khufu as an early Eco-Building (EGBC 2011)

However, present and future challenges face Egypt with a population of about 90 million, increasing annually by about 1.3 million, and concentrated in nearly 5% of the total area of Egypt. Conventional construction technologies are not ecologically friendly and require extensive energy in the production of building materials. Energy demands have increased considerably in the past decade and conventional energy production is limited (Beshara

2008 and Bishay 2010). However, Egypt has significant potential in terms of renewable energy production (Med-Enec 2010). The west of Suez Gulf zone has wind speeds of about 8-10 m/sec, and other sites have speeds of 7-8 m/sec. Direct solar energy reaches 6 kWh/m^2/year, which is high number in international standards (Ahmad 2002 and Med-Enec 2010).

Nile water resources are also limited and under political threats. Nevertheless, sea water desalination and groundwater sources provide significant potential in Egypt (Bishay 2010). Egypt has many building raw material sites as shown in Figure 3. These raw materials include clay, sand, lime stone, marble, granite, basalt, steel, sand stone, and gravel.

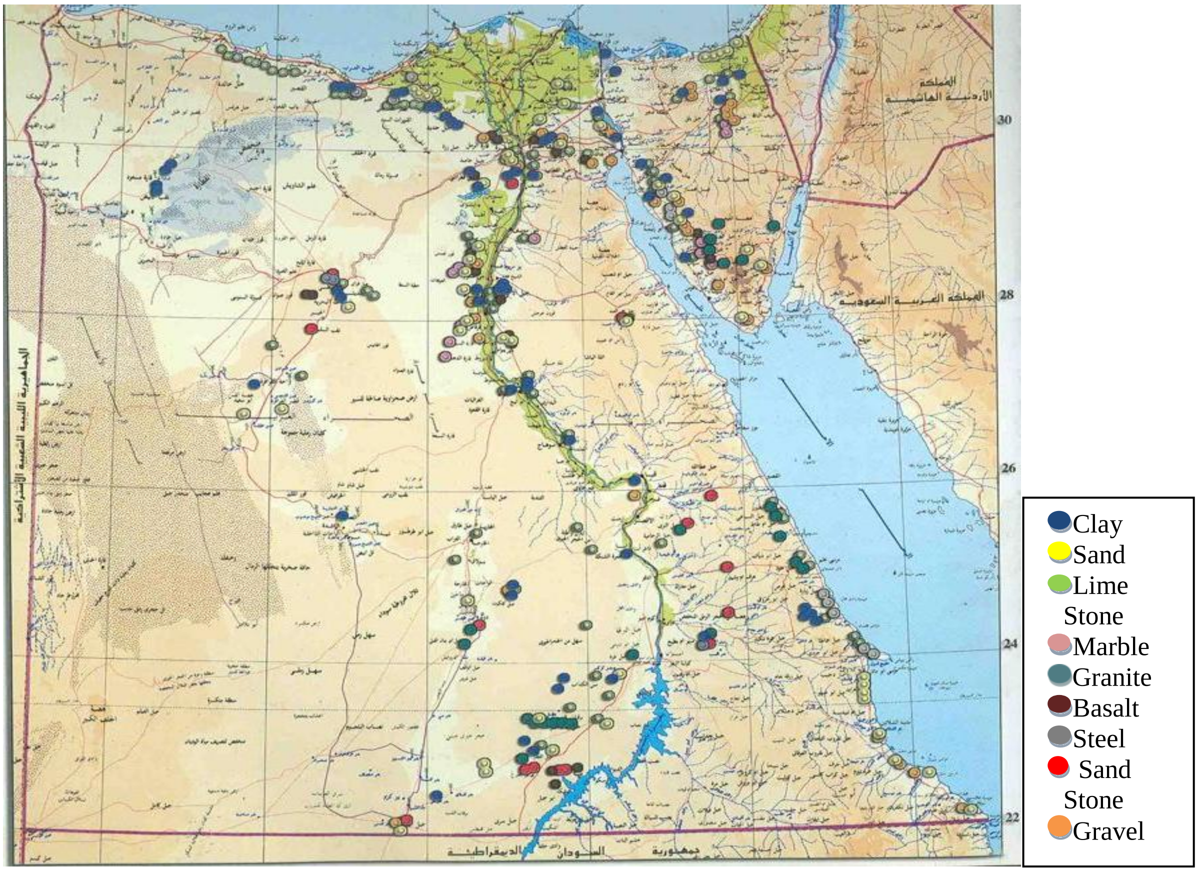

Figure 3. Building Material Sites in Egypt (HBRC 2008)

Efforts have been made to enhance building bricks in Egypt as an important building material and various types of bricks have been used to increase thermal capacity in arid conditions. A brick using rice straw has also been used using rice straw, which has been linked to major pollution problems in its burning by farmers and has been linked to the black cloud over Cairo (HBRC 2006 and MoEA 2010).

Case Study Application in Wardan, Egypt

The case study is of the renovation of a house in Wardan, Egypt, located about 20 km east of the 58th km milestone of the Cairo-Alexandria Desert Highway. The coordinates of Wardan is 30o 22’N, and longitude 30o 27’E, which is about 50 km north west of Cairo. Figure 4 shows the location of Wardan in Egypt.

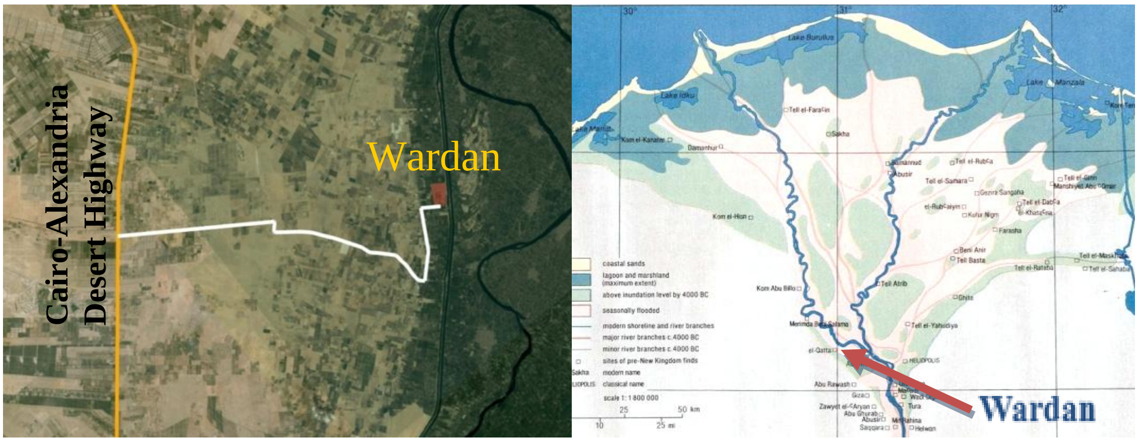

Figure 4. Location of Wardan in Egypt.

A perspective of the house before renovation is shown in Figure 5 and the original plans of the ground and first floors in Figure 6.

Figure 5. Northwest Perspective of the House before Renovation

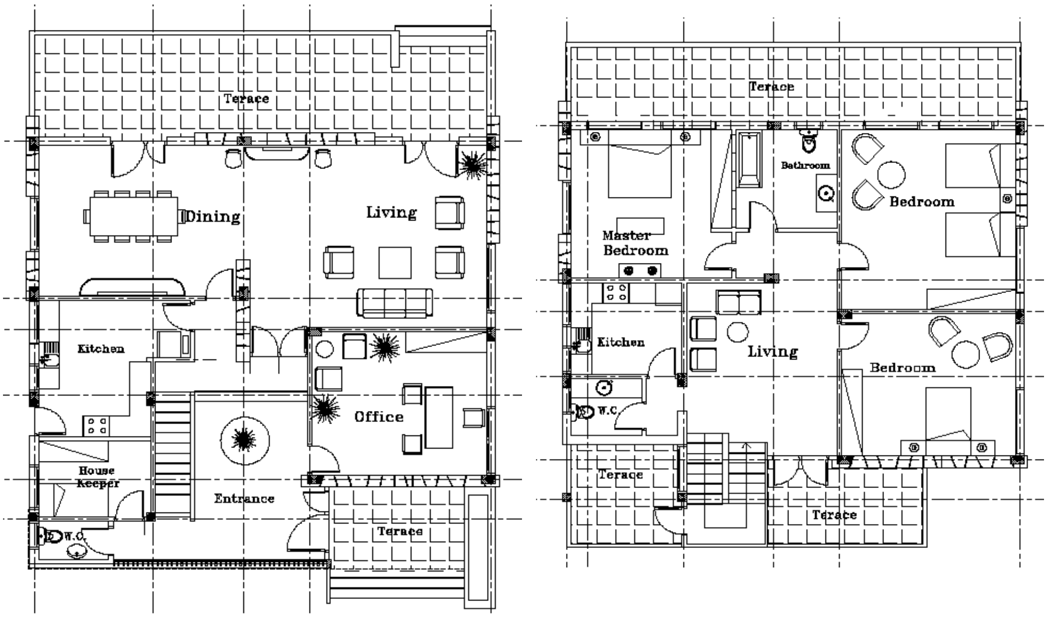

Figure 6. Original Ground and First Floor Plans before Renovation

Actual temperatures were taken in the existing building in the hottest months of the year, July and August as shown in Table 1. The range of temperatures outside the building is 26-36 ^{o}C and inside the building is 28-34 ^{o}C. To overcome these temperatures, the ecological design concepts described in this case study were applied.

Table 1. Measured Temperatures in the Existing Building in July and August

Date	**Time**	**Morning**							
		North Room		**East Room**		**South Room**		**West Room**	
		Outside	**Inside**	**Outside**	**Inside**	**Outside**	**Inside**	**Outside**	**Inside**
1/7/2010	8:00 AM	26	28	28	29	30	28	28	29
15/7/2010	8:00 AM	26	29	29	29	32	30	27	30
1/8/2010	8:00 AM	29	30	29	30	30	29	29	30
15/8/2010	9:00 AM	30	28	30	31	34	31	29	32
31/8/2010	9:00 AM	30	29	30	31	34	31	30	32
1/7/2010	5:00 PM	34	30	30	29	30	32	34	32
15/7/2010	11:00 PM	34	31	30	29	31	33	34	32
1/8/2010	5:00 PM	35	32	31	30	31	32	36	32
15/8/2010	7:00 PM	36	33	32	30	33	34	35	33
31/8/2010	7:00 PM	36	33	33	31	33	34	35	33

Indoor Environmental Quality

The ground and first floors were modified to allow for natural ventilation as shown in Figure 7. Living & dining area become open areas to allow the air movement from north to south direction in the ground floor. Wind catchers (air malqaf) were located in the ground floor living area to supply the cold air from lower inlets and exit the hot air to the south malqaf beside the main entrance. Wind catchers (air malqaf) in the first floor (bedrooms) were to introduce cold air from lower inlets and push out hot air to the south malqaf and to the stair windows over the roof. Staircase extends above the roof to exhaust the hot air from the first floor and along the villa, and provide the villa day lighting through its windows. Ceiling fans were introduced to assist in air movement, when necessary.

Double external walls consisted of existing lime stone wall from outside and 5 cm reinforced foam panel “thermal insulation” and 2.5 cm rammed earth plastering from the inside to increase the thermal resistance of the inside surface. External white paint was used to reflect solar heat. A wall section for external wall insulation is shown in Figure 8.

Water Management

Two water sources existed for the building, a source of natural water from the Nile River (Elbaheiry branch) and two underground water wells. The Nile River water was not available all year round and the water wells had salinity issues in some periods of the year. A green belt of vegetation was used to filter sand and dust from prevailing wind direction. Irrigation of the green belt was via trickle irrigation that saves about 66% of the amount of irrigation water. Sprinkler systems could also have been used, but the water savings would have been less.

Figure 7. Natural Ventilation System (Ground & First Floor Plans)

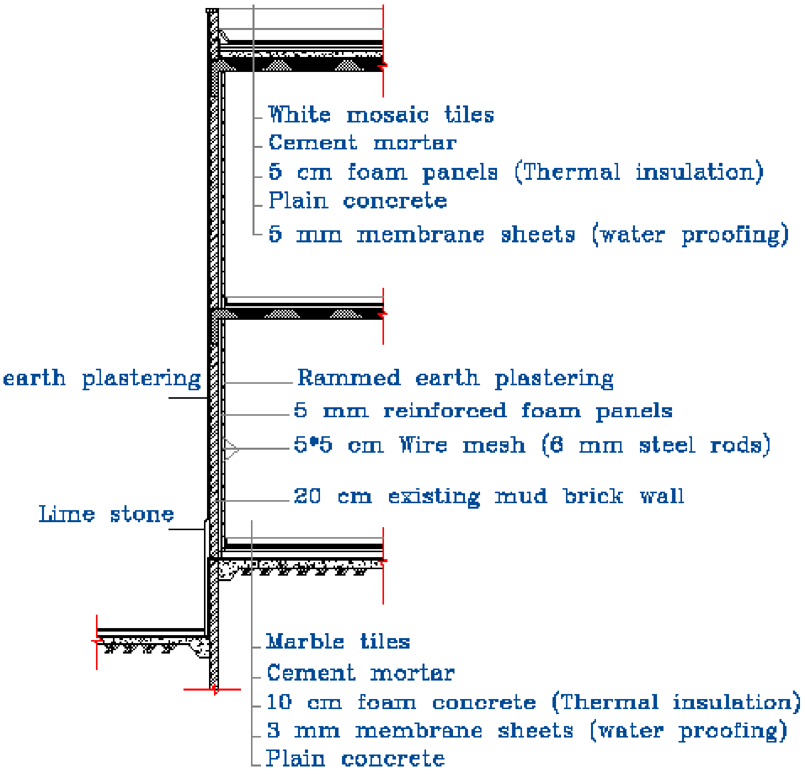

Figure 8. Wall Section for External Insulation

It was necessary to reserve the precious water sources by using a grey water system for reusing water provided by basins and shower for toilet flushing. The grey water storage was kept in an underground water tank. Furthermore, rainwater was collected from the roof and stored in the underground water tank. The water system and full ecological design is shown in Figure 9.

Eco Materials

The building site is located in a rural area near the Nile Valley region, the available local materials are Limestone, Marble, Granite, Sand, Basalt, Gravel and Clay. Therefore, the materials used in the renovation works were:

Flooring: marble; ceramic tiles; mosaic tiles; and softwood floors.
Walls: eco-painting; local ceramic tiles; rammed earth plastering; and foam panels.
Doors and windows: existing wood and glass doors and windows were renovated.
Water insulation: rubber membrane sheets.

Waste Management

Recycling practices were performed for garbage separation and sold to local recycling firms/traders. Color baskets were used where white basked was used for paper, red for glass and blue for organic waste.

Ecological Sites

The site of the house was away from contamination and a green garden was created around the house including a row of high trees to filter incoming air from dust and sand.

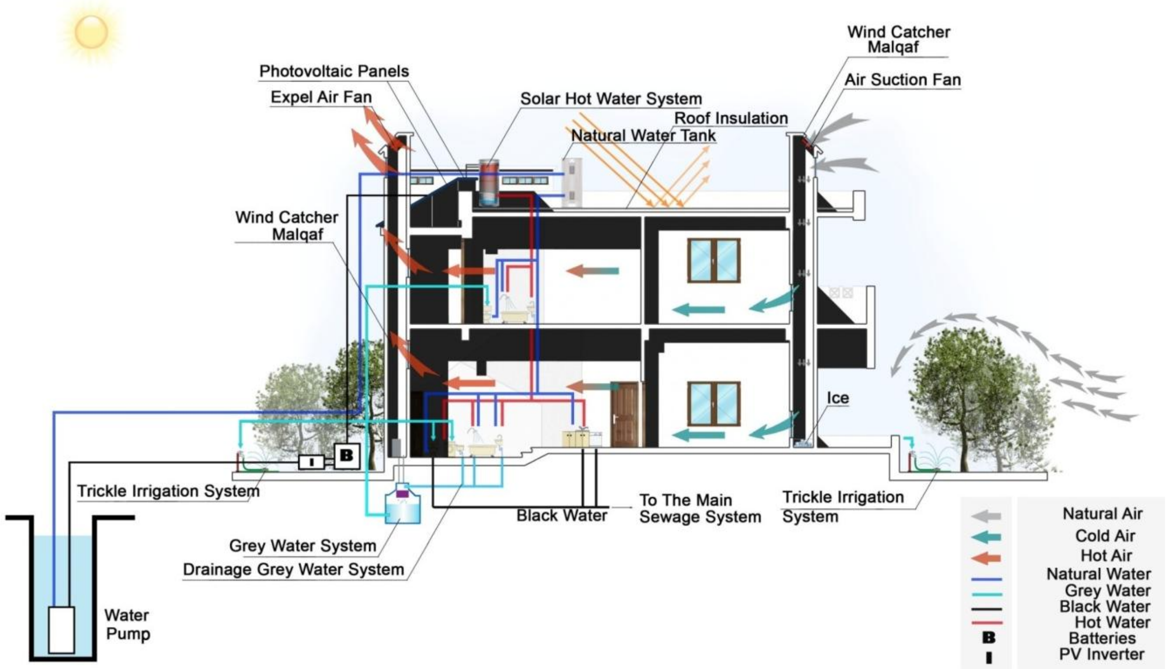

Figure 9. Proposed Ecological Design

Energy Efficiency

Solar energy was used via photovoltaic (PV) panels to generate electricity & hot water. Solar exposure over the area is about 19.11 MJ/m^2/day or 5.31 kWh/m^2/day (Robaa, 2006).

The system of solar energy using photovoltaic panels and solar hot water system is shown in Figure 9. The average daily energy load requirements was shown in El-Menchawy, Bassioni, and Farouk (2001) and necessary PV array sizing, design of the storage system, and specifications of the DC/AC converter. The life cycle costs of the system over 25 years were calculated and found to be 0.30 USD/kWh, whereas the cost of a diesel generator was calculated to be 0.39 USD/kWh, thus showing the economics of solar energy systems over the long term. This of course was not competitive with the cost of subsidized government electricity rates of about 0.07 USD/kWh. Nevertheless, when introducing the cost of installing electric cables from the nearest source, the local electricity life cycle cost jumped to 0.32 USD/kWh. This means that solar energy alternatives is economical in cases of rural houses and would be recommended in cases of privatized new desert settlements away from government provided energy.

Renovation Cost Comparison Between Ecological and Traditional Designs

The costs of typical renovation of such an existing building was calculated as part of an actual project, and compared to the cost estimate of the ecological renovation in terms of initial construction costs, as in Table 2. The cost traditional system uses Air Conditioner (AC) to decrease temperatures in hot months and government supplied electricity for water heating, whereas the ecological system uses the natural ventilation system for decreasing temperatures and solar energy for water heating. With the steep drop in solar PV systems in past few years, quite cheap prices are obtainable. A quick internet search showed systems in the order of 1-2 USD per Watt (FOB – Freight on Board). A price of about 4 -5 USD per Watt was found in the United States (all expenses). The international market affects the Egyptian market in the medium and long run, therefore, a conservative pricing of 7 USD per Watt was considered in this case study. The system is 564 Watts, thus making the total price in the order of 4000 USD, in addition to about 1000 USD for installation.The total typical renovation cost was budgeted in the project as 225,000 EGP (about 37,500 USD), while the cost estimate of the ecological renovation was about 221,000 EGP (about 36,830 USD). Costs are quite comparable, if estimating inaccuracies are allowed for.

Life Cycle Cost Analysis

Initial costs are not enough to compare costs in a fair manner. Thus, life cycle costs were estimated, as shown in Table 3 in terms of the Net Present Worth (NPW) of each alternative. The first alternative is the typical design renovation cost with the assumption of local nearby electricity available. The second alternative assumes electricity is not available in the whereabouts of the house, and thus a hefty installation cost exists. The third alternative is the case of ecological renovation with natural ventilation systems and a solar system for electricity and water heating.

The equations for the present worth of replacement costs, present worth of annual costs and payback period are as follows (Ahmad 2002; and Nafeh 2009):

$$PW = \frac{PC(1+i)^n}{(1+d)^n} \qquad (1)$$

Where: P = present worth, PC = purchasing cost, i = inflation rate, d = discount rate, and n = number of years. (Assuming the inflation rate = 12%, and discount rate is 8%)

$$PW = \frac{A(1+d)^n - 1}{i(1+d)^n} \qquad (2)$$

Payback period = Total net present worth / net present annual savings (3)

Table 2. Costs of Typical and Ecological Design Renovation

Work Item	Typical Design Renovation	Typical Cost (EGP)	Ecologic Design Renovation	Ecologic Design Cost (EGP)
Demolition	Removing all the damaged materials	5,000	Removing all the toxic and damaged materials	10,000
Wooden Maintenance	Wooden floors and cupboards	4,000	Doors, windows, wooden floors and cupboards	12,000
Water Insulation	Rubber 5 mm layer	5,000	Rubber 5 mm layer	5,000
Thermal Insulation	–	–	Roof and walls insulation - 5 cm reinforced foam panels	12,000
Reinforced Concrete	–	–	Air catchers, photovoltaic slab and stair clear story.	5,000
Plain Concrete	Insulation protection layer	5,000	Insulation protection layer	5,000
Brick Works	Normal bricks	5,000	Air catchers, walls with bricks containing rice straws	7,000
Plastering	Cement plastering	10,000	Rammed earth plastering	5,000
Ceramic Works (Walls)	Local and imported ceramic tiles	25,000	Local ceramic tiles	15,000
Marble	Local marble	5,000	Local marble for living and entrance area floors	10,000
Int. painting	Eco- paintings	15,000	Eco- paintings	15,000
Ext. painting	Cement dry mix plastering	15,000	Rammed Earth plastering	10,000
Windows	Aluminum windows	15,000	The existing wooden windows are renovated	1,000
Doors	Soft wood with HPL finishing layer	15,000	The existing wooden doors are renovated	1,000
Electrical Works	Transformers, cables, generators, main and distribution panels	36,000	Distribution panels and electrical features	10,000
Photovoltaic System	–	–	Photovoltaic panels, inverter and batteries & installation	30,000
Plumbing	Wells, tanks, piping and plumbing features.	40,000	Piping and plumbing features.	50,000
Underground Water	–	–	Submerged pump in the well and water tank	10,000
Grey water System	–	–	Grey water filter, pump and underground tank	5,000
Air Conditioning	Air conditioning units, compressors and connections	25,000	–	–
Air Fans	_	_	Ceiling and wall fans	3,000
Total in EGP	**225,000**		**221,000**	
Total in USD	**37,500**		**36,830**	

The ecological design is quite competitive in this case, showing a saving of 5589 USD (31%) in the NPW against typical design (with nearby electricity), and a saving of 17,989 USD (60%) in the case of no nearby electricity. The payback period based on savings in the case of typical design with nearby electricity is about 2.2 years, and about 0.68 years in the case of typical design with no nearby electricity.

Table 3. Life Cycle Cost Analysis of Typical vs Ecological Designs

Cost Items		**Typical Renovation Case (Alt.1)**	**Cost (USD)**	**Typical Renovation Case (Alt.2)**	**Cost (USD)**	**Ecological Renovation Case (Alt.3)**	**Cost (USD)**
Initial Cost	**Electricity Installation**	Available local Electricity	2,000	Unavailable Local Electricity	14,400	PV System	5,000
	Ventilation System	Air Conditioning	5,000	Air Conditioning	5,000	Air Malqafs + fans	1,500
	Thermal Insulation	-	-	-	-	Roof and Walls	2,000
	Initial Cost	7,000		19,400		8,500	
	Useful Life	24 years		24 years		24 years	
Repla-cement Cost	**Replacement Cost**	Air Conditioning Units (12 years) PW = 7,090		Air Conditioning Units (12 years) PW = 7,090		Batteries Units (PC = 1,000) 8 Years: PW = 1,337 16 Years: PW = 1,789	
Annual Cost	**Maintenance Cost**	Air Conditioning Units	50$	Air Conditioning Units	50$	PV System	50$
	Operation Cost	Electricity Bill	250$	Electricity Bill	250$	Electricity Bill	0.0
	P W	3748		3748		623	
NPW	**NPW**	17,838		30,238		12,249	

Conclusion and Recommendations

The aim of this paper is to review the main ecological design principles in international sustainable rating systems and international eco-housing examples and apply these guidelines to a case study in Wardan, Egypt, using available local technologies and evaluate the economics of the alternative ecological design. International sustainable rating systems that mostly started as ecological housing standards were reviewed as well as relevant international eco-houses. The ecological housing design principles were presented including indoor environmental quality, energy efficiency, water management, eco-materials, and ecological sites. These categories were used to present the eco-house challenges in Egypt.

The principles were applied to a case study concerning the renovation of a rural house in Wardan, Egypt. Actual air temperatures were recorded in the hot summer months as an input to the design and ranged from 26-36 ^{o}C outside the building and 28-34 ^{o}C inside the building. The ecological design consisted of wind catchers (air malqaf) and ceiling fans for assist in air movement. Double external walls were used with an additional layer of reinforced foam panels to add to the existing lime stone wall’s thermal insulation. External white paint was used to reflect solar heat. Rammed earth plastering was used as an environmentally friendly energy efficient material. Marble and local ceramic tiles were also used. Rubber membrane sheets were used for water insulation. Groundwater wells were used in addition to local River Nile Water and a green belt of vegetation was created around the house to encourage wildlife and trap incoming air dust and sand. The irrigation system used was trickle irrigation to save water. A grey water system was used and kept in an underground tank to reuse water. Waste recycling management was also applied. All the technologies used are readily available in the Egyptian construction market, thus making the ecological design more constructible and hopefully adoptable.

A photovoltaic solar system was introduced for electricity and water heating. The economics of the ecological design evaluated, where construction costs were found to be competitive and the life cycle costing comparison showed the ecological design to be more economical, than typical design methods. Savings were very high in the case of no nearby sources of electricity.

The findings in this paper showed the high possibility of applying ecological design concepts to renovating rural houses. Contemporary government policies and public concern in Egypt to relocate the population outside of the narrow and highly condensed Nile Valley gives particular significance to the findings, as it provides high potential to utilize the solar energy in the Egyptian deserts and build new settlements for industrial and agricultural purposes. Therefore, it is recommended that government and industry organizations provide support to such initiatives. Further research can also be useful to introduce new, or promote current, technologies in the cases of both new and existing buildings, whether rural or urban.

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