ZERO ENERGY RETROFIT: CASE STUDY OF A CHALET IN AIN-SUKHNA, EGYPT

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ABSTRACT

This paper presents the results of combined economic and computational study of different integrated passive and active design strategies for the Red Sea Coastline of Egypt. A chalet, located in Ain-Sukhna is selected as a case study for the zero energy retrofit. The aim of the study is to investigate the potential of achieving thermal comfort and delivering electrical demands for existing buildings on site. The Red Sea Coastline of Egypt has a semi arid climate with an annual total irradiation above 2409 bankable kWh/m^2 per year with approximately 3300 hours of full sunshine. Moreover, the annual monthly averages of wind speed in this region range from 5.0 to 7.1 m/s. Therefore, different passive and active design strategies are discussed and compared to reach an annual net zero energy demand for the existing building stock. In order to achieve zero energy retrofit certain strategies are examined. For example, internal loads reduction, envelope retrofitting in addition to the installation of solar water heater, photovoltaic and small-scale wind turbine. Based on a month-by–month demand analysis, internal loads and envelope performance are analyzed in order to explore the existing economical potential. Simulation software TRNSYS is used to examine the strategies proposed to achieve annual net zero energy performance for a the chalet. The final result of this study compares the potential and constraints of each strategy and ranks them based on economical feasibility. For the considered location and weather conditions the Chalet can provide thermal comfort for occupants and meets the zero energy objectives. The research also proofs that some strategies applied for retrofitting are cost effective rewarding with a payback period ranging from 2 to 7 years.

1. INTRODUCTION

Renewable energy resources in Egypt include solar, wind and biomass. For example, the average annual total irradiation is above 2409 bankable kWh/m^2 per annum with approximately 3300 hours of full sunshine and the annual monthly averages of wind speed range from 5.0 to 7.1 m/s. However, these resources are generally not yet exploited in the Egyptian building sector on any scale. On the other hand, given the depletion of global fossil fuel resources and the exponential population growth, Egypt declared in 2007 the commencement of its program for nuclear power plants [1]. As a response to the previously mentioned contradicting facts it is of the utmost urgency that the existing building stock gets retrofitted to achieve an annual net zero energy performance [2]. There is potential for bioclimatic design in all climatic regions of Egypt with the assistance of active solar systems [3]. The building stock can easily achieve the zero energy objectives. This is due to match between annual solar irradiation curve and the cooling demand curve [5]. For that reason, the research set a zero energy retrofit objective. The zero energy objectives will expand the architect's bank of ideas and broaden the range of choices. Needless to say, any design decision will require energy performance verification. Therefore in this research, different passive and active design strategies are compared in terms of their energy savings, with the aid of simulation tools based on performance, and also in terms of their economical viability.

2. METHOD

The hypothesis of this research is straightforward. For a passively designed chalet, installing solar thermal systems (STS) and solar electric systems (SES) in addition to wind turbines would generate sufficient energy to meet the annual demand. The research methodology is based on the following below listed steps:

- 1. Bioclimatic Site Analysis
- 2. Month-by-Month Electric Demand Analysis
- 3. Passive and Active Strategies Implementation
- 4. Energy Performance vs. Economical Feasibility

The research will start with determining the annual average of kWh usage, to determine the user's seasonal electric consumption patterns and peaks. By this, the research acquires a starting point for comparing the energy output of various systems. Then, passive and active design strategies will be implemented in order to achieve a zero energy performance without compromising human comfort. The passive and active design strategies include the installation of thermal insulation, shading devices, energy-efficient lighting, systems and appliances, double glazing, thermosyphon, photovoltaic panels and wind turbines. Simultaneously, TRNSYS simulation tool is used as a verification tool to predict the energy performance of each strategy. Finally, the paper investigates the potential and constraints of each strategy then rank them based on the economical feasibility of each of them.

3. AIN SUKHNA CHALET ENERGY ANALYSIS

3.1 Existing Situation

The Chalet is located in Ain-Sukhna city (Lat., 29° 32.0' N. Long., 32° 24.0' E) on the Gulf of Suez, 140 km east of Cairo and was built in 1992. The modular chalet unit represents the typical tourist accommodation type that is spread along the Egyptian Red Sea Riviera. The chalet is the first unit of an array of single-story units with a back and front garden. The total floor area of the chalet is 64m^2 plus 60m^2 for the terrace and garden. The chalet consists of a main living room with a small kitchenette in addition to a bedroom and a bathroom. Openings have an east-west orientation and the living room is facing the sea on the east. The external wall construction is made out of 250mm silt-brick integrated within a reinforced concrete structure (roof and columns).

There is no thermal insulation, all windows are single glazed (3mm glass) and transparent. Also the Chalet is exposed to high solar irradiation, which drove the owner to plant dense vegetation all around the building. The chalet has a window type air conditioner (AC) for cooling, three excessively used ceiling fans (CF) and an electric heater for domestic hot water (DHW) (Fig. 1a-b).

3.2 Bioclimatic Site Conditions

The weather pattern in Ain-Sukhna is characterized by being extremely hot and dry (Group B, according to Köppen Classification). Average annual precipitation is 18mm; and average daily temperature during July is 35.4 ^{o}C. However, wide variations of temperature occur in Ain-Sukhna, ranging from a maximum of 39° C, during daylight hours, to a minimum of 6° C before sunrise. Average summer relative humidity is 55%. For this study, climate data were obtained from the Egyptian Organization of Meteorology (EOG). Solar irradiation is very strong, and may reach 12.3 Kwh/sq m x day on a horizontal surface (during June and July). The intensity of solar radiation during the winter is relatively high and reaches 6.7 kWh/m^2 x day on a horizontal surface. For the simulation no weather file exists for Ain-Sukhna. Therefore Cairo Airport weather file was selected [8]. Despite that Cairo and Ain-Sukhna almost fall on the same latitude, Ain-Sukhna has much clearer sky and higher irradiation and ambient temperatures (fig 1.c-d).

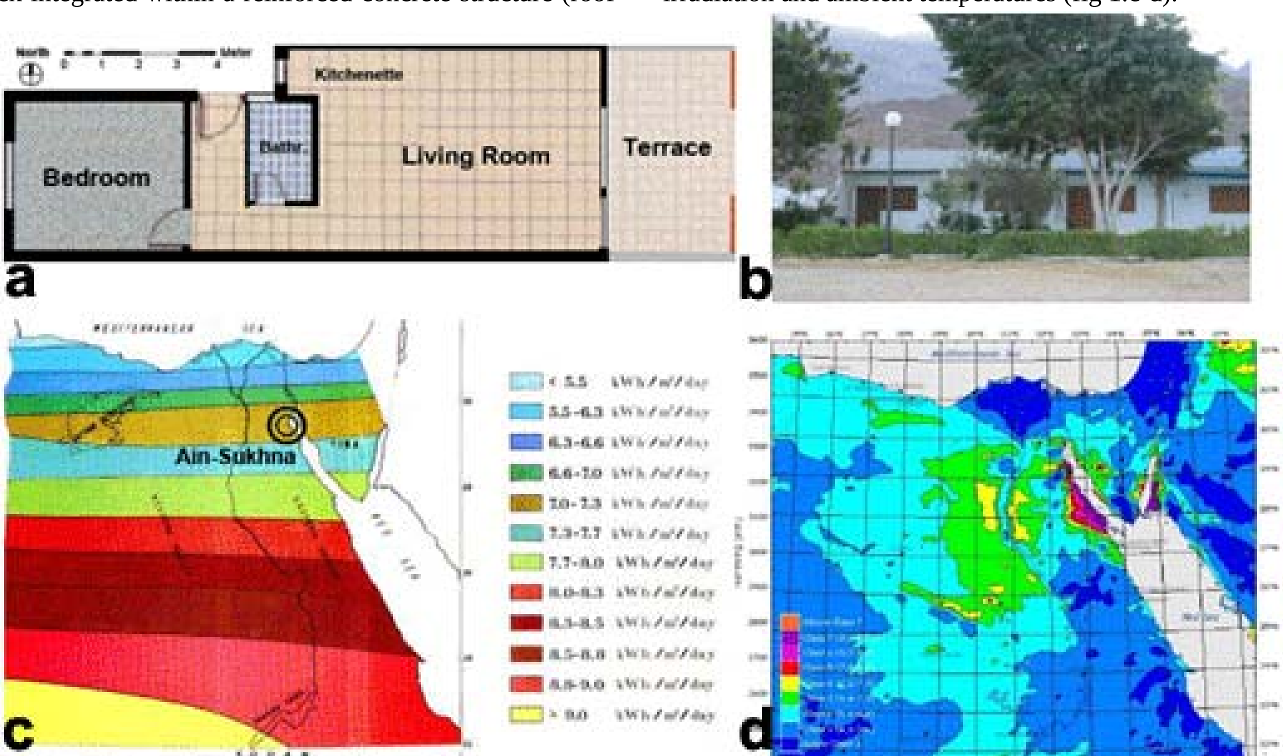

Figure 1a: Chalet floor plan, Fig.1b: Array of single floor chalets, Fig.1c: Ain-Sukhna location & average annual solar irradiation in Egypt [6], Fig. 1d: Wind resource map [7]

3.3 Electric Demand Analysis

After investigating the bioclimatic site conditions, the research defined the internal loads for the Chalet. Since electricity is the only source of energy for the Chalet, a month-by–month electricity consumption compilation was done. The number of total kilowatt hours (kWh) consumed in 2006 was 3486 kWh. Next, a field survey for appliances and lighting usage patterns was conducted for the month of August. The results of this survey, in addition to the monthly bills were collected and utilized to breakdown the total consumption and calculate the cooling and heating loads (Fig.2 and 3). According to figure 3, the required cooling energy is extremely high as heat gains are also high. The main reason for this is the absence of a thermal insulation and bioclimatic building skin treatment. For such a small chalet, the internal heat gains are not dominant. From an energy point of view, the energy loads are skin dominated.

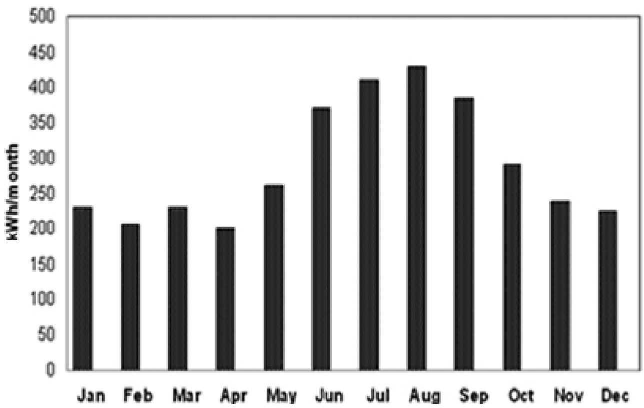

Figure 2: Average monthly electric demand

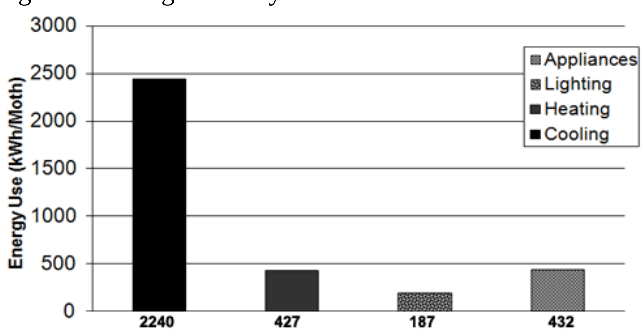

Fig. 3: Energy consumption in August 2006

4. DESIGN STRATEGIES

4.1 Strategy 1: Reduce Heat Gain, Thermal Skin – Insulation:

The first step that can reduce heat gain significantly is to install an external thermal insulation. This was done to maintain effectiveness of thermal mass. The strategy suggests building new external walls, 250mm wide, from silt-brick working as a second-skin façade over the original. Also a 60 mm polystyrene insulation is recommended to increase the wall resistance up to R-3.70 (Egyptian Standard = R-1.1). For the roof, an 80 mm polystyrene insulation will increase the resistance up to R-5.23 (Egyptian Standard = R-2.8). Table 1 describes the material characteristic and R-Value for the new building skin construction. This new strategy complies with the Egyptian Energy Standard (ECP306-2005), which is implemented on a voluntary basis. Moreover, to achieve high albedo surfaces, the walls will be painted with white semi gloss paints and the roof tiles will be made from white cement [9,10].

Table 1: Proposed Building Skin R-Values

1)Concrete Slab Roof	**2)Silt-Brick Wall**
Outside surface air film = 0.04	Outside surface air film = 0.04
Wht Cmnt Tiles 20 mm=0.018	Mortar 10mm = 0.00995
Mortar 20 mm = 0.020	Silt-Brick 250 mm = 0.312
Sand 60 mm = 0.060	Plaster 20 mm = 0.0199
Water Proofing 5 mm = 0.035	**Plstryne Insul. 60 mm = 3.70**
Sloped Conc. 50 mm= 0.050	
Conc Slab 120 mm = 0.068	
Plstryne Insul. 80 mm = 5.23	Inside surface air film = 0.18
Inside surface air film = 0.11	
R-value (m^2 K/W) = 5.631	**R-value (m^2 K/W) = 4.27**
U-value (W/m^2 K) = 0.177	**U-value (W/m^2 K) = 0.234**

Shading and Windows: Also to avoid the solar gains in the chalet and consequently reduce the cooling loads, openings require improved glass surfaces and shading devices. Overhang shading devices should admit low angle sun in the morning or winter when heat is needed, screen the sun in the middle of the day and in summer when overheating is a risk. The first step is to replace all single pane windows with 2.5R double-pane windows (low-e) with a 6mm air space. Second, is to add shading devices to the east-façade. Since the main window is facing east and the window dimensions are 2.4 m by 1.2 m the chalet requires an overhang. The overhang will be cantilevered for 1 meter, to protect the living room from the sun between April and October as shown in figure 4.

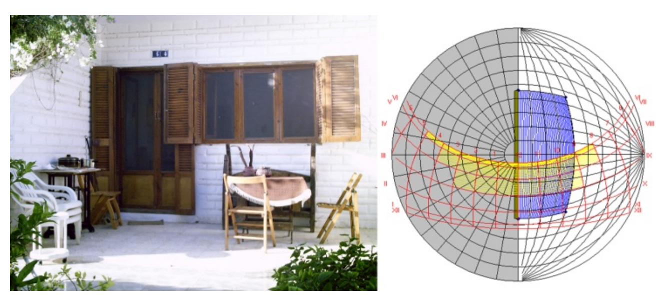

Figure 4: The chalet east-façade and Sunpath tool result

4.2 Strategy 2: Reduce Internal Loads

Daylight and Appliances: The existing daylighting system is acceptable in the chalet based on the owner's opinion. The openings were mainly designed to maximize the view therefore glare cannot be avoided without compromising the view. Meanwhile, the existing window wooden blinds are a sustainable solution to manually control illuminance and daylight distribution. Besides, all artificial lighting sources are going to be replaced with low energy lamps in addition to efficient appliances. In particular, all 80 watts CFL will be replaced with efficient 50 watts CFL. Next, the 1200 watt AC will be replaced with an efficient 900 watt unit.

4.3 Strategy 3: Passive Cooling

During spring and autumn, passive cooling can be provided through natural ventilation. The building should be prepared to allow air to flow through the building at night and when outside temperature is lower than inside the building. The chalet design was revised to make sure that openings and doors with built-in vents will allow cross air ventilation. In fact, while verifying the success of this strategy is not within the scope of the study, however, in a later phase of the research its effect could be quantified through real measurements and computational fluid dynamics (CFD) simulations.

4.4 Strategy 4: Solar Thermal System (STS)

A market survey suggested using the thermosyphon for economical reasons. The NGO-150 solar thermosyphon was selected. The thermosyphon has an annual solar fraction of 93% (5 %) and the daily consumption is 150 liter/day with an average temperature of 50 ^{o}C. The expected energy produced by this system is equivalent to 1,224 kWh/yr. The 2m^2 unit will be installed on the roof and inclined to the south with a tilt angle of 42^{o} from the horizontal because the thermosyphon will be turned off during the summer. Besides, the existing electric water heater would be kept as an instantaneous back up water heater.

4.5 Strategy 5: Solar Electric System

The electricity consumption analysis shows that the chalet consumes approximately 3.5 MWh/yr. After implementing the previous mentioned strategies to the model, TRNSYS [11,12] simulation estimated a reduction of 1600 kWh/yr. This step was fundamental prior to sizing the PV panels. Now, the chalet needs approximately 2 MWh/yr. After consulting several companies in Egypt, most of them agreed that 10 m^2 of PV panels will yield approximately 2.1 MWh annually. The chalet is considered as grid-connected with a 1.1 kWp system. In fact, the available modules in the Egyptian market are assembled from polycrystalline cells (module efficiency 10.5%) and can be mounted on the flat roof with 29^{o} inclination. Figure 5 shows the predicted system output.

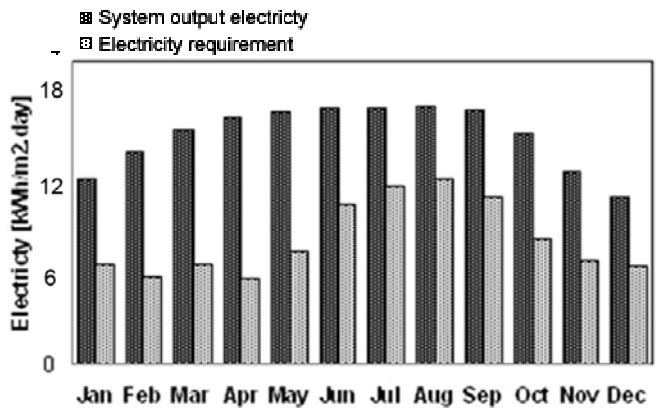

Figure 5: System output vs. demand

4.6 Strategy 6: Wind Turbines System

Despite several existing wind farms that are spread all over the Red Sea Coast, there is no trace for small-scale wind turbines in Egypt. Even research centers did not install any of those recently marketed small wind turbines. The study however, will proceed with building up the case, using a small-scale wind turbine (D400 Wind Turbine). The total weight is 15 kg and the diameter is 1.10 m. The turbine head will stand 2.20 m above the roof requiring an average wind speed of 5 m/s. In addition, an inverter, which turns the wind-generated electricity from DC to AC, has to be provided. The turbine will produce between 0 and 10 kW hours per day, depending on the prevailing wind speed. A realistic annual yield would equate to 1.8 kW hours per day.

5. RESULTS

5.1 Energy Performance

The chalet was modeled using TRNSYS to analyze the existing and combined effect of the integrated design strategies. First, the base case was modeled. Several iterations took place to match the predicted electric consumption with the 2006 billed kWh. Secondly, each strategy was separately integrated in the model and compared to the base case to determine the energy savings that would be achieved.

Table 2: Share of each passive strategy in the reduction,

Passive Design Strategy		Before-	After kWh	Reduction%
Reduce Heat Gain	Walls & Insulation	2440	1680	-40%
	Shading Device			-2%
	Windows Glazing			-6%
Reduce Internal Loads	Efficient Lamps	187	85	-6%
	Appliances	432	107	-20%
Total share of reduction		**3486**	**1862**	**-74%**

Table 3: The PV panels and wind turbine generated 2760 kWh/yr.

Active Design Strategy		Before-After kWh		Reduction%
STS Thermo.	DHW	427	110	-26%
Total share **of reduction**		**3486**	**1872**	**-26%**
Active Design Strategy		**After**		**Generation %**
SES	PV panels	+2100		+112%
Wind Turbine	Wind Turbine	+660		+ 35%
Total share **of generation**		**0**	**2760**	**+147%**

Table 2 shows the passive design strategies vs. savings. In fact, passive design strategies achieved a total annual energy saving of 48%. The largest savings was achieved from the building envelope retrofit (48% savings), followed by the installation of the solar thermosyphon for space heating and domestic water heating (26% savings). Also improving the appliances efficiency helped in cutting down the total energy demand (20% savings). The implementation of the previous strategies had a significant impact in reducing the chalet energy consumption to 1872 kWh/yr. The PV panels were seized to deliver 2100 kWh/yr with the addition of a small-scale wind turbine, which is expected to deliver 660 kWh/yr. In fact, the chalet meets the zero energy objectives. Table 3 shows the expected annual yield after implementing the active strategies. The study shows that an annual energy surplus design could be achieved by combining all strategies. Finally, all implemented strategies were ranked based on the energy efficiency as shown in figure 6.

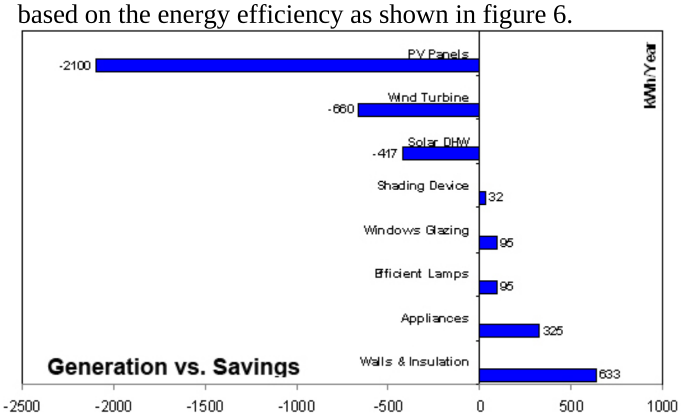

Figure 6: Ranking of energy-efficient strategies

5.2 Economical Feasibility

The aim of the economic analysis is to compare the cost-effectiveness of the energy-savings or generation for each design strategy. The analysis was performed using economic analysis method described in ASHRAE [13] and by Haberl [14]. The cost analysis is based on the utility rate in Egypt for the year 2007. There are many inputs for the economical feasibility analysis. In Egypt, the utility rate is 0.01 US$ per kWh for residential units, however, because the chalet is located in the Red Sea tourism development region, the rate is 0.05 US$ per kWh. The effective tax rate is 20% and the utility inflation rate is assumed as 4%. Table 4 shows the retrofit strategies with the cost analysis. The economics of each strategy is explained separately. Starting with the envelope, the cost of the retrofit is 2520$. This step has reduced the electric consumption by 21%. The retrofit included the new wall construction, insulation, shading device and new windows. The 800mm polystyrene insulation is the most expensive part that will cost alone 1250$. This cost is considered very high with a payback of 19 years.

The most cost effective strategy is the installation of a solar thermosyphon which will cost $935. The expected life time of the system is 15 years. The average annual utility savings are $71 and $1,063 for 15 years. Moreover, the payback including the property value appreciation is 2 years (net cost - property value increase / before tax average annual utility savings) or 7 years without the property value appreciation. The calculation shows that installing the thermosyphon will increase the value of the chalet by $780 based on an effective tax rate of 20% (before tax average annual utility savings = average annual utility savings / 1 – 20%). From an economic point of view installing a solar thermal system is economically rewarding. The system is manufactured in Egypt and can be easily installed and maintained.

However, the cost of the 10 m^2 PV panels, which is $13,255, is too high. The expected life time of the system is 25 years. The average annual utility savings are $374 and $9,355 for 25 years. Moreover, the payback including the property value appreciation is 19 years or 28 years without the property value appreciation. The calculation estimates that the PV panels will increase the value of the chalet by $4,320. But since (1) there are no incentives for installing PV panels, (2) utility rates are low due to subsidy and (3) surplus electricity generated by the system will not be credited back to the utility bill, installing a $13,255 system will is not economically feasible at the moment.

For the small-scale wind turbine the manufacturer confirms a 25 years life expectancy with a $500 replacement after 15 years. This means that the total cost will be approximately $3600. For a 660 kWh/yr wind turbine, the average annual utility savings is only $70. In fact, the payback including the property value appreciation is 26 years or 41 years without the property value appreciation. Also there are no providers for such a system in Egypt. The assumption is based on importing the unit from the UK. Table 5 and Figure 7 list the total cost for each strategy with the relevant payback period.

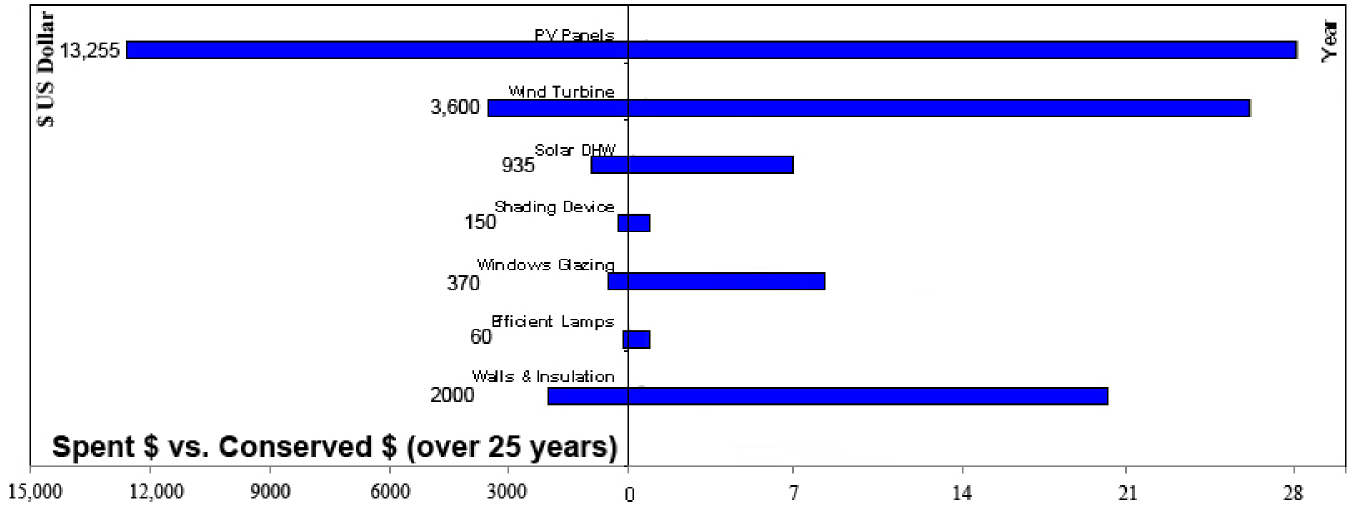

Figure 7: Ranking of design strategies according to cost and payback

Table 4: Cost analysis for installations and construction,

	Total Cost (US $)	Payback years
Walls & Insulation	2000	19
Shading Device	150	
Windows Glazing	370	
Efficient Lamps	60	<1
Thermosyphon	935	2-7
PV panels Inverter	13255	19-28
Wind Turbine Inverter	3600	26-41

Table 5: Total cost vs. Payback

(US $)		Items	Installation	Total
Envelope	Walls	575	175	750
	Insulation	1,200	50	1,250
	Shading Device	120	30	150
	Windows Glazing	320	50	370
Efficient Lamps		60	0	60
Thermosyphon		835	100	935
PV panels incl. Inverter & Batteries		13,120	135	13,255
Wind Turbine*		1,800	200	3,600
Inverter		1,600		

*Not available in the Egyptian market

6. CONCLUSION

This study investigated passive and active design strategies for an existing chalet in order to reach a zero energy retrofit. In this way the study is deliberately forward looking, evaluating and assessing the energy potential and economic feasibility providing an examination and vision for designs that may soon be implemented. First, it was especially important to determine the monthly average of kWh usage and the site's bioclimatic parameters. This step allowed understanding the user's consumption pattern and acquiring a basecase for energy use after the implementation of different passive and active strategies. On the energy level, the passive design strategies demonstrably have the potential to reduce the consumption of the basecase by 48%. Improving the envelope properties and design in addition to installing efficient appliances and lamps can create this result. The remaining 52% would be delivered through the active design strategies. One of the most significant results of the study is that the bioclimatic site potential can sustain zero energy developments. The intensity of solar irradiation and wind speed are indeed present year round and are strong enough for this purpose.

However, on the economical level, most active strategies are not feasible. The CFL and solar thermosyphon for DHW were the only exception, with a less than 1 year and 2-7 years payback period. There are two main reasons behind that. The first, electricity prices are still low because the Egyptian government subsidies the energy. The second is the lack of incentives and the lack of building codes for existing buildings. Nevertheless, in the future cost can change rapidly because already the government decided lately to discontinue subsidizing energy [1]. Also, cost can vary significantly if the Egyptian institutions adapt an energy conservation policy and if solar (electric and thermal) systems become locally manufactured and commercialized.

Finally, the research highlighted the energy and economic potential for different design strategies for an existing individual unit. Until now, the barriers are mainly economical and technological in Egypt. However, renewable resources are available in Ain-Sukhna and the Red Sea Region. The demonstrated viability of the solar thermal system might be expanded to other applications. This means that future research might consider investigating the design of solar thermal systems on a district scale development and examining the potential of thermal energy for air conditioning.

7. ACKNOWLEDGEMENTS

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