Strategic Decision Making For Zero Energy Buildings in Hot Climates

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Abstract

The Net Zero Energy Buildings (NZEBs) objective has raised the bar for sustainable development among architects and developers in hot climates. The objective of this paper is to investigate the influence of setting a zero energy objective for existing buildings in hot climates. The paper compares the impact of passive and actives design strategies on energy consumption and comfort. Using EnergyPlus for energy simulation, an existing prototype of a residential apartment module will be used to evaluate energy performance and thermal comfort in two parametric series. The first one is the result of passive design strategies and the second one is guided by active solar strategies. Results show active design strategies can be reliable for constant energy generation for buildings in the existing urban context. However, the zero energy building objective needs to be the considered from early design phases during urban and architectural design process.

1. Introduction

The Net Zero Energy Buildings (NZEBs) objective has raised the bar of building performance and will change the way building are designed and constructed. The building design community at large is triggered by mandatory codes and standards that aim to aim to reach a zero energy built environment [1-3]. On the other hand, the design and implementation of NZEBs in hot climates has been scarcely studied. Most energy efficiency research is conducted with cold climate in mind. Perhaps because industrialised countries spend about twice as much energy for residential heating as they do for cooling [4]. Thus the body of knowledge for NZEBs is growing mainly there.

However, economic changes in hot climate regions are occurring fast. In non-industrialized countries including Brazil, China, Egypt and India residential energy consumption rises by 2 percent per year, compared with 0.4 percent per year for the OECD countries (Organisation for Economic Co-operation and Development). In those emerging countries the patterns of residential energy use are well established and faster population growth and young populations translate to larger increases in energy demand [4-5]. Therefore, it is essential to address NZEBs design in hot climates.

This paper is a presentation of the initial findings of a research project concerning the design of NZEB in hot climates. The project aims to examine the potential benefits and feasibility of NZEBs and to investigate design and simulation methodologies. The projects will consider wide range of building typologies and design strategies but this paper is concerned with a particular case for a residential apartment module. The aim of this paper is to develop a basis for strategic decision making of NZEB design by comparing active and passive design strategies in hot climates. The methodology used consists of screening the design strategies suitable in hot climates. The study includes an inventory of suitable design settings that can be used as solutions for NZEBs. Then a typical basecase building is selected for simulation analysis to exmaine two parmetric series of passive and acive design strategies. The building energy use analysis will be performed using the EnergyPlus v.5 program aiming to conduct global parametric analysis where the parameters are varied. Finally, analysis of result provides guidance on the strategic design decision making for NZEBs.

2. Design principals and building strategies for NZEB in hot climates

By default NZEBs benefit from abundant renewable energy sources such as direct solar radiation, wind and the earth's thermal storage capacity. Implementing of design strategies that takes advantage of these natural energy sources in building design contributes to lowering the energy consumption and generating its own energy needs [6]. This section reviews design solutions for residential buildings in hot climates and list multiple passive and active climate-responsive strategies and solutions.

In hot climates, it is always necessary to avoid sensible and latent heat gains in every possible way and to achieve comfort conditions while minimizing energy consumption. Therefore, passive design solutions couple two major strategies, heat rejection and heat release [7, 8]. The heat rejection strategies are environmentally protective and include solar and thermal control in addition to thermal zoning or buffering concepts [9]. The heat release strategies are environmentally reversing the heat effect through cooling and include passive cooling techniques. Similarly, active design solutions aim to reject and release heat but mechanically. However, the difference between active and passive design strategies is not only the mechanical intervention, but it is also the generation of thermal and electric needs on site. These main differences are illustrated in Figure 01 and discussed in the following paragraphs.

2.1. Passive Design Strategies:

Solar Control: The envelope is commonly the element of a building that is most exposed to the sun. Solar radiation absorbed by the envelope surfaces raises he surface temperatures, driving heat transfers toward the interior buildings, as well as the ambient air and sky. The peaks in surface temperatures are affected by solar radiation and thus the design of building envelope should seek to control the absorption of solar radiation and its effect indoors. This should be achieved by sun protection and shading of the envelope to reduce incidence of direct solar radiation. The optimal choice of orientation, building compactness, window to wall ratio (WWR) and form is important. Light coloured external finishes can also reduce absorptance of solar radiation. Shade trees and ground cover can also help if properly placed to block the sun and reduce the reflectance [10].

Thermal Control: Thermal and humidity control are essential for the building skin in hot climates. The thermal exchanges between buildings and the outdoor micro-climate depend on the temperature difference between inside and outside, as well as on the exposure and thermal properties of external building elements. The use of wall cavities, thermal mass, thermal insulation, and external reflective materials, can help prevent heat gains and suppresses these exchanges.

Thermal Zoning: The positioning of the building spaces with regard to the path of the sun, prevailing winds, and openings locations can lead to improved thermal comfort in relation to the functions and climatic requirements. In hot climates, the concept of thermal zoning or heat buffering entails creating intermediate semi-controlled outdoor zones that serve as an active double skin. These outdoor zones serve to block the heat in the mass of spaces and include courtyards, deep veranda, porches and earth sheltered partitions of buildings. A combination of shade and natural ventilation also plays a key role in the process of thermal zoning aiming to improve the internal temperatures.

Passive Cooling: The application of passive cooling is most appropriate to release the heat in buildings in hot climates. This includes evaporative, cooling of outdoor air supplied to a building for ventilation, or radiative and convective cooling to cool the buildings structure. Passive cooling includes also ventilation. Ventilation is the provision of a fresh air supply necessary for occupant health and hygiene in buildings. The ventilation process consists of a rate of air exchange that can vary as a function of fresh air requirements, as well as the mechanism of air supply [7].

2.2 Active Design Strategies

Active design is referred to mechanical and technological solutions, as is illustrated in Figure 01. The active design strategies include electric and thermal energy generation (photovoltaic panels, wind turbines, thermosyphons etc.), movable sun protection, active cooling (solar assisted or conventional HVAC), artificial lighting and mechanical ventilation. One of the most discussed topics concerning active strategies for NZEBs is the efficiency of the equipment and appliances that achieve those strategies. This includes efficient HVAC equipment, efficient household appliances and high performance ceiling fans.

2.3. Inventory of Passive and Active Solution Sets for NZEB in Hot Climates

Climate-specific strategies hint to climate-specific solutions. An inventory for passive and active main solution sets for NZEBs is presented in Figure 01.

3. Evaluating Passive and Active Design Strategies

To analyse the influence of active features and passive design, a residential apartment module was studied in the city of Cairo, Egypt (30.1N, 31.4E). Since the selected case is an existing building not all design strategies discussed in section 2 was implemented. Only design strategies that can be classified as add on were selected to optimise the performance of the existing building aiming to reach the zero energy objective.

3.1. Climate Characteristic

Geographically, Egypt is part of the mid-latitude global desert zone and its climate is considered extremely hot and dry according to Köppen Classification (Group B) [11]. The only exception is the north region adjacent to Mediterranean Sea, which is considered as hot and humid climate due to the effects of the sea. The apartment block is located in a residential community called New Maadi located in the south east of Cairo, 3.6 km east the Nile. The weather patterns in Cairo are characterized by being extremely hot and dry (Group BSh-Hot subtropical steppe, according to Köppen Classification). Average annual precipitation is 11mm; average daily temperature during July is 35.4 ^{o}C; summer temperatures above 40^{o}C are not uncommon and often temperatures rise above 39^{o}C. Average summer relative humidity is 62%. According to ASHRAE classification Cairo falls in zone 4B (Mixed Dry) with 424 HDD and 1859 CDD.

3.2. Apartment module description

The apartment module is part of a typical apartments block in Cairo. The apartment block is a free standing structure 30 m × 20 m with 9 stories and 4 apartments per floor. The block is elongated along an east-west axis. The south and east facades face two main streets (20m wide) and the north and west facades face two internal streets (8 m wide) as shown in Table 01a. All apartments have a concrete structure and brick walls without thermal insulation. The amount of glazing is 46% for the elongated facades and 40% for the shorter facades of the total wall area. There is no solar protection for the facades.

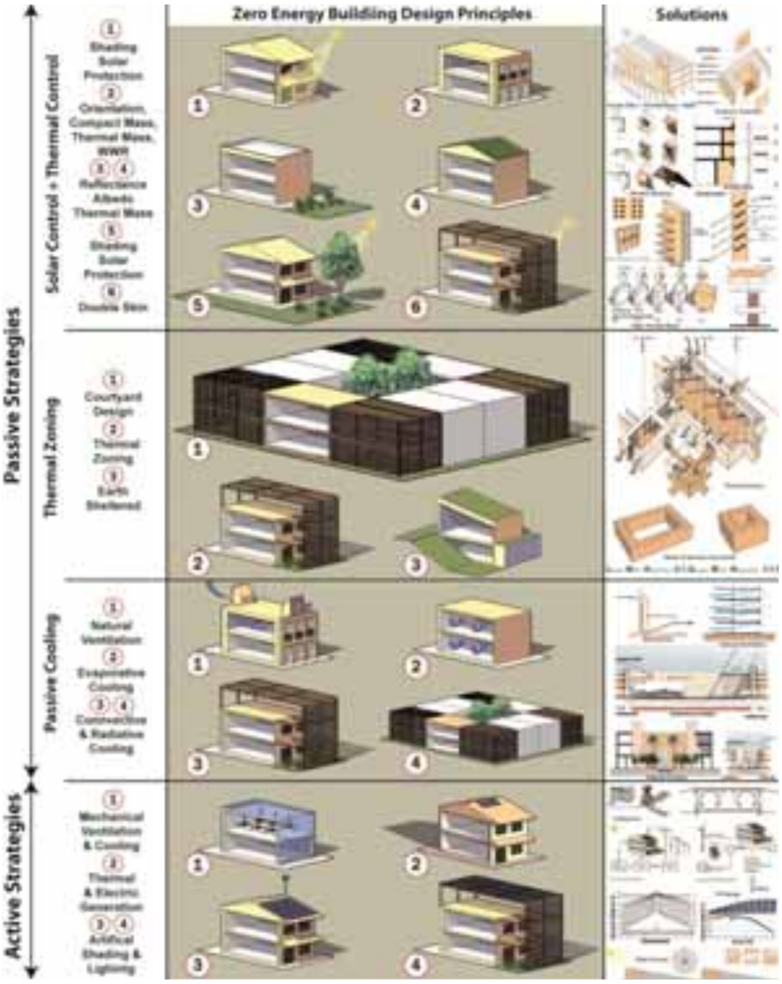

Fig. 1. Inventory of passive and active solution sets for NZEB in hot-humid climates

The building features split HVAC system units in each apartment (DX-cooling) for space cooling and an electric heater for domestic hot water (DHW). The basecase module has dimension 15 m × 10 m × 2.7 m. Table 1b, lists the general description of the sample building and some properties for the construction sections used, respectively.

In the study approach, two variations parametric series were performed, representing the two different strategies. The two strategies were referred to as passive strategies and active strategies to represent a reference point for the energy analysis. The properties of the new variations are listed in Table 1. The basecase variations were simulated using the EnergyPlus building simulation program. Simulation was conducted to determine the building annual energy consumption and the peak load. Several iterations took place to match as possible the field survey for electric consumption. A typical meteorological year (TMY2) of climate data in Cairo was considered for simulations.

3.3 Comfort criteria and Bioclimatic Analysis

In hot climates thermal comfort in buildings is crucial to determine the periods where passive strategies function appropriate without compromising comfort. In the analysis of passive strategies we have applied the PMV-Model, developed by Fanger and the adaptive model in ASHRAE standard 55-2004 that are

Table 01. Basecase building characteristics

Basecase Module	General Characteristic
Shape	Rectangular (15 m × 10 m)
Height	2.7 m height per floor
Volume	324 m^3
Wall area	120 m^2
Roof area	96 m^2
Floor area	120 m^2
Windows area	12.24 m2, 34% of total wall area
Exterior Wall U-Value	1.78 W/m2 K
Roof U-value	1.39 W/m2 K
Floor U-value	1.58 W/m2 K
DHW system:	100L Electric water heater,0.86 EF

based on earlier research by Brager and De Dear [12, 13]. The adaptive model allows us to depends more on the adaptability of humans and their environment and maintain upper limits of thermal comfort during extreme warm periods. Both models have been applied to the bioclimatic analysis in order to predict different operational simulation periods (schedules). Figure 2a shows the primary climatic assessment for the suggested passive design strategies [14]. On the other side, Figure 2b shows three different operational periods defined using dynamic simulations. The result of this analysis defines three major periods when the building is naturally ventilated, fans ceiling ventilated and mechanically ait conditioned.

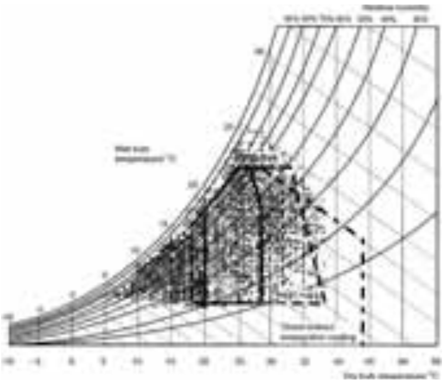

Fig. 2a. Psychrometric chart analysis for Cairo

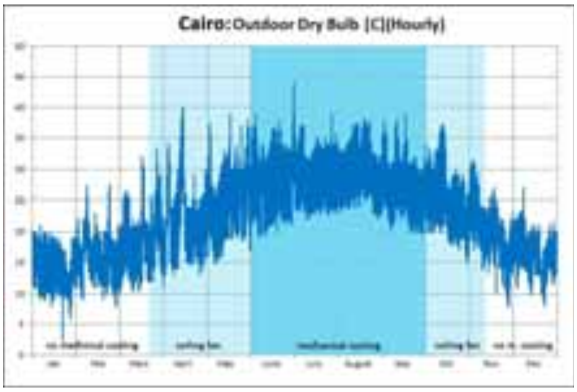

Fig. 2b. Operational periods defined using simulations

3.4 Parametric Analysis

The first series of variations (numbers 1-10, see Table 2) improves the basecase by implementing passive design strategies principles featuring the principals discussed in Section 2.1 and 2.2. The original design characteristics are kept, while the performance of individual changes is observed. Some parameters including the orientation and building compactness were not changed due the physical building constrains. However, many other passive strategies were implemented to the apartment module including shading, thermal mass and natural ventilation. The second series (11-16, see Table 2) improves the basecase through actives design strategies. For the sizing PV solar system the calculations were based on using the maximum available surface area on the roof for one apartment module (15m^2). The annual and monthly electrical energy use was obtained from the EgyPV Estimator program [15]. The input values for EgyPV Estimator are listed in Table 2.

Active feature have changing patterns in space and time making it difficult bridge the natural energy supply and building energy demand. Therefore, the simulations were used on a detailed time basis with 12 time steps per hour, not only to determine the total energy consumption but also determine the energy demand and supply match and critical instances. EnergyPlus was used to perform a parametric analysis for every parameter in relation to the total consumption [16].

Table 2. Base-case building characteristics (only the values in bold are used for this study)

	Parameter	Parameter Value
Passive Strategies	**1- Orientation**	N, NE, E, SE, **S**, SW, W, NW (no change)
	2-Building Compactness	(no change)
	3-Light shelves	**0.5 m**, 1.0 m
	4-Overhang	**Projection Factor 0.6** (1.5 m wide roof eaves,)
	5-Blinds	**Internal rolling blinds, Shading coefficient >0.5,** External rolling blinds, Shading coefficient: <0.5
	6-Insulation	R-10, **Floor U-value: 0.35 W/m^2 K,** R-55, **Ceiling U-value: 0.29 W/m^2 K** R-15 cavity + R-30 insulation, **Wall U-value: 0.4 W/m^2 K**
	7-Thermal Mass	Light, **medium (160 kJ/m^{3}K)**, heavy wall
	8-Glazing	**U-value: 0.14**, **SHGC: 0.48**, Fiberglass frames, 15%, 20%, **25%**, 30%, 35% window size of wall area
	9-Albedo	0.5, **0.7**, 0.85
	10-Night Ventilation	1, 4, 10, **20**, 30 ACH
Active Strategies		
	11-Ceiling Fans	**0.7 m/s High Performance Fans**
	12-Efficient Lights	**0.05 kW**
	13-Plug Loads	**7 W/m^2**
	14-HVAC efficiency	**2.58 COP**
	15-Solar Hot Water	2m^2 collector area, **160 L** storage (Thermosyphon)
	16-Photovoltaic System	PV, monocrystalline, efficiency 14%, nominal power **2.24 kW** per apartment (area= 15m^2, tilt=0°, azimuth=0°)

4. Analysis and Results

The simulations results are presented in Figure 3a-b. Figure 3a, compares the basecase with the NZEB case after implementing the passive and active strategies. The figure illustrate the yearly energy performance including the electric consumption for cooling, DHW, plug loads and lighting. The implementation of passive and active design strategies (excluding PV and Thermosyphon) achieved high reductions in energy consumption relative to the basecase. The cooling loads were reduced by 46% and the plug loads was reduced by 19% and the lighting by 55%. The space heating demand was eliminated due to the effect of insulation and the DHW loads are met by the solar thermal system. The total energy consumption reduction relative to the basecase is 45%. The basecase consumption was reduced from 24.8 kWh/m^2/year to 13.7 kWh/m2/year.

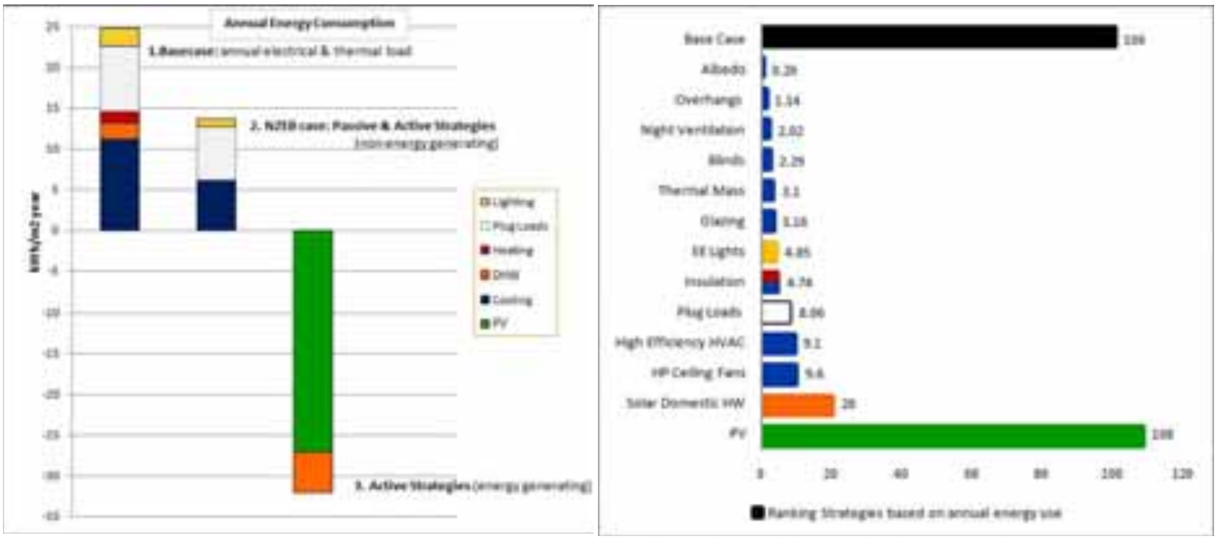

Fig. 3a. Basecase vs. NZEB energy consumption, 3b. Ranking of design strategies

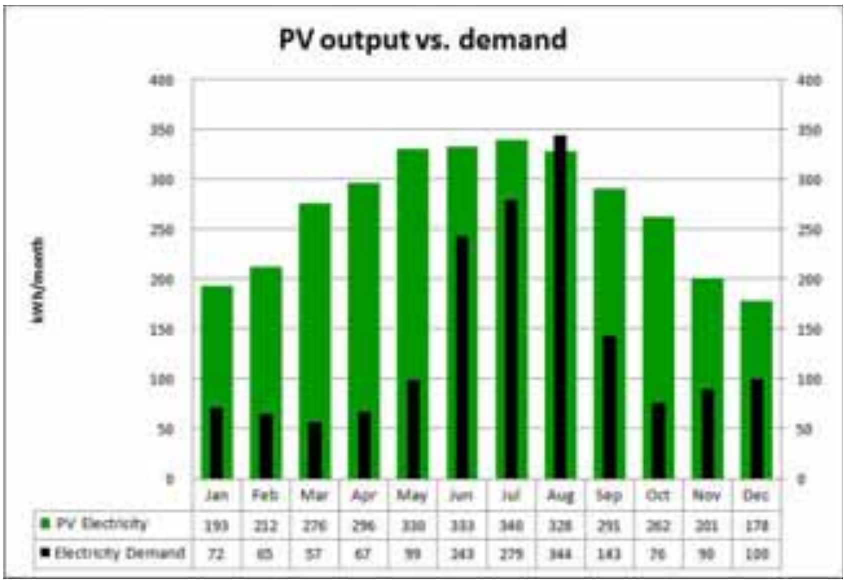

Fig.4 Monthly PV output vs. Electric demand

The implementation of energy generating active strategies (PV and Thermosyphon) met the electric and thermal demand generating almost the double (197 %) of the building electricand thermal (250%) needs on an annual basis. However, by analysing the electric output on a monthly basis the electricity demand in August exceeded the generation (Fig. 4). Apart from the active generating strategies the most three influential energy conservation measures were the installation of high performance ceiling fans, high efficiency air-conditioners and shaving the plug loads to a 7 W/m2. The insulation in particular succeeded to eliminate the space heating loads (Fig. 3b). Finally the combination of both strategies met the building demands exceeding the NZEB objective.

5. Discussion & Conclusion

The results demonstrate that the apartment module meet the zero energy use objective. Despite that not all passive and active design strategies were tested the case allows us understand the building performance in such a hot climate. Most studied strategies are less architectonic and more active and technical. Results indicate that the most influential indoor strategies were the installation of efficient ceiling fans, efficient AC and controlling plug loads. Controlling the plug loads in theory is feasible but not guaranteed in real building life because it is dependent on occupants' behaviour. The following most strategic decisions are the installation of efficient glazing, insulation and lighting equipments. Surprisingly, the thermal mass in combination with nocturnal ventilation was not effective due to the small temperature difference between day and night. Concerning the active energy generating systems the installation of a thermosyphon is an effective strategy. The PV system requires more experimental study. Figure 00 proofs that there is a relative monthly match, except for August, between solar electric generation patterns and cooling demand patterns. However, a more detailed study should be conducted for more precise PV sizing in relation to the electricity grid. In order to optimize the match in general and in particular the daily match during summer and winter and its effect on the daily peak load. Matching the solar electric energy profile to the urban residential demand is very important. In the case of Cairo, the results of ranking the passive and active strategies are useful for future residential apartment renovation plans. However, the ranking of the strategies will change if coupled with the local electricity prices, life cycle assessment (LCC) and cost parameters. The existing situation of the local context should determine the decision.

The results also highlighted the importance of maintaining comfort in the apartment module in relation to the dynamic severe climatic conditions. The basic idea of a NZEB in a hot climate is to provide comfort in close interaction with the dynamic conditions in the built environment. Achieving that requires a patch work of different design solutions and strategies to provide comfortable and energy independent buildings. The passive strategies are essential to optimise the performance; however the NZEB will only be achieved through mixed mode systems and hybrid mode mechanism.

Due to the building settings the study results were more focused on add-on post-construction active strategies. However, a successful NZEB should implement design strategies during early design phases within a multidisciplinary process. Passive measures are considered to be a first step NZEB design. Many simple passive design concepts already prove to be beneficial. Future work should also address NZEB design for new constructions.

Finally, the impact of different passive and active climate-responsive strategies on the seasonal comfort performance is theoretically studied in this paper. The methodology and design strategies presented in this study to reach NZEBs in hot climates could be applied for other cities in hot climates. However, the results are necessarily local. To make best of this study, NZEBs in hot climates must be responsive to their local climate.

References

[1] *IEA*-SHC *Task 40*, Towards Net Zero Energy Solar Buildings, . 2009: Montreal.

[2] ASHRAE, ASHRAE Vision 2020, Producing Net Zero Energy Buildings. 2008.

[3] Jukwey, J. (2010) EU agrees mandate for "nearly zero energy" homes. Volume,

[4] DOE/EIA, International Energy Outlook 2010. 2010, DOE/EIA.

[5] Sivak, M., Potential energy demand for cooling in the 50 largest metropolitan areas of the world: Implications for developing countries. Energy Policy, 2009. 37: p. 1382-1384.

[6] Torcellini, P. and D. Crawley, Understanding Zero-energy Buildings. ASHRAE, 2008. 10.

[7] Givoni, B., Comfort, climate analysis and building design guidelines. Energy and Buildings, 1992. 18: p. 11-23.

[8] Fathy, H., W. Shearer, and A. Sultan, Natural energy and vernacular architecture : principles and examples with reference to hot arid climates. 1986, Chicago: University of Chicago Press. xxiii, 172 p.

[9] Harriman, L., The ASHRAE Guide for Buildings in Hot and Humid Climates. Vol. 1. 2008, Atlanta: ASHRAE.

[10] Koch-Nielsen, H., Stay Cool : a design guide for the built environment in hot climates. 2002, London, UK: James & James. 159 p.

[11] Peel, M.C., B.L. Finlayson, and T.A. McMahon, Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci., 2007(11): p. 1633-1644.

[12] Brager, G. and R. De Dear, Thermal adaptation in the built environment - a literature review. Energy and Buildings, 1998. 27(1): p. 83-96.

[13] Nicol, F., Adaptive thermal comfort standards in hot-humid tropics. Energy Buildings, 2004. 36(7): p. 628-637.

[14] Attia, S. and A. De Herde. Bioclimatic Architecture: Design Strategies in Egypt. in Sustainable Energy Technologies,. 2009. Aachen, Germany.

[15] Attia, S. and A. De Herde. Sizing Photovoltaic Systems during Early Design A Decision Tool for Architects. in American Solar Energy Society. 2010. Arizona, USA: ASES.

[16] DOE. EnergyPlus. 2010, v.5, [cited 2010 May]; Available from: http://apps1.eere.energy.gov/buildings/energyplus/.