Bioclimatic Design in Casablanca: Decision Support through Building Performance Simulation

In this paper, bioclimatic design strategies in Moroccan architecture have been analyzed for the city of Casablanca.

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The aim of this study is to enable architects to re-understand the lessons of tradition, because the way towards bioclimatic architecture should start by understanding vernacular architecture. The first part of the paper presents climate analysis and a set of bioclimatic principles addressing orientation, shading, thermal mass, insulation and natural ventilation as a mean for passive cooling. The second part explores the potential of implementing the Passivhaus Standard in Casablanca. Based on a validated building model, the performance of one of an apartment, satisfying the Passivhaus Standard has been determined by means of building performance simulation. The analysis evaluated different bioclimatic strategies and examined the transfer of the Passivhaus concept to hot warm climate, while ensuring thermal comfort during summer. Results showed that the studied building concept, comprising several bioclimatic design strategies can be transferred, with appropriate adaptations, also to hot climates. Finally the study developed significant recommendation that support architects with principles and strategies for bioclimatic design.

INTRODUCTION

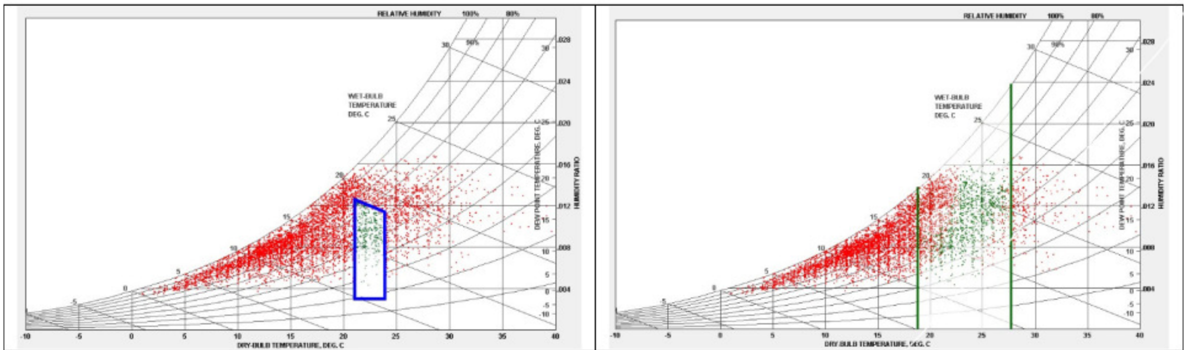
Morocco is full with examples from history that can teach us several architectural concepts allow minimizing the demand for energy used to cool the buildings in hot climates. Lessons, known as sustainable, vernacular, bioclimatic architecture, involve minimizing heat gain by the building, minimizing solar heating of the envelope and solar penetration through windows and so on. Bioclimatic design employs appropriate technologies and design principles based on thoughtful approach to climate and environment. [1,2] From this aspect, architecture is environmental, consuming from the natural resources of the environment the necessary minimum, without affecting it all. However, for the last 50 years, Moroccan practice abandoned the bioclimatic design and did not consider the existing vernacular buildings as the predecessors for a modern bioclimatic architecture practice. Instead, the built environment witnessed a continuous rapid urbanization, which does not respond to climate, coupled with rising use of fossil fuels and electricity. Therefore, the aim of this paper is to present the initial findings of a research project concerning the bioclimatic and passive design in hot climates. The project aims to examine the potential benefits and feasibility of the Passivhaus Concept and to investigate design and simulation methodologies.[3] 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 bioclimatic design by comparing different passive design strategies in Casablanca, Morocco. The methodology used consists of screening the design strategies suitable in Casablanca. The study includes an inventory of suitable design settings that can be used as solutions for Passivhaus Concept. Then a typical basecase building is selected for simulation analysis to examine two parametric series of bioclimatic and passive design strategies. The building energy use analysis will be performed using the TRNSYS and WUFI program aiming to conduct global simulation analysis where the parameters are varied.[4,5] Finally, analysis of result provides guidance on the strategic design decision making for the Passivhaus Concept in Casablanca.

BIOCLIMATIC ANALYSIS AND PASSIVE DESIGN STRATEGIES

By default bioclimatic design 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 climate and natural energy sources in building design contributes to lowering the energy consumption and generating its own energy needs.[1] This section reviews design solutions for residential buildings in Casablanca and list multiple passive and active climate-responsive strategies and solutions.

Climate Analysis : Morocco is located between the arid regions of the Western Sahara and the moderate Mediterranean and Atlantic regions. The arid regions are marked by weak seasonal variations with episodic rainfall, whereas in the Mediterranean and Atlantic regions moderate, wet winters and hot, dry summers prevail. Casablanca has a very mild Mediterranean climate (Köppen climate classification Csa). Casablanca's climate is strongly influenced by the cool currents of the Atlantic Ocean which tends to moderate temperature swings and produce a remarkably mild climate with little seasonal temperature variation and a lack of extreme heat and cold. Casablanca has an annual average of 74 days with significant precipitation, which amounts to 427 millimeters per year. The highest and lowest temperatures ever recorded in the city are 41.6 °C (107 °F) and −2.7 °C (27 °F), respectively.[6] According to ASHRAE classification Casablanca falls in Zone 3 (Humid Warm) with 1250 HDD and 1065 CDD.

Figure 1, shows a Psychrometric chart analysis and the corresponding passive design strategies for Casablanca. The climatic data has been incorporated into ASHRAE psychrometric chart, Milne and Givoni Diagram and Szokolay s' equation, and adapted those specifically for the city. Also an average comfort zone was derived for application in the three climate regions. With the aid of a computer program (Climate Consultant 5.4) and



Warm Humid Casablanca Lat 33.3 ºN, Lon 7.5ºW	Warm Humid Casablanca Lat 33.3 ºN, Lon 7.5ºW
ASHRAE Comfort ASHARE 2005	Adaptive Comfort ASHRAE 55
5.8% Comfort (504 hrs) 16.7% Sun Shading (1463 hrs) 9.6% Thermal Mass w. nocturnal v. (840 hrs) 1% Natural Ventilation (87 hours) 24.6% Passive Solar Heating (2157 hrs) 4.5% Dehumidification (394 hrs)	21% Comfort (1860 hrs) 19 % Sun Shading (1666 hrs) 2.4% Thermal Mass w. nocturnal v. (206 hrs) 16.7% Natural Ventilation (1467 hours) 14.5% Passive Solar Heating (1272 hrs) 14% Dehumidification (1228 hrs)
12.7% Fan Forced Ventilation (1114 hrs) 14% Cooling and Dehumidification (1233 hrs) 75.7% Heating and Humidiifcation (6629 hrs)	1.8% Fan Forced Ventilation (156 hrs) 4.7% Cooling and Dehumidification (412 hrs) 65.7% Heating and Humidiifcation (5751 hrs)

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the Department of Energy (DOE) weather file of Casablanca (Nouassera Airport) psychrometric charts were produced. The weather pattern for Casablanca was analyzed for a typical meteorological year. Figure 1 is showing a primary climatic assessment and the suggested passive design guidelines in correspondence with Casablanca's climatic regions. Hourly dry-bulb temperatures are plotted in a form of dots representing 365 days. The comfort zone is defined on the chart and every possible bioclimatic and passive design strategy is defined as percentages of hours that fall in each range of each strategy.

Design Principals and Strategies for Bioclimatic Design in Casablanca: In hot humid 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.[8,9] The heat rejection strategies are environmentally protective and include solar and thermal control in addition to thermal zoning or buffering concepts.[10] The heat release strategies are environmentally reversing the heat effect through cooling and include passive cooling techniques. These main strategies are discussed in the following paragraphs.

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

Figure 1: Psychrometric chart analysis and the corresponding passive design strategies for Casablanca[7]

and emissivity of solar radiation. Shade trees and ground cover can also help if properly placed to block the sun and reduce the reflectance. [11]

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. [12,13]

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. [13]

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.[8,14]

EVALUATING BIOCLIMATIC DESIGN STRATEGIES

To analyse the influence of bioclimatic design, a residential apartment module was studied in the city of Casablanca. The most influential design strategies for thermal control, solar control and ventilation were implemented. Also the impact of applying the Passivhaus Standard on thermal comfort was explored.

Apartment module description: The apartment module is part of a typical apartments block in Casablanca. The apartment block is a 2 facades standing structure, 22 m × 13 m with 6 stories and 3 apartments per floor. The block is elongated along an east-west axis. The south and east facades are attached to neighbouring buildings (13m wide) and the north and west facades face two internal streets (22 m wide) as shown in Figure 2. All apartments have a concrete structure and brick walls with thermal insulation. The Passivhaus is a 5 person family with a total net surface of 119 m². It has a considerable thermal mass; given by brick walls of 25 cm. Thermal insulation of the envelope is provided by 18 cm of mineral wool and windows with three glazed layers. The percentage of glazed surface amounts to 30%. An air exchange of 0.8 volumes per hour is guaranteed by a mechanical ventilation system with heat recovery in a counter flow exchanger. There is solar protection for the south facades.

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Figure 2: Basecase building characteristics

Simulation model: The basecase variations were simulated using the

TRNSYS and WUFI building simulation program. In the study approach, several variations parametric series were performed (Table 1), representing different strategies. The Passivhaus is a multi-zone TRNSYS model, which has been developed and validated during previous research, with a typical range of measured performances in comparable studies.[15,16] One of the major study requirements was to simulate the envelope's thermal flux and provide recommendations on thermal mass vs. insulation and the position of potential insulation layer (inner or outer). Simulation was conducted to determine the thermal comfort for the Passivhaus scenario.[3] Since all studied cases are equipped with mechanical ventilation system, the internal temperature was assessed applying the comfort limits of the Fanger model or PMV model.[17] This model is based on the correlation between climatic variables (temperature and relative humidity) and subjective conditions (metabolic activity and thermal resistance of the clothes). If the "predicted mean vote" or PMV index is within the range between -0.5 and 0.5, there are less than 10% of unsatisfied persons. All the strategies considered in this work had to guarantee a satisfactory level of comfort.

	Parameter	Parameter Value
Passive Strategies	**1- Orientation**	0º,90º
	2-Windows Shading	SF 0.2-0.4
	3- Insulation & Thermal Mass	Internal Insulation, 2cm
		External Insulation, 2cm
		28 cm Concrete
	Passivhaus	18-22 cm
	4-Envelope Insulation and Heating	18-22 cm
	5-Ventilation System and Cooling	1.8-2.5 ACH

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Table 1: Simulation model parametric variation

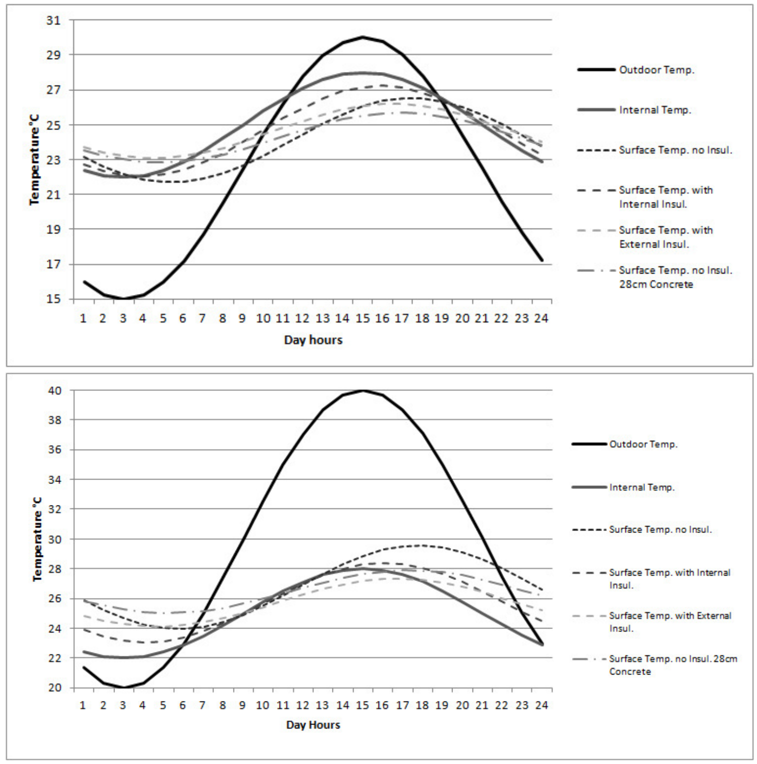
ANALYSIS AND RESULTS

The combination of bioclimatic strategies, evaluated in this study and adapted to Casablanca's conditions, are presented and discussed in following paragraphs.

Building orientation: Changing the orientation of the building from South to East had practically no significant effect – neither on the winter nor on the summer behaviour of the building: heating loads varied less than 0.4 kWh/m²/year were not much influenced. These results could be due to the particular geometry, the massive structure and the optimised structural shading of the Passivhaus.

Shading devices: The results of simulation with and without shading devices showed that solar gains can be reduced by 30%, which corresponds to a reduction of up to 1.2 kWh/m²a for Casablanca. This result is in the same order of magnitude than what was observed by Attia et al.[15]

Envelope Insulation and Thermal Mass : For a midsummer in Casablanca the averaged maximum temperature is about 30°C and the irradiation is 0.7 kW/m². During the parametric analysis the goal was to keep the wall temperature cool during the day and to improve the feeling of comfort (operative temperature). Figure 3a shows the impact of adding insulation and thermal mass on the internal surface temperature. The first intervention was simulating the internal surface temperature without any insulation. The second intervention was to add the insulation (2 cm rock wool) on the interior. Surprisingly, adding the insulation on the inside had a worse effect compared to not adding any insulation. The third intervention of adding insulation (2 cm rock wool) on the exterior was effective in reducing the internal surface 1°C. The fourth intervention of adding having a 28cm concrete wall with high heat capacity was the most effective in reducing the internal surface 1.5°C. Thus for average outdoor temperatures, the exterior insulation is almost as effective a thickening of the wall to maintain a fresh inner surface temperature. The 28cm wall with high thermal mass dampened the high amplitude of temperature variation between the outdoor ambient temperature and internal temperature for 2.5 hours. For shifting an outdoor



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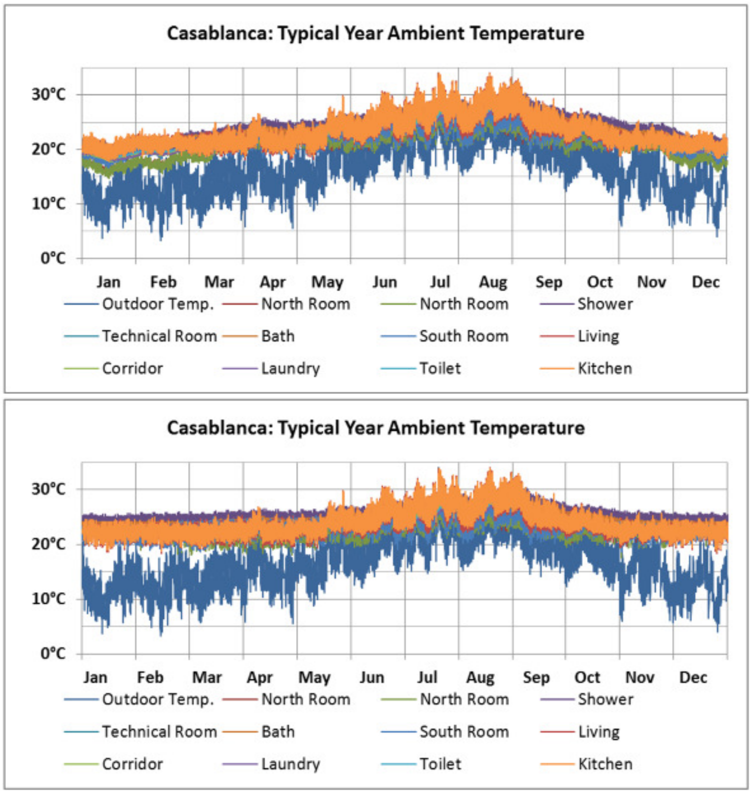
heat wave 6-7 hours until the outdoor temperature ranges below 21 °C for nocturnal ventilation the concrete wall must be 65cm of concrete. The wave is then depreciated 96%. Therefore, to provide damping temperatures interior, the building structure must be massive and accessible. Also it is essential that the thermal mass is associated with a cooling capacity of natural nocturnal ventilation.

However, for higher ambient temperatures during heat waves, the exterior insulation is more effective than wall thickening to maintain an inner surface temperature cool (Figure 3b). Thus the reduction of the thermal flux in Casablanca requires external insulation and thermal mass at the internal side to damp fluctuations. Thermal mass and insulation can either be separated or integrated in one material like sand brick (foamed concrete) or the typical Moroccan mud brick. However, the combined impact of these two measures is sensitive and difficult.

Envelope Insulation and Heating: The simulation results show the dependence of the heating loads on insulation thickness, the cooling loads are much less influenced. The simulations verified that the 18 cm insulation layer of outer walls did decrease the heating load drastically, allowing thus to comply with the Passivhaus limit for the thermal transmittance of 0.2 W/m^2K. Another simulation was carried switching-off the heating in winter season. The results showed an internal temperature trend remained always above 18°C. Figure 4a shows the impact of insulation of internal indoor temperature without ventilation and heat recovery

Figure 3: a.The impact of insulation and thermal mass in Casablanca during midsummer days , b. the impact of insulation and thermal mass in Casablanca during extreme hot summer days

Ventilation System and Cooling: However, relying on insulation levels is not enough in Passivhaus buildings without ventilation and heat recovery. The ventilation of 2.5 air change per hour of natural ventilation gave good



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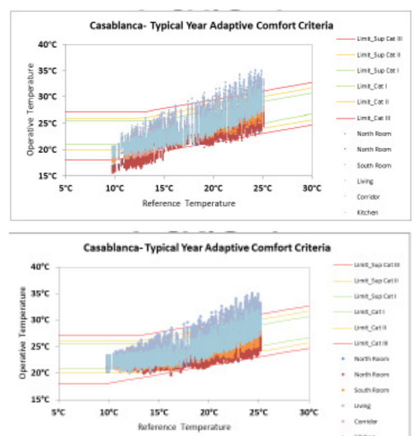
results regarding the internal temperature trend. This resulted in reducing the degree hours exceeding the 26°C to acceptable levels. Figure 4b illustrates the internal temperature profile in Casablanca and Figure 5 illustrates the difference on internal comfort. The insulation of walls, at the Passivhaus level did not create summer comfort problems. This level of insulation (18cm) coupled to ventilation recovery system can no longer need heating.



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DISCUSSION AND CONCLUSION

The strategies proposed for the selected apartment in Casablanca succeeded in providing a good internal thermal comfort in the Passivhaus. A different orientation of the building resulted in a minimal reduction of the loads, whereas the use of shading devices decreased the mean solar gains up to 30%. Moreover it was shown, that the ideal insulation position should be external with an 18 cm thickness. The variation of ventilation rate in passive cooling on the basis of the local climate permitted to reach very good internal conditions for apartment zones. The results also highlighted the importance of maintaining comfort in the apartment module in relation to the dynamic severe summer climatic conditions. The basic idea of a Passivhaus 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 bioclimatic strategies are essential to optimise the performance; however the Passivhaus will only be achieved through mixed mode systems and high-tech systems for ventilation and heat recovery.

Figure 4: a. Indoor temperature trends as an effect of insulation , b. Indoor temperature trends as an effect of adding insulation and a ventilation heat recovery system

Figure 5: Comparison of thermal comfort

There were limitations to our study. The study remains theoretical and the results are necessarily local. The implications of these data regarding energy are potentially intriguing. To make best of this study, the concept of Passivhaus in hot climates must extended and coupled to economic and energy consumption parameters. In the current Moroccan regulation environment and energy economics it is too far to apply the Passivhaus concept.

Bioclimatic design in Casablanca can provide thermal comfort and reduce the energy consumption for residential buildings to low levels. The role of architects is to continue inventing a contemporary bioclimatic architecture, for large housing developments, adapted to the local climate, drawing on traditional, bioclimatic and cost effective architectural strategies.

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