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Indoor Environment Mitigation with Desert Climatic Conditions for Affordable Passive Housing

دراسة تكيف البيئة الداخلية مع ظروف الصحراء المناخية للاسكان السالب منخفض التكاليف

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الملخص

تعد العمارة السالبة استراتيجية فعالة للاسكان المنخفض التكاليف في البلدان النامية. حيث تكمن أهمية التصميم السالب في تحسين الراحة الداخلية بطريقة قليلة التكلفة و قليلة الصيانة و ذات موثوقية عالية بالاضافة الي التأثيرات النفسية البيئية. تعتبر الظروف المناخية القاسية للمناطق الصحراوية تحدي للاسكان المعالج بطرق طبيعية و محاكاة ظروف البيئة الداخلية يعد اختبار لمدي جدوي النظم السالبة. يهدف هذا البحث الي دراسة قدرة تكيف البيئة الداخلية مع ظروف الخارجية للبيئة الصحراوية القاسية. اختار البحث أحد المشروعات المنخفضة التكاليف و التي تم تطويرها من قبل القطاع الخاص في صحراء القاهرة، هرم سيتي –مدينة الهرم- هو تجمع سكاني جديد يتبع لمدينة السادس من أكتوبر و يحتوي علي 70.000 وحدة سكنية. يعتمد تصميم هرم سيتي علي مبادئ العمارة السالبة للمناطق الصحراوية من حيث سمك الحائط و صغر نسبة الفتحات للحائط و الأسقف ذات القبب و القبوات. استخدم البحث برامج المحاكاه الرقمية لمقارنة قياسات درجات الحرارة و معدلات التهوية بالحدود المثالية للبيئة الداخلية لقياس مدي قدرة التكيف لحالة الدراسة. أظهرت المحاكاه التأثير الايجابي للقباب و القبوات كما أظهرت التأثير السلبي لغياب التظليل الكافي للحوائط والفتحات. تظهر النتائج قدرة حالة الدراسة علي التكيف مع ظروف الصحراء المناخية علي ثلاث مستويات: الفراغات الشمالية و الدور الأرضي لها القدرة علي الوصول لبيئة داخلية مناسبة بينما الفراغات الغربية تحتاج الي حماية أكثر من الاشعاع الشمسي. توصي الدراسة باستخدام برامج المحاكاه في مراحل التصميم الاولية للحصول علي تنبؤات دقيقة حول أداء المبني.

Abstract

Passive architectural design is an effective strategy for affordable housing in the developed countries. The importance of passive design comes from improving indoor comfort with low cost, low maintenance, high reliability and environmental psychology effects. The difficult climatic conditions of deserts regions consider a challenge for using passively treated housing significance, simulates the indoor environment conditions are good examination for its feasibility. This research aims to study the indoor environmental adaptation capacity with the extreme outdoor conditions of desert climate. The study selects one of low-cost housing projects developed by private sector in Cairo desert; Haram-city is a new existing community located in 6th of October city and has about 70.000 housing units. Haram-city housing design is based on passive design approach of desert climate such as thick walls, low window-wall ratio, domed and vaulted rooftop. The research use digital simulation software to compare temperature degrees and air flow rates measures with indoor environmental quality standard to address mitigation ability of this case. The simulation has shown the positive effect of domed and vaulted roofs, and the negative effect of window and wall shading absence. The study results on the ability of case study to mitigate with desert climatic conditions at three levels; ground floor and north-oriented spaces are able to reach IEQ standers and west-oriented spaces need more protection from direct radiations. The study recommended using digital simulation in early design stage to get accurate predictions of building performance.

Keywords

Indoor Environmental Quality – Desert Architecture - Passive Design – Affordable Housing

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1. Introduction

Improving affordable housing quality consider an important issue for developed countries that each improvement increase building cost and impact upon project budget. Passive architectural design is worldwide strategy that reaches human comfort with little or no additional costs of building budget. It's benefit from natural energies such as sun and wind to adapt building with climate. Passive systems had lower maintenance and higher reliability, and the greatest advantage of passive reliance is that usually results in a more pleasant indoor environment [1]. Passive design also is an environmental friendly strategy and has the ability to reduce environmental impact and carbon dioxide concentrations [2].

1.1. The Problem

Using of passive design in some developed countries such as Egypt face some difficult problems concerning the passive strategies ability to mitigate with desert climatic conditions, where the desert and semi-desert regions represent more than 90% of Egypt land area [3]. Difficult climatic conditions of deserts regions consider a challenge for using passively treated housing.

1.2. The Aim of Research

Indoor environmental quality is good examination for passive design feasibility. If the indoor spaces reach comfort standers, it's an evidence of the design success. This research aims to study the indoor environmental adaptation capacity with the extreme outdoor conditions of desert climate.

2. Desert climatic conditions

There are many different classifications of climate based on its purpose; some are based on vegetation, others on evapo-transpiration. For the purposes of building design a simple system is distinguished only four basic types, is adequate [4]. This is based on three atmospheric factors having the greet influence on human comfort in the particular location; temperature, humidity and air movement. Köppen climate classification is one of the most widely used climate classification systems based on vegetation combined with temperature and precipitation. The simple form of Köppen climate map is near to the purposes of building design, besides the polar zone –which rarely have a stable urban settlement- there are four climatic zones; tropical, dry, temperate and cold zone. The dry zone -the focus of this study- has some characteristics shown in the following points.

2.1. Hot-Arid Zone Conditions

Hot-arid zones lay approximately between 15°: 30° north and south the Equator that have a hot temperature with average monthly temperature around 30°C and maximum temperatures of 40 to 45°C are common. Hot-arid zones have low relative humidity throughout the year, with average humidity of 20%. It has low precipitation level between 0-150 mm with occasional light cloud. The main regions belongs to the dry zone are the Sahara, Saudi Arabia, large parts of Iran and Iraq, California, southern Russia, South Africa and much of Australia. The hot-arid areas have problems concerning its accommodation due to the excessive heat and glaring sun. [5]. climatologists could divide hot-arid climate into two sub-zones;

- *Dry savanna regions*; transitional area from humid to arid zones.
- *Desert and semi-desert regions*; the very arid zone with scarcity of vegetation.

Desert and semi-desert regions which is the target of this research have long diurnal and very intense sun direct solar radiation which unbroken due to the stable descending air and high pressure. Dust and sand storms are possible. It has a very hot day-time temperature reach 40:45°C in some areas and warm night-time temperature reach 20:25°C, although the hot temperatures, night-time temperatures can drop to freezing or below during colder periods of the year due to the exceptional radiation loss under the clear skies. The rainfall in desert areas is less than 100 mm per year and some years may experience no rainfall at all, also slight relative humidity between 10% up to 55% only during the shortly following rainfall. Desert is almost barren because of some reasons; deep-lying ground water level, the rainfall is too low to sustain any vegetation and high possibility of winds at low level. So, the vegetation in the desert usually consists of cactus, low and shallow-rooted grass, small thorny trees and bushes and very scanty scrub.

Fig. 1; World deserts and semi-deserts regions (orange/yellow) [14]

Desert areas in the world shown in figure 1, are Great Basin desert, Peruvian desert, Atacama desert, Patagonian desert, Sahara desert, Arabian desert, Turkestan desert, Great Indian desert, Gobi desert, Kalahari desert and Australian desert.

2.2. Egyptian Desert Climate

The Egyptian map could be classified to sub-zones according to the similarities in geographical and climate conditions. The climatic sub-zones are very useful to determine occupants' needs. In the Egyptian energy and architecture guide [6], Egyptian climatic map divided to 6 zones, and don't separate Nile valley to an isolated climatic zone. The semi-desert zone which include Cairo zone needs to:

- High thermal storage elements design up to 11.9 months/year.
- Cold night protection up to 3 months/year.
- Outdoor sleeping applicability in 1.3 months/year.
- And no need to rain-water protections.

The semi-desert zone represents transition stage between semi-Mediterranean zone and desert zone. It has hot summers and semi-cold winters. The average maximum temperatures reach to 36.5°C and average minimum temperatures to 10°C, and average relative humidity around 50%

3. Indoor environment parameters

Indoor Environmental Quality "IEQ" term refers to the quality of air and environment inside the building, based on conditions that can affect on health, comfort and performance of occupants. The factors affect on the quality could be classified into four sets; indoor air quality, visual environment, thermal environment and acoustic performance [7]. Each tries to reach the comfort zone. For this study, thermal comfort and indoor air quality are the main interest for desert conditions.

Indoor air quality deals with the quality and rates of ventilation, levels of indoor emissions and pollutant control. Ventilation of buildings refers to the air exchange of indoor air with outdoor air depending on utilization requirements [8]. Natural ventilation is useful way to decrease the indoor pollutant and physiological cooling effect of air motion. The design guidelines of good ventilated space implanted that the natural ventilation should be a first choice for the architect.

Human thermal comfort depends on achieving a balance between the heat being produced by the body and the loss of heat to surroundings. Research in that field shows that people are not passive in relation to their thermal environment, they look for comfortable conditions and adjust them to feel more comfortable. However, designers aim to design according to internationally accepted fixed design temperatures. Determine the comfort zone is a subjective matter, which depends on many factors. These factors can be grouped into three sets [9];

- *Environmental factors*; air temperature, air movement, humidity and radiant temperature.
- *Personal factors*; metabolic rate (activity), clothing, state of health and Acclimatization.
- *Contributing factors*; food and drink, acclimatization, body shape, subcutaneous fat, age, gender and occupancy density

There are essentially two methods available for ascertaining people's thermal comfort:

i. By questionnaires, with simultaneous measurement of conditions, used mostly in spaces normally occupied by the respondents [10], i.e. in field studies. The designers aim to reach the comfort zone in which at least 80% of people would feel comfortable

ii. By measurements of physiological changes [11], such as sweating, skin wittedness or skin temperature, which would normally be carried out in scientific research laboratories such as controlled environment rooms or climate chambers

In this research, Environmental factors are our main interest which affected directly by outdoor conditions. The following points address the main parameters regarding measure thermal performance and ventilation rate.

3.1. Air Temperature

Air temperature is the most important environmental factor, measured by the dry bulb temperature (DBT). The suitable indoor air temperature related to outdoor mean temperature. Thermal comfort rage differs from climate to another, where the human body feels not comfort if the air temperature exceeds than 25°C the body fails to reach thermal balance, table 1 comfort and temperature.

Table 1: Comfort and Temperature [10]

Temperature		
°F	°C	
78	25	Optimal for bathing, showering. Sleep is disturbed
75	24	People feel warm, lethargic and sleepy. Optimal for unclothed people.
72	22	Most comfortable year-round indoor temperature for sedentary people.
70	21	Optimum for performance of mental work.
64	18	Physically inactive people begin to shiver.

3.2. Air flow

Air movement is measured by its velocity (v, in m/s) and it also affects the evaporation of moisture from the skin, thus the evaporative cooling effect. See table 2, the air passing over the skin creates a physiological cooling effect that can create thermal comfort when the indoor air temperature is somewhat above the normal comfort zone [1].

Table 2, the relation between air speed and reduction of acceptable operative temperature [11]

	Air Speed 0.6 m/s	Air Speed 0.9 m/s	Air Speed 1.2 m/s
Δt°	1.2°C	1.8°C	2.2°C

The airflow rate is measured by air volume per time. The ASHRAE standard rates of air flow for People Outdoor Air Rate; 5 cfm/person and 2.5 L/s· person [12], where The Egyptian code standard rates of air flow of residential buildings for people airflow rate is 3 L/s· person [13].

Table 3; The effect on temperature and comfort due to various air velocities

Air velocity fpm	Equ. Temperature Reduction (°F)[a]	Effect on Comfort
10	0	Stagnant air slightly uncomfortable
40	2	Barely noticeable but comfortable
80	3.5	Noticeable and comfortable
160	5	Very noticeable but acceptable in certain high activity areas if air is warm
200	6	Good air velocity for natural ventilation in hot-dry climates
400	7	Good air velocity for natural ventilation in humid climates
900	9	Considered a "gentle breeze" when felt outdoors

[a] The values in this column are number of degrees Fahrenheit that the temperature would have to drop to create the same cooling as the given air velocity

3.3. Humidity

Humidity of the air also affects evaporation rate. This can be expressed by relative humidity (RH, %), absolute humidity or moisture content (AH, g/kg), or vapor pressure (p, in kPa). Comfort zones concerning humidity are bounded by an upper limit of 0.012 humidity ratio (level at which mildew becomes a problem) and lower limit of 0.0043 (level at which respiratory discomfort [10], such as caught and nosebleeds, due to excessively dry air is expected).

3.4. Radiation

Radiation exchange will depend on the mean temperature of the surrounding surfaces. The mean radiant temperature cannot be measured directly, but it can be approximated by globe temperature measurements. The radiant heat loss increases with the difference in temperature between the skin and surrounding air and surface. Radiant heating or cooling is effective comfort factor for passive architecture where it is not practical to condition the air such as outdoors and very large interiors.

4. Methodology

The research depends on analytical methodology of a simulation-based study. The study analyzes main parts of building design ground and first floor and four oriented spaces in order to determine its performance separately so its ignore influence of open space plan and cross ventilation. The study carried out digital simulation of existing case according to weather data file and site location.

4.1. Simulation Programs

The study use CFD software because it's mainly depends on airflow and makes detailed predictions of thermal comfort and indoor air quality, such as the distributions of air velocity, temperature, relative humidity and contaminant concentrations. The program used is Autodesk simulation CFD 2013, because its availability, architectural interface and acceptable validation of physical simulation [15].

The study carried out two simulation processes represent indoor environment; ventilation study to measure air speed and airflow rate under maximum and minimum average hourly statistics for wind speed of this region and thermal study under hot day-time conditions. The thermal study is done due to solar heating effect and may ignore the influence of occupant thermal radiations as its difficulty of accurate measuring.

4.2. Evaluation Criteria

Evaluation criteria based on standard of Egyptian code for improving energy efficiency in the buildings [13], part one for residential buildings. The thermal comfort ranged from 18.3:25 ^{o}C, in which there is no need for heating or cooling loads. For wind speed from .5:1.5 m/s is acceptable and for airflow rate 3L/s·

person in living and bedrooms and 14L/s· person in kitchen and services. Humidity and radiation results follow temperature and wind speed results.

5. CASESTUDY

As affordable housing importance for developing countries and particularly for Egypt case, the study selects one of low-cost housing projects developed by private sector in Cairo desert. Haram-city is launched in May 2007 as the first integrated affordable housing town in Egypt developed by Orascom housing communities OHC. It's located in 6th of October 2km west of Cairo and built approximately on one thousands of feddans and has 70.000 housing units.

Fig. 2; Haram city clusters orientations

The master plan of Haram city consists of housing clusters with central zone for commercial, educational, health-care and other services. The housing clusters are linearly designed in different orientations see figure 2. The cluster has 4 units; each has two or three levels. The unit consists of living, 2 bedrooms, kitchen, bathroom and open terrace. Figure 3 and 4 show image of the units and architectural design of typical unit.

Fig. 3; two levels cluster, 63m^2 model

Fig. 4; Architectural design of typical unit

The building has plain domed roofs on the two bedrooms and bathroom, and large vault on living space and open kitchen. The building has no shading on its vents but use deep-set windows as a solar protection strategy. The study selects north-oriented unit as a case, in which bedrooms facing west direction, living on north direction and services on south zone.

6. Results

The two conceptual simulation results of indoor environment; airflow and solar heating could be summarized in the table 4 show average max and min results during day-time simulation. The maximum temperature records on 1st floor bath zone at 12:00pm as 31.3^{o}C, and the minimum records on the ground floor rooms at 6:00am as 16.2^{o}C.

Table 4; average max. and min. results during day-time (6am:6pm) simulation.

	Temperature ^{o}C		Wind speed m/s	
	max	min	max	min
Ground floor 0	24.8	18.7	0.74	0.61
Living^{0}	23.0	18.9	1.32	1.22
Bedrooms^{0}	26.3	18.4	0.50	0.39
Bathroom^{0}	25.3	19.1	0.25	0.22
First floor 1	26.1	19.1	1.08	0.70
Living^{1}	24.6	19.2	1.43	1.31
Bedroom^{1}	27.5	18.8	0.59	0.48
Bathroom^{1}	26.4	19.4	0.31	0.25

The research notes the following;

- The first floor has better ventilation than the ground one by 0.34 m/s and worth thermal environment by 1.3^{o}C.
- The north-oriented space "living" is better than west oriented "rooms" by 2.6^{o}C for thermal environment and by 0.9m/s for average wind speed due to the cross ventilation impact, see figure 5.

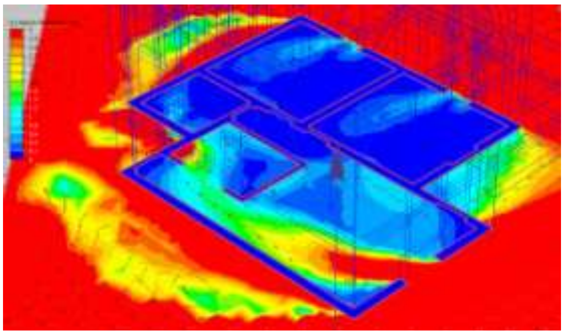
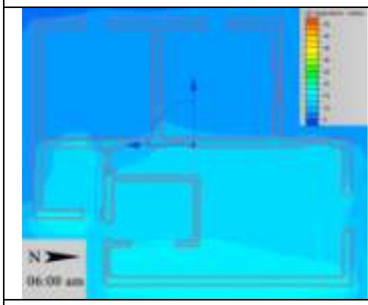
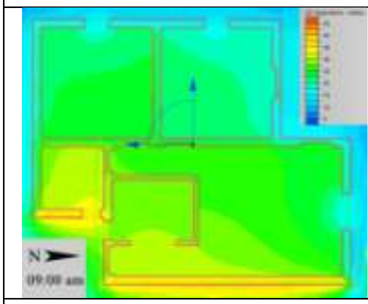
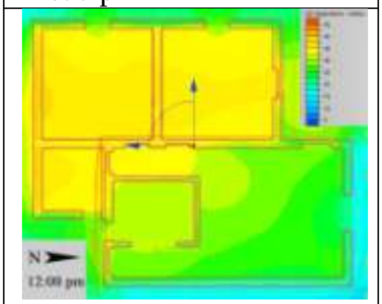
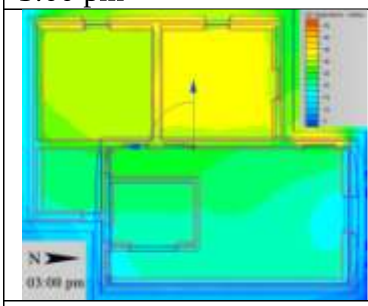
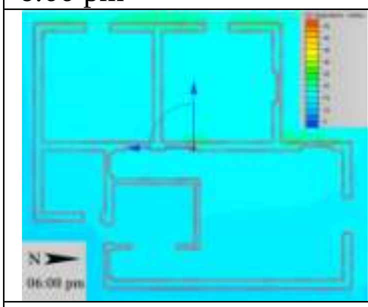


Fig. 5; wind speed intensity & distributions

Table 5; first floor solar heating analysis

image	analysis
6:00 am 	Beginning of sun rise show low radiation influence on eastern wall
9:00 am 	Radiation intensity on eastern façade total heat flux reach 6.38 w, and warm indoor space.
12:00 pm 	Direct noon sun, radiation intensity on dome large than on vault due to the plain curved of dome, and creates indoor hot space.
3:00 pm 	Declined sun rays enter to the western zone raising temperature and comfort north and east zones "living"
6:00 pm 	After sunset, warm walls emitted heat to indoor spaces create thermal comfort
green color represent thermal comfort zone	

7. DISCUSSIONS

The simulation results showed some of important passive factors affecting indoor environment performance:

- Rooftop performance; the large vault on living space has great effect on keeping indoor space thermally comfort with adequate rate of airflow rate see fig 6, where the domed roof has a lower effect than the vault due to its low depth and better than the flat roofs.
- Windows performance; window-wall ratio not exceed 10% which is recommended by Egyptian code, where the deep-set windows design provide shading effect but still not enough for west and south façades, see figure 7; the influence of sunrays in west zone.

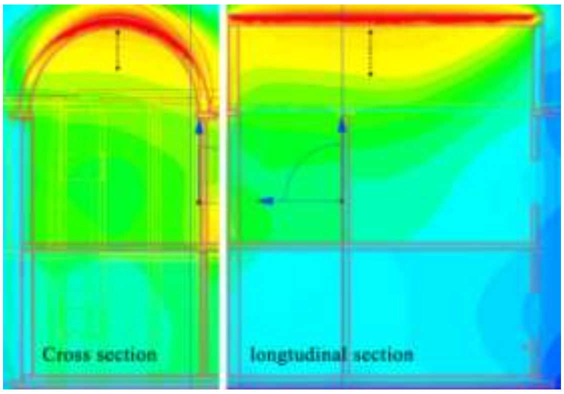


Fig. 6; Cross and longitudinal sections on vault solar heating simulation at 12:00 pm.

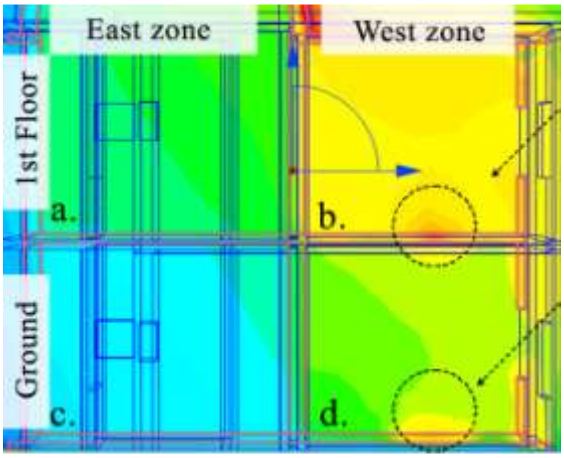


Fig. 7; unit cross section for solar heating simulation at 3.00 pm.

- Ventilation technique; the unit design has the ability to increase airflow through terrace vents, in the examined case only windows are opened which provide adequate airflow for living and rooms spaces. The cross ventilation created by north-south vents duplicate air speed.
- Earth contact; the earth has positive impact on improving thermal performance and hence indoor environment, ground floor has lower temperature degrees than first floor by 1.3^{o}C, and the difference seems to be increase with consider the impact of green landscape and surrounding vegetated area.

8. CONCLUSION

Affordable housing integration with passive design guidelines should be the first choice strategy for architects and building developers to deal with different climatic conditions. For desert climate, insurance of indoor environment conditions quality are very important for healthy space and occupants' performance ability that could be achieved with little additional costs.

For Haram city case, the indoor environment of affordable passive unit could mitigate with desert climate conditions at the following levels;

- High mitigation level, in which indoor space could attain standard performance, obtained for north oriented spaces that had low solar heating effect and comfort airflow rate.
- Accepted mitigation level, in which indoor space could reach minimum standard performance, obtained for ground floor spaces that had low solar heating effect and accepted airflow rate.
- Low mitigation level, in which indoor space couldn't reach minimum standard performance, obtained for west and south oriented spaces that had high solar heating effect and low airflow rate.

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