Comparison between environmentally designed houses and standard houses regarding thermal behavior

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Abstract. Based on the literature review and environmental studies, it is well known that the fundamental design standards focus on the building orientation, materials, form, window wall ratio, and passive tools for cooling in hot climates. This was the reason behind this paper, to verify and prove that if a building is designed according to these standards then it could achieve thermal comfort and energy efficiency. So, a comparison was held between four case studies, two of them were designed according to those standards and the other two were not. Hygrometer data loggers that measure ambient air temperature and relative humidity were placed in living rooms and on roofs in the four villas for one month in order to compare and analyse the measurements. In the coming paragraphs, each case study is explained and measurements and analysis are presented in order to reach the conclusion of this paper study. Fixed parameters were set for comparison between the four cases, those parameters were as follows: Orientation- wall thickness- building material- WWR (window wall ratio) - Number of Floors- Type of roof – Surroundings. Data was collected based on these parameters to be able to compare between the results. After comparing those parameters in the four villas, it was concluded the great influence of the surrounding buildings on each villa on its internal temperature. And so therefore a simulation has been made to measure the effect of the surrounding buildings.

1. Introduction
According to the annual report issued by the Ministry of Electricity in Egypt (2016-2017), the greater source of energy is thermal (92%) which depends on burning fossil fuel that of course produces tons of CO₂ contributing in the greenhouse effect and raising the temperature of the planet globally.

Also the greater sector of consumer is the residential sector 50.5% [1].Since Egypt is committed to the “Paris Agreement” held in 2015, Egypt should improve the climate change performance according to the “Climate change performance index” that is issued annually where Egypt holds the 24th in the ranking over the world. The ranking results are defined by a country’s aggregated performance regarding 14 indicators within the four categories “GHG Emissions”, “Renewable Energy” and “Energy Use”, as well as on “Climate Policy”, in a globally unique policy section of the index [2]. Based on the above mentioned figures, serious action should be taken via Architects to help decrease these percentages, since energy is used mostly in houses for cooling purposes beside other domestic purposes. This consequently, derives Architects towards designing and building houses using Environmental design standards.

Figure 1: Types of Energy Generated (GWh)  
Figure 2: Energy Distribution according to purpose (%)
2. Case Studies
For each of the following case studies, two hygrometer data loggers were placed, one was placed in the centre of each zone (reception area) and another outdoor. The parameters measured in this research were indoor and outdoor temperature. The devices used were eight Perfect Prime TH0160, USB temperature and humidity data loggers. The runtime for the measurements was 20 days.

2.1. Villa A:
Location : El Thawra El Khadra next to El Sheikh Zayed- 6th of October City
Orientation : South West/North West
Building materials : Lime Stone
WWR for the living room : SW orientation =20% SE orientation =14% NW orientation=12% NE orientation= 40%
Height of floor : 5m
Roofs: Cross Vaults
Number of floors : Basement +2 floors
Surface area to volume ratio: 0.2
Neighbours : No neighbours or trees surrounding the villa from all directions

The Villa is located near El Sheikh Zayed which is considered hot arid climate. The architect designed his Villa to be an icon for Vernacular Architecture. There is a wind catcher on the ground floor that is connected to the basement where the air circulates and drops more of its temperature. They are tall towers on the building’s roof tops with several vents to capture wind for cooling the interior spaces. Wind catcher openings are usually positioned facing desired wind directions. Wind catcher functions based on pressure difference between leeward and windward which is positive in inlet opening and negative outlet vent. Venturi effect causes air to come down through the wind catcher channel at a higher velocity and lower pressure [3]. The Villa contains air shafts that are embedded in the walls; these shafts pull the cool air from the basement to the upper two floors through small openings in the walls of the rooms, this help deliver cool air to most of the rooms of the villa.

There is also an inner court that also helps in enhancing the natural ventilation and day lighting. Courtyard buildings have been always recommended as a passive architectural technique in desert environments in order to maintain indoor thermal comfort. A previous study, however, showed that in desert environments, the energy performance of two-storey residential courtyard buildings proved less efficient than other solid forms, even when attached to neighbouring buildings from three sides in a compact urban fabric. Their performance was relatively better in mild desert climates than in extreme hot ones. Another previous study showed that in Cairo, significant saving were only achieved at large building depth (18m-20m) and low height proportions (1:0.25 to 1:1) while a significant increase in consumption occurred especially at small building depth and higher height proportions in most cases [4]. The structure of the villa is bearing walls structure. Wall thickness is 45 cm of lime stone that delay heat from entering at day till it reaches the night hours. All roofs are in the form of Vaults or Cross Vaults or Domes which also help cooling the spaces underneath it. The hygrometer data logger was placed in the living room in the ground floor where its roof is cross vault so there is no other floor above this part of the ground floor.
**Figure 3:** Villa A Layout

**Figure 4:** Villa A Ground Floor Plan

**Figure 5:** Villa A Section

**Figure 6:** Villa A Elevation

**Figure 7:** Wind Catcher

**Figure 8:** Cross vaults roof

**Figure 9:** Air shafts
2.2. Villa B:
Location : El Sheikh Zayed- 6th of October City
Orientation : South West/North West
Wall thickness : 25cm Building materials : Bricks
WWR for the living room : SW orientation =40% Height of floor : 3m
Roof type : Flat slab Number of floors : Basement + 2
Surface area to volume ratio : 0.16 Neighbours : Neighbours are surrounding the villa from three directions and all have the same number of floors.

The Villa is in a compound in El Sheikh Zayed and surrounded by neighbours from 3 sides. It is not designed based on any environmental design standards or used any passive cooling tools. It is a standard basic prototype of a villa composed of a basement and two floors, the basement is connected with the other floors through external staircase. The structure of the villa is column and beam structure with wall thickness 25cm. The hygrometer data logger was placed in the reception in the ground floor.

Figure 10: Villa B Layout

Figure 11: Villa B Ground Floor

2.3. Villa C:
Location : 6th of October City Orientation : East
Wall thickness : 12 cm Building materials : Bricks
WWR for the living room : East orientation = 22% Height of floor : 3m
Roof type : Flat slab Number of floors : 2 floors
Surface area to volume ratio : 0.16 Neighbours : Neighbours surrounding the villa from three directions

The Villa is in one of the districts in 6th October and surrounded by neighbours from 3 sides. It is also not designed based on any environmental design standards or used any passive cooling tools.
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North

It is a standard basic prototype of a villa composed two floors and a basement. The structure of the villa is column and beam structure with wall thickness 12 cm. The hygrometer data logger was placed in the reception in the ground floor. All the surrounding buildings are 5 stories but the villa is only two floors high which cast shadow on the villa, there is also a fence on the eastern side between the villa and its neighbour which funnels the air through this zone.

Figure 13: Villa C Layout

Figure 14: Villa C Ground Floor

Figure 15: Villa C Section

2.4. Villa D:
Location : 6th of October City
Orientation: North East/ South East
Wall thickness : 30 cm
Building materials : Double wall from bricks with insulation in between
WWR for the living room : North East orientation = 11%
 South East orientation = 34% (Shaded)
Height of floor : 3m
Roof type : Flat slab
Number of floors : Basement + 3
Surface area to volume ratio: 0.1
Neighbours : Neighbours surrounding the villa from three directions

The Villa was designed using passive cooling design strategies. It consists of three floors beside the basement. The wall thickness is 30cm and built of double wall with inner insulation. The Villa contains a wind catcher and is oriented to the North West and rises above the roof by 1.5m. It also contains a solar chimney that is painted black and works along with the wind catcher to enhance the natural ventilation in the villa. The wind catcher is connected to the solar chimney through tubes buried under the basement floor. The temperature of the air flowing in the solar chimney is higher due to the black paint of the chimney, this air escapes through the vents of the solar chimney and is replaced by cooler air, which comes from pulling the air coming through the wind watcher and cooled through the buried tubes in the basement floor. This air cools the rooms of the villa without having to use any mechanical cooling. There is also a skylight centred in the villa that provides natural lighting to the living spaces. In past, usually one of these items was used in architectural designs to help natural ventilation but with this combination (wind catcher and solar chimney) we can achieve more efficient ventilation system. Meir explains that the air trap operates with the change of air temperature and the difference of weight between the inside and outside of the trap. The difference of weight of the air impels a suction process which causes the air to flow either to the bottom or to the top [5].
3. Analysis
Four Hygrometer data loggers were placed for 15 days (from 20th of October to 5th of November 2018) on the top of roofs in each case to record the ambient air temperature and relative humidity, and accordingly it was divided into two climatic zones: Zayed and 6th of October. Villa A and B are in Zayed zone and Villa C and D are in 6th of October zone. Four other Hygrometer data loggers were placed at the reception in the ground floor in each Villa to record the indoor temperature degrees at the same time duration. Readings were taken and presented in the form of charts.
Figure 21: Chart analysis for villa A and B over two weeks

In Figure 21, the chart shows the outdoor ambient air temperature in Zayed zone throughout the day and night for 2 weeks and it also shows the indoor air temperature in Villa A and Villa B for the same duration. From the Chart, it shows that although villa A is design according to environmental design standards as explained before, its indoor air temperature recorded is higher than Villa B which is not designed according to any environmental design standards.

Figure 22: Chart analysis for villa A and B over 24 hours

In Figure 22, the chart shows the outdoor ambient air temperature in Zayed zone for 24 hours and it also shows the indoor air temperature in Villa A and Villa B. Form the Chart, it shows that the indoor air temperature recorded in Villa A has reached 30°C while Villa B has reached 26°C.

Figure 23: Chart analysis for villa C and D over two weeks

In Figure 23, the chart shows the outdoor ambient air temperature in 6th October zone throughout the day and night for two weeks and it also shows the indoor air temperature in Villa C and Villa D. From the Chart, it shows that villa D reached 26°C and villa C reached 27°C, which is so close to each other although villa D is designed according to environmental design standards as explained before, but Villa C is not designed according to any environmental design standards, this is because villa C is surrounded by tall and close buildings which cast shadows on the villa and protect it from heat.
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In Figure 24, the chart shows the outdoor ambient air temperature in 6th October zone for 24 hours and it also shows the indoor air temperature in Villa C and Villa D. Form the Chart, it shows that the indoor air temperature recorded in Villa D is almost the same as Villa C.

Figure 25 compares between the four cases throughout 24 hours, it shows the ambient outdoor air temperature in Zayed zone and 6th of October zone, and it also shows the indoor air temperature recorded in the four villas, where Villa A came out to be the highest case in the four cases.

This result was unexpected since Villa A was designed based on environmental design strategies for hot arid regions, but from comparing the four cases based on the parameters previously mentioned (Orientation- wall thickness- building material- WWR (window wall ratio) - Number of Floors- Type of roof –Surroundings), the following could be concluded:

- The surroundings had a great effect on the indoor air temperature, since Villa A was the only case without any surrounding, neither buildings nor landscape, which means that shading the roof and facades had a major role in decreasing the indoor air temperature.
- The WWR especially for SE and SW orientation also had a great effect since villa A had 20% WWR in SW orientation which is considered a high percentage.
- Surface area to volume ratio, where Villa A had no upper floors above the living area and so the ratio was 0.2 which affected negatively on the indoor temperature since it exposed larger areas to direct sunlight radiation.

And so, to verify this conclusion, a simulation has been made for Villa A, using Design Builder, where surrounding buildings were added to see its effect on the internal ambient temperature.

In the simulation, a model for the living space was built with abstract forms, and the weather file of the program has been used for the same duration that the Hygrometer data loggers recorded the ambient temperature. The results were as follows:
Figure 26: Model for the living space of villa A built using design builder

Figure 27: Simulation chart for villa A after adding surrounding context

Figure 27 shows that just by adding a surrounding context, the maximum indoor ambient temperature dropped to 28°C after being 30°C, and the minimum indoor ambient temperature is almost stable at 25°C after being fluctuating between 23°C and 27°C.

4. Conclusion
Villa A and D didn’t have any air conditioning system, but villa B and C had air conditioning system but were turned off during the monitoring since the weather was pleasant at that time of the year and because they were surrounded by buildings same height or higher that cast shade on them, so there was no need for the ACs. The Four villas were occupied by senior residents. Fixed parameters were set for comparison between the four case studies. Those parameters were orientation, wall thickness, building material, WWR (window wall ratio), number of floors, type of roof and surroundings. The paper concluded the great effect of the surroundings in a hot arid climate where buildings should be arranged in compact arrangement. The simulation proved the importance of the surrounding urban context and its effect on decreasing internal ambient air temperature where it dropped two degrees Celsius. Therefore, it is expected that by decreasing the WWR for the SW oriented wall, and also by decreasing the surface area to volume ratio of the villa, the internal ambient temperature will drop further more degrees and could become less than the other cases. This conclusion could be helpful when designing new settlements in hot arid regions.

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