Simulation As a Tool to Develop Guidelines of Envelope Design of a Typical Office Building in Egypt

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ABSTRACT

This paper describes the use of building performance simulation software in order to develop guidelines for designing energy-efficient office building.

In Egypt energy codes for all building types are being under development. On the other hand market trends have driven office buildings architecture towards neglecting not only environmental considerations but also local context and vernacular architecture.

The case study presented in this paper is an attempt to use simulation tools to evaluate variants of envelope thermal characteristics at early stage of design in order to assist creating an energy efficient structure, providing best comfortable conditions for inhabitants and at the same time maintaining the vernacular character of the building.

In order to achieve these aims Ecotect is used to conduct a series of thermal and lighting analyses which have good prospects of influencing building performance. Subsequently sensitivity analysis calculations were performed to define the parameters that contribute significantly to energy efficiency and thermal comfort.

INTRODUCTION

Since mid 90s the office buildings sector in Egypt has been developing due to the urban and economic growth concentrated in the Nile Delta. Many new buildings were constructed without paying attention to environmental considerations at the early stage of design which has led to a wide use of active air-conditioning to provide thermal comfort and well lit indoor spaces. As a result, buildings' energy consumption has been increasing to meet the requirements of cooling and electric lighting. On the other hand most of these new buildings had been designed as glass boxes deprived of local architectural character or vernacular style.

Vernacular architecture - which evolves in response to function, climate, natural forces, local resources, and culture (Rau S., Schierle, G. 1994) - is seen as a vital element in planning new cities and future urban expansions and office buildings are essential cores of this future urbanism. Therefore, developing design guidelines for office buildings is considered an important approach to sustainable architecture in new cities and urban expansions.

Courtyard office building is considered an example of providing comfortable thermal environment as it creates fascinating interior views using different elements of landscape, in addition to providing natural ventilation and day-lighting which minimize cooling loads and energy consumption.

The court and dome are amongst the architectural elements that could be extracted from the work of the architect *Hassan Fathy* who articulated cultural authenticity as the main theme of his message. He also rejected architecture that was not rooted in the location and the culture of the area, while he remained open to use of the objective measurements of science such as thermal comfort, cost and energy efficiency (Serageldin, I., 2007).

In this research, the integration of building simulation tools during early design phases is performed since it's widely accepted that putting analysis tools in the hands of the architect during the early phases of design has a large role in ensuring the performance of the end product.

While thermal comfort, day-lighting and view were identified as three main challenges to the design concept, the following strategies provide a key towards achieving energy-efficient buildings within the overall design process:

1) Minimize the overall need for heating, cooling and lighting: by evaluating thermal comfort, energy performance and lighting quality of the building at the preliminary design stage, this will allow critical choices to be made before the final work starts.
2) Utilize *renewable energy* RE sources to provide the remaining heating, cooling and lighting needs, then use fossil fuels efficiently to provide any remaining needs.
3) *Sensitivity analysis* SA was employed as a tool to evaluate the impact of design parameters on the overall building performance as calculated by building performance simulation software, thereby identifying the most important parameters.

METHODOLOGY

Computational model of the case study building:

The simulation software used was Ecotect, which allows geometrical modeling, performing thermal analysis and lighting analysis to the same model in the same program while benefiting from an interactive and user-friendly user interface.

Case-study characteristics:

As seen in figure 1, a typical courtyard office building is planned with 12 rooms per floor, 3 on each side (North, South, East and West). The office room volume is 6.00m x 4.00m x 3.60m, it is occupied by 6 persons and 2 computers are installed.

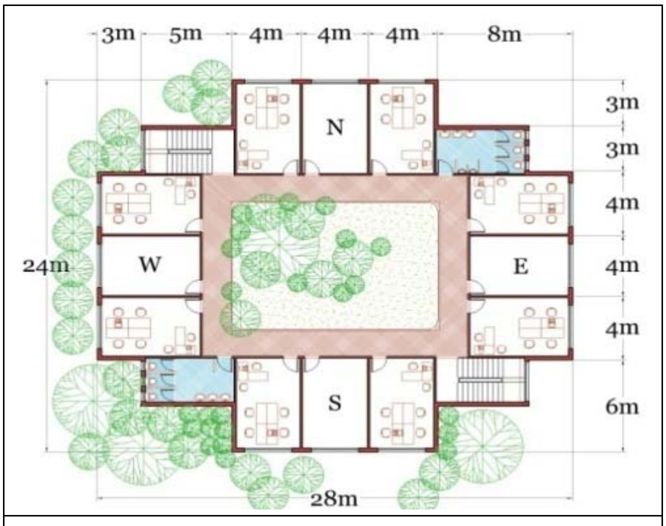

Figure 1. Typical floor plan for case study.

Sensitivity Analysis

Sensitivity methods are used to study the impact of input parameters on different simulation outputs compared to a base case situation. Then, the results are interpreted to predict the likely responses of the system (Lam J.C. and Hui S.C.M. 1996). Important input design parameters of the building systems are identified and analyzed from the points of view of: Annual building energy consumption, peak design loads and building load profiles.

The purposes of the analysis are assessing the significance and impact of input design parameters in addition to identifying important characteristics of the input and output variables.

SIMULATION PROCEDURES

First stage

Simulation is processed on four office rooms; each room faces a different orientation (N, S, E and W) respectively as shown in figure 2. Eight alternative models for each office varying in windows size, location and arrangement were created to study the building's thermal behavior, natural ventilation, and interior day-lighting as shown in figure 3.

Informed by the fact that some design changes would improve one performance element and might hinder another, the next series of analysis were performed, and thereby an optimum solution could be selected to deliver the best overall result.

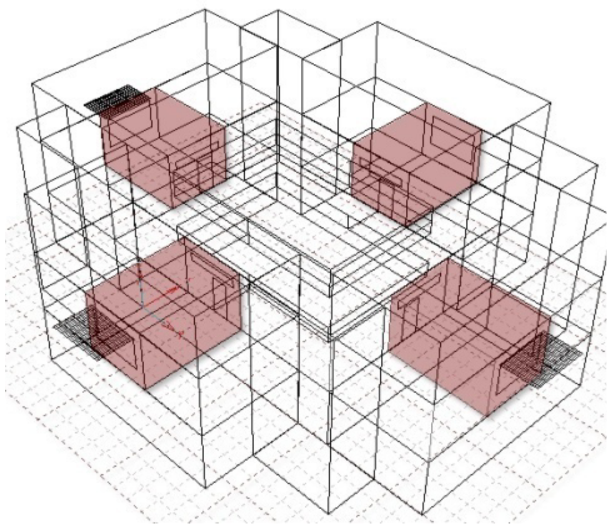

Figure 2. Simulated rooms (N, S, E, and W) in Ecotect perspective view.

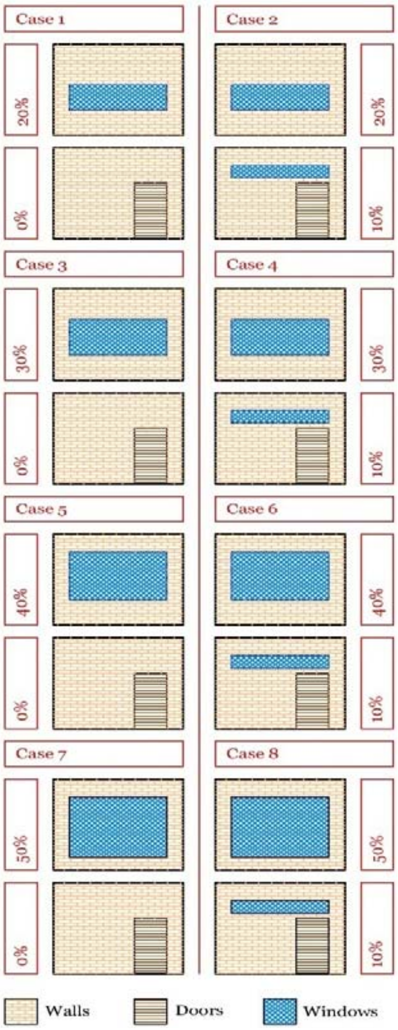

Figure 3. Variants of windows size, location and arrangement.

Second stage

Aiming at defining the best parameters values for final design using sensitivity analysis methodology, the optimum case was chosen as a baseline to assess the effect of each design parameter on the overall building energy consumption. The following aspects were considered in the sensitivity analysis: walls and window types.

Third stage

Inspired by the integrated design process *IDP* and based on the results from previous stages, the optimum solution was selected to perform an upgrading phase through which an efficient use of renewable energy can be achieved in addition to integrating vernacular architecture style elements in building's facades.

ANALYSIS

First stage

Figure 4 illustrates the energy consumption per square meter of the eight alternatives of each of the four typical offices:

- The energy consumption is directly proportional to window size, arranged in an ascending manner as follows: North, South, East then West façade, to record a minimum value in case N1 and a maximum value in case W8.
- The west side office recorded maximum energy consumption values relative to the other side in most of simulated variants.
- Energy consumptions in cases 2, 4, 6 and 8 exceed cases 1, 3, 5 and 7 respectively.

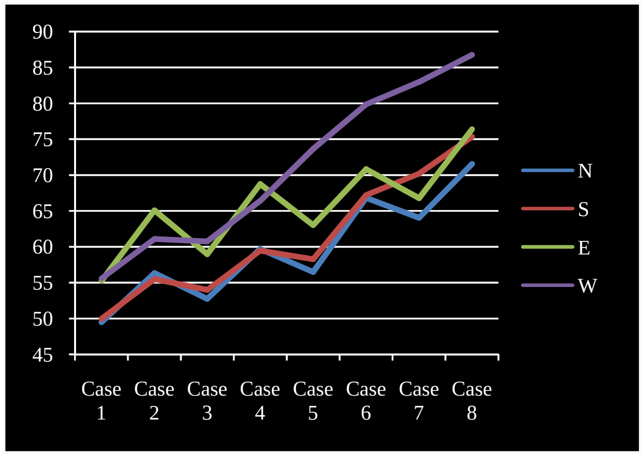

Figure 4. Comparison of energy consumption per m^2 for 32 alternatives

Table (1) illustrates the day-lighting simulation results for the eight alternatives. The minimum required average daylight Factor ADF is 5%, and minimum required uniformity value is 0.3 as the optimal values designated for well-lit office spaces.

- The ADF of cases N6, N7, N8, S6, S8, E6, E7, E8, W6, W7 and W8 exceeds 5%.
- The value of uniformity in cases N1, N3, N5, N7, S1, S3, S5, E1 and W1 is lower than 0.3.
- The cases 6 and 7 have achieved best interior day-lighting conditions with acceptable energy consumption levels compared to other cases as seen in the daylight analysis grid of case 6 indicated in figure 5.

Cases		Daylight Factor (%)			% of Area > certain DF			Uni.
		ADF	Min.	Max.	>10%	>5%	>2%	
N	1	2.67	0.60	20.60	5.00	10.90	26.90	0.22
	2	3.44	1.20	21.20	5.90	12.20	72.20	0.35
	3	3.51	0.80	20.80	8.70	15.30	42.80	0.23
	4	4.26	1.40	21.40	9.10	17.20	95.00	0.33
	5	4.47	1.20	21.20	11.20	21.60	79.70	0.27
	6	5.21	1.80	21.80	12.40	23.70	99.10	0.34
	7	5.13	1.40	21.40	12.50	24.10	94.10	0.27
	8	5.85	2.10	22.10	13.40	28.10	100.00	0.36
S	1	2.54	0.60	20.60	4.40	13.10	31.20	0.24
	2	3.29	1.20	21.10	5.30	13.80	74.40	0.36
	3	3.32	0.80	20.80	7.80	16.60	45.90	0.24
	4	4.06	1.40	21.40	8.10	18.40	93.40	0.34
	5	4.22	1.20	21.20	8.40	21.90	83.70	0.28
	6	4.94	1.80	21.80	9.70	26.20	99.70	0.36
	7	4.92	1.50	21.50	10.90	26.20	95.00	0.30
	8	5.63	2.10	22.10	11.90	31.20	100.00	0.37
E & W	1	2.55	0.60	20.60	5.60	10.90	30.60	0.24
	2	3.35	1.40	21.40	6.90	13.80	72.80	0.42
	3	3.34	1.00	21.00	6.90	16.90	46.30	0.30
	4	4.15	1.80	21.80	8.70	19.10	94.40	0.43
	5	4.22	1.40	21.40	9.70	22.80	84.70	0.33
	6	5.09	2.10	22.10	10.90	27.20	100.00	0.41
	7	4.72	1.50	21.50	10.30	24.70	91.90	0.32
	8	5.54	2.10	22.10	11.60	28.10	100.00	0.38

Table 1: Comparison of day-lighting analysis of all alternatives

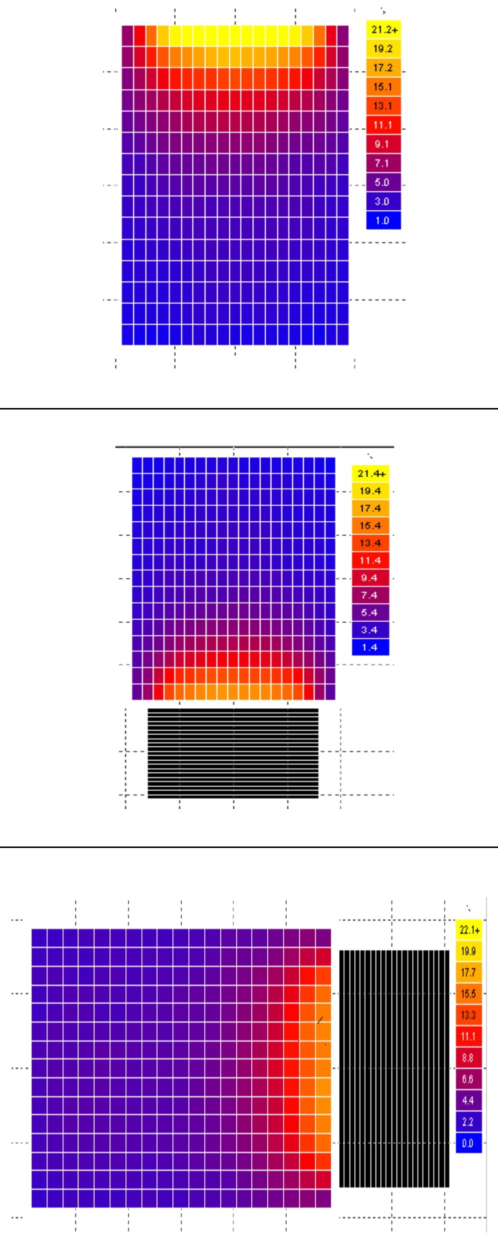

Figure 5. Daylight analysis grid of case 6

In order to assist defining the optimal case, a comparison of annual degree-hours and passive gains breakdown – for fabric, solar and ventilation - between cases 6 and 7 are shown in tables 2 and 3 respectively.

- Using natural ventilation has reduced annual degree-hours significantly in case 6.
- Passive gains breakdown shows significant role of ventilation in heat losses for case 6.
- Case 6 of is defined as the optimal case for this stage and the sensitivity analysis will be processed on it in the next stage.

	Too Hot	Too Cool	Total Degrees
N6	4364	247	4611
N7	5403	183	5586
S6	4383	255	4638
S7	5611	192	5803
E6	4326	386	4711
E7	4964	359	5323
W6	4872	326	5198
W7	5879	259	6138

Table 2: Discomfort Degree-Hours for cases 6 and 7

Category	Gains	Losses	Gains	Losses
	N6		**N7**	
Fabric	64.40%	18.50%	73.30%	19.80%
Solar	0.00%	30.30%	0.00%	30.00%
Ventilation	35.60%	11.90%	26.70%	8.10%
	S6		**S7**	
Fabric	64.40%	18.50%	73.30%	16.60%
Solar	0.00%	30.30%	0.00%	43.10%
Ventilation	35.60%	11.90%	26.70%	6.80%
	E6		**E7**	
Fabric	66.40%	17.30%	73.90%	17.00%
Solar	0.00%	36.50%	0.00%	40.70%
Ventilation	33.60%	10.20%	24.80%	6.40%
	W6		**W7**	
Fabric	65.60%	17.40%	72.40%	19.30%
Solar	0.00%	32.70%	0.00%	28.80%
Ventilation	34.40%	10.60%	26.40%	7.90%

Table 3: Passive gains breakdown for cases 6 and 7

Second stage

Table (4) illustrates the total energy consumption of five alternatives for windows and four alternatives for walls.

- Using window types of low U-value has provided 15-24% reduction in the total annual energy consumption of the four typical offices. While walls types provided 20% reduction.
- Using the best types of both walls and windows recorded 37% decrease in total annual energy consumption relative to the base case.

Windows	U-value	KWh/m^2	% Change
Single Glazed Timber Frame (Base Case)	5.1	71.188	0.00
Double Glazed Timber Frame	2.9	60.316	-15.27
Double Glazed Aluminum Frame	2.7	58.752	-17.47
Double Glazed Low E Aluminum Frame	2.41	54.757	-23.08
Double Glazed Low E Timber Frame	2.26	54.190	-23.88
Walls	**U-value**	**KWh/m^2**	**% Change**
Brick Timber Frame (Base Case)	1.77	71.188	0.00
Reverse Brick Veneer R015	0.49	56.926	-20.03
Reverse Brick Veneer R016	0.39	56.862	-20.12
Timber Clad Masonry	0.3	56.753	-20.28

Table 4: The effect of envelope's variants on total energy consumption.

Third stage

In this stage an electric lighting is provided as a provision for day-lighting then photovoltaic system is planned on the roof of the building to supply the building with a renewable energy source.

- Figure 6 shows the analysis grid for electric Lighting.
- Figure 7 shows a comparison between annual energy produced by the PV System installed above the north and south rooms.
- The energy generated by the PV system covers 48% of the total energy demand for offices spaces, which equals approximately the energy consumed by both of electric lighting and computers in the best case.

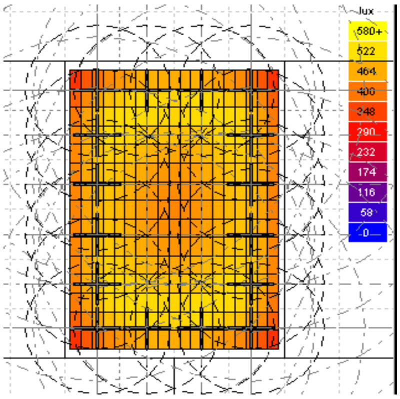

Figure 6. Electric lighting analysis grid.

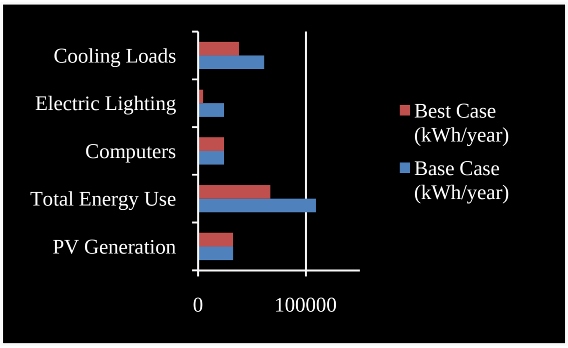

Figure 7. Comparison of the energy generated by PV and the energy consumption in the office building.

- Figure 8 illustrates the proposed façade design using vernacular architectural style which was chosen as its elements - arches, domes, wooden shading, etc. - are identifying vernacular Egyptian architecture, and at the same time enhances the building's energy performance.

Figure 8. Proposed elevation inspired by vernacular architectural elements.

RESULTS

Using energy simulation software tools plays an important role in the formation of the building instead of personal preferences, as these tools assist making informed design decisions at early design phases.

Investigating Vernacular and local architecture could assist creating energy-efficient architecture that respond to its location's unique characteristics.

Sensitivity analysis technique helps to identify the elements that have a major impact on enhancing thermal comfort and energy consumption of the building.

Insulating walls of the envelope has the major effect on the energy consumption, and then comes windows and roof as the results of the case study has shown. And the effect of material use is essentially relevant to its surface area.

Day-lighting analysis plays a decisive role in configuring building's envelope through windows size and arrangement.

Window openings control three important parameters: day-lighting, heat gains and losses, and view.

Day-lighting is more preferred than electrical Lighting for reducing heat emissions into the space and therefore reducing energy consumption.

Shading Devices are designed to permit diffuse light and prevent direct sunlight, also to control glare and minimize heat gains.

Larger areas of openings enlarge average daylight factor, but also bring more heat gains and cause brightness problems.

Rising window's base height results in better distribution for day-lighting, but it does compromise the visual connection between indoor spaces and external view for occupants.

North windows bring day-lighting with less heat gains than that of south windows, while putting an opposite window in the south enhances cross-ventilation.

Using renewable energy sources such as photovoltaics can cover a significant percentage of building's energy use while reducing the negative impacts on surrounding environment.

CONCLUSIONS

This paper presents a case study for the role of simulation as a practical and effective tool for assessing design stage by stage, in environmental and energy efficiency perspective.

Increasing population in Egypt causes much need for services and new buildings, this urban expansion should take into consideration sustainable development and energy efficiency.

The architect can play an important role in balancing functional requirements, aesthetic considerations in the context of creating energy-efficient buildings.

Integrated design process approach can be re-formulated or re-shaped through any design problem to meet sustainable design requirements as its essential role.

Integrating building performance simulation software enhances the designer ability to make decisions based on environmental analysis rather than personal preferences and choices.

Sensitivity analysis represents a significant tool in reading and analyzing outputs of simulation processes.

In the case study presented in this paper a courtyard office building is designed to fulfill its basic functions in addition to reduce the overall energy consumption relative to its baseline case.

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