The 6th IBPSA Canada Conference
La 6e conférence d'IBPSA – Canada
Winnipeg, May 19 – 20

SIMULATION AS A TOOL TO DEVELOP GUIDELINES FOR THE DESIGN OF PORTABLE LIBRARY IN THE CAMPUS OF MANSOURA UNIVERSITY

Ahmed Nabih Ahmed [1], Mina Michel Samaan [2], Osama M.A. Farag [3], Alaa Shams El Aishy [4]
[1] Assistant Lecturer, Department of Architectural Engineering, University of Mansoura
[2] Instructor, Department of Architectural Engineering, University of Mansoura
[3] Professor, Department of Architectural Engineering, University of Mansoura
[4] Lecturer, Department of Architectural Engineering, University of Mansoura

ABSTRACT

This paper describes the use of transient building performance in order to develop design guidelines for a portable library.

This project has been introduced to the officials of Mansoura University – by our research group - as a solution for the problem of insufficient library spaces available for students and staff members in most of the faculties of Mansoura University as a result of increasing the numbers of enrolled students due to general population growth in Egypt. For example there's only one library reading hall for The Faculty of Engineering where thermal comfort and lighting is not acceptable especially in the summer.

In this paper, the case study is presented as an attempt to explore the approach of using simulation technology to evaluate a variety of envelope thermal characteristics at early design stage in order to assist creating an energy efficient structure in addition to providing best comfortable conditions for the students. The focus of this paper doesn't cover the details of deploying and constructing the portable library but only provides guidelines for selecting envelope materials and integrating Renewable Energy (**RE**) in the design.

In order to achieve these aims Ecotect software is used to conduct a series of thermal and lighting analysis which have good prospects of influencing building performance. Subsequently sensitivity analysis (**SA)** calculations were done with the aim of obtaining and defining the parameters that contribute significantly to energy efficiency and thermal comfort. Amongst the parameters investigated are windows size and arrangement, wall types, glazing, roof construction and insulation. Hence we applied (**SA)** techniques to the output of simulations carried out by Ecotect program to identify the most relevant parameters in the proposed portable library design.

The premise of the work is that design decisions taken during early stages of the building process have a large impact on the performance of the resulting building.

In the study reported here, a procedure was established to enable a design team to evaluate the feasibility of sustainable technologies using a simulation-based decision support system. This paper presents the design procedure and the results from the case study. Inspired by many approaches towards integrating simulation into early stages of design such as the integrated design process (**IDP**), the procedure entails a three stages process: a feasibility study followed by a parameter-based analysis, an integrated software environment was proposed and its use demonstrated through a case study. This network-based decision support system allows a design team to exchange information within a collaborative framework.

INTRODUCTION

In the last few decades, the rates of enrolling students in Mansoura University has grown very rapidly due to general population growth and the concentration of major population in the Nile Delta of Egypt fig(1).

To face this challenge, faculties' buildings and facilities have been expanded throughout the university's campus with the focus on increasing the capacity of certain elements such as classrooms, laboratories, and staff rooms, neglecting in many cases libraries and cultural facilities.

At the same time many new buildings have been erected without paying attention to the 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.

Therefore, this paper deals with the idea of expanding university's facilities by creating energy-efficient transportable structures. A library space has been chosen as a case study as it's very important to conduct research which will contribute to the foundation of a standard for low and energy-efficient buildings, moreover to give the alternative solution to increase the thermal comfort of the occupants.

This research is also focused on the integration of building simulation during early design phases since it's widely accepted that putting analysis tools in the hands of the architect during the early phases of design can have 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:

- Minimize the overall need for heating, cooling and lighting: by evaluating 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 started.
- Utilize renewable energy (**RE**) sources to provide the remaining heating, cooling and lighting needs, then use fossil fuels efficiently to provide any remaining need, and only if no renewable sources are available.
- Sensitivity analysis (**SA**) was employed as tool to evaluate the impact of design parameters on the overall building performance as quantified through building performance simulation software, thereby identifying which parameters are the most important ones.

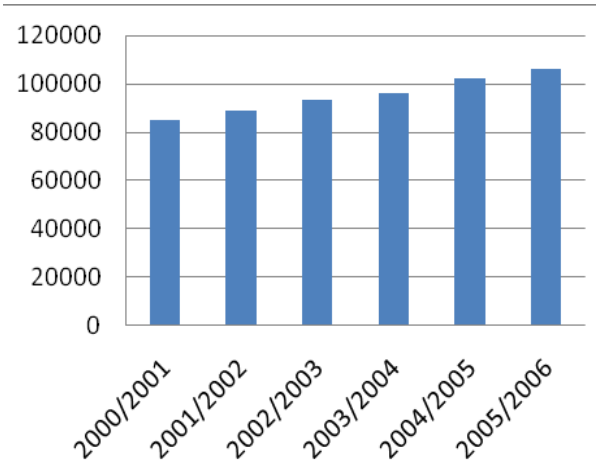


Fig (1) Statistics of enrolled students in Mansoura University

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 (2) the building volume is 6.60(width) × 9.90(length) × 4.20(height).

-The building is oriented along the east–west axis to maximize day-lighting and on the other hand to benefit from natural ventilation.

- Efficient functional arrangement of furniture elements inside the volume of space.
- The building is planned to be occupied by 24 persons as the standard number of a study group, and the operation time is planned to be four hours starting from 9 am.
- Since the outdoor air temperature in the most of summer season is higher that 40° C, it has been found too difficult to depend totally on passive techniques of cooling and the building is planned to run in a mixed mode system.
- Therefore the total energy consumption of the air-conditioning system is set to be an indicator of the building performance and thereby the output value of all sensitivity analysis calculations in the paper.

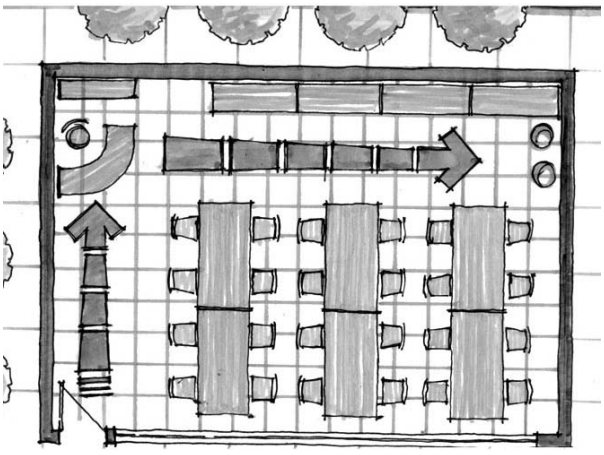


Fig (2) Floor plan shows functional arrangement of furniture elements.

Integrating Design and Simulation

According to the integrated design process (**IDP**) approach it's so important to combine knowledge from engineering and architecture in order to solve very complicated problems connected to the design of buildings. The integrated design process works with the architecture, the design, functional aspects, energy consumption, indoor environment, technology, and construction [Hansen H.T.R. and Knudstrup M.A., 2005].

In this paper the performance elements analyzed includes: Energy consumption, Day-lighting, in addition to the view of interior space as an important architectural quality as seen in figure (3).

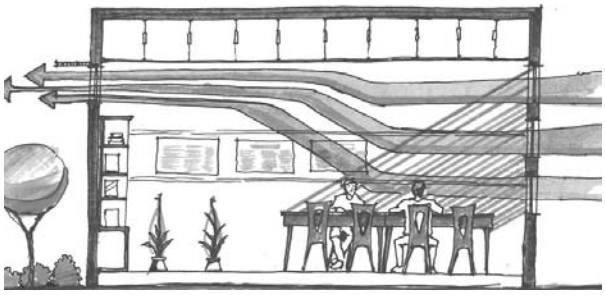


Fig (3) section through the case study.

Sensitivity Analysis

Sensitivity methods are being used to study the impacts of input parameters on different simulation outputs, as compared to a base case situation. Then, the results are interpreted and generalized so as 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 analysed from the points of view of:

1. Annual building energy consumption.
2. Peak design loads.
3. Building load profiles.

The purposes of the analysis are:

1. To assess the significance and impact of input design parameters.
2. To identify important characteristics of the input and output variables.
3. To study the responses of building systems to perturbations.

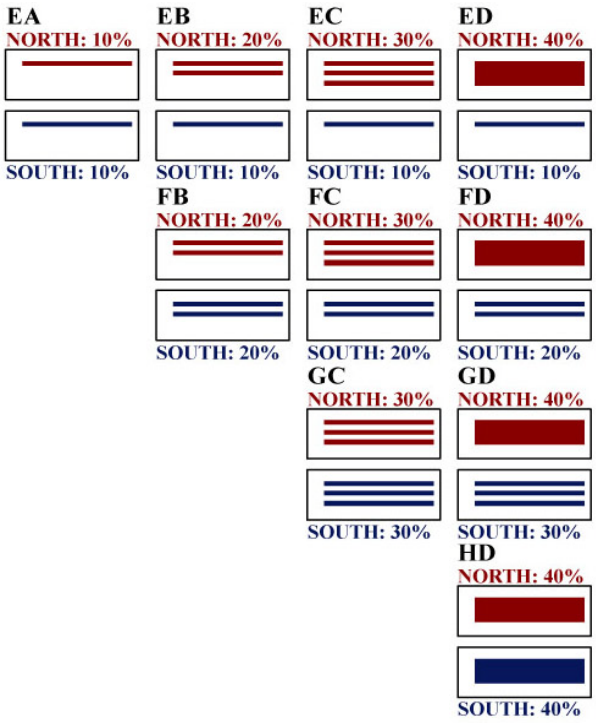
SIMULATION

Simulation Procedures:

First stage: ten alternative models varied in windows size, location and arrangement were created to study the building's thermal behaviour and interior day-lighting as shown in figure (4). Informed by the fact that some design changes would improve one performance element and might hinder another these series of analyses were performed, thereby an optimum solution can be selected to deliver the best overall solution for all three criteria.

Second stage: aiming at the definition of the best parameter values for an efficient final design by 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: wall types, window types, roof types, shading and hours of operation.

Third stage: inspired by the integrated design process (**IDP**) and based on the results from the previous stages, the optimum solution was selected to perform an upgrading phase through which an efficient use of renewable energy can be achieved.



Fig(4) Variations of window openings' size, location and arrangement

ANALYSIS

First stage: Figure (5) illustrates the energy consumption per square meter of the ten alternatives.

1. The energy consumption is directly proportional to window size especially in south facade, to record a minimum value in case EA and a maximum value in case HD.
2. The energy consumption is relatively close in the first three cases (EA-EB-EC) as a result of using double glazing and low emitting glass on both facades.

Table (1) illustrates the day-lighting Simulation Results for the ten alternatives.

- Minimum required average daylight Factor (**ADF**) is 5%, and minimum required uniformity value is 0.3.
- The (ADF) of case EA is the only one lower than 5%.
- The value of uniformity in both of case EC and ED are lower than 0.3.

The case EC is considered the best solution since it has achieved the minimum energy consumption without compromising the quality of view, while day-lighting quality is considered relatively acceptable with a minor defect in uniformity.

Second stage: table (2) illustrates the total energy consumption of four alternatives for walls, windows and roof.

- The most sensitive parameter is walls since the reduction of energy consumption ranges from 24.00% → 30.00%.
- Improving windows type is not as effective as increasing the overall resistance of walls since the reduction of energy consumption ranges from 3.00% → 7.00%.
- The effect of changing roof type on the overall energy consumption is negligible compared to both windows and walls.

Table (3) shows that natural ventilation plays an important role in heat losses as a passive technique for cooling.

Fig (6) illustrates the energy consumption per m^2 of five alternative operation schedule of four hours period and the sixth is reduced for three hours only.

- The operation time starts at 1 pm and ends at 5 pm has achieved a noticeable reduction in energy consumption of the air-conditioning system.

The elements of walls, windows and roof that achieved minimum energy consumption have been chosen for the assembly of an optimized solution for the proposed building.

Third stage: Back to the sketching phase fig (7), an external envelope has been deployed aiming at achieving these goals:

- Providing an external shade to reduce heat gain through east and west walls in addition to the roof.
- Facilitating the installation of a PV system as a renewable energy source in attempt to meet the energy demand of the air conditioning system.
- Enhancing the lighting quality of the daylight as it has increased the uniformity value to reach an acceptable limit fig (8) comparing to electric lighting in fig (9).
- Creating a distinctive architectural character of the proposed building as shown in fig (10).

Fig (11) shows that the energy produced by a PV system - installed on the rooftop of the envelope - is higher than the energy demand by air-conditioning system. Therefore, some concepts have been proposed to deal with the extra energy generated by the PV system:

1. To reduce the size of the PV arrays in order to match the energy demand and then reducing the initial cost.
2. To double the operating time of the facility by: extending the operating time during the day or extending the operating time during the night which requires installing an electric lighting systems.

Comparing the results shown in fig (11) and fig (12):

- Energy demand of the air-conditioning system is still lower than the energy produced by the PV system, which calls for reducing the size of the PV system to match the demand and then reduce the initial cost of the building.
- Energy demand by both of the air-conditioning system and the electric lighting in the case of extending operating hours during the night has matched approximately the energy production of the PV system.

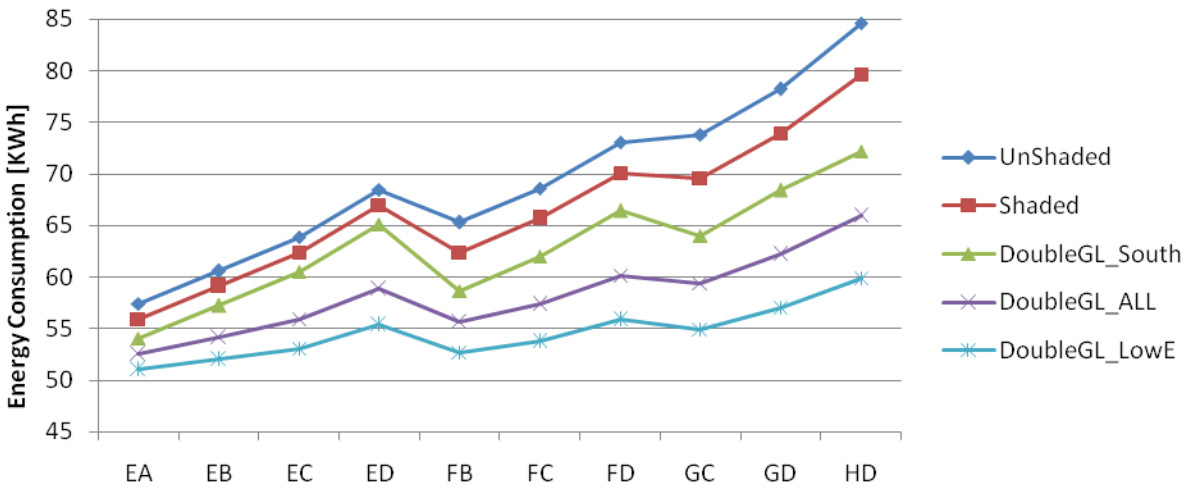


Fig (5) Comparison of energy consumption per m^2 for ten alternatives simulated using shading and four different glazing types.

	Average Daylight		Daylight Level			% of Area > DF			Uniformity	Quality of view
	Factor	Level	Center	Min.	Max.	> 10%	> 5%	> 2%		
EA	4.4	369.9	4.9	120	620	0	24	98	0.32	25%
EB	6.9	587.3	6.8	180	1180	14	78	100	0.31	50%
EC	9.8	830.6	8.3	210	2110	33	92	100	0.25	75%
ED	12.1	1026.1	9.9	240	2440	47	96	100	0.23	100%
FB	9.3	789.3	9.4	320	1220	28	99	100	0.41	50%
FC	12.2	1035.9	11.0	400	2100	62	100	100	0.39	75%
FD	14.5	1232.6	12.7	450	2850	82	100	100	0.37	100%
GC	15.0	1272.3	13.1	720	2120	95	100	100	0.57	75%
GD	17.3	1467.1	14.7	810	2810	99	100	100	0.55	100%
HD	18.8	1598.5	16.2	810	2810	100	100	100	0.51	100%

Table (1) Comparison of day-lighting analysis and quality of view.

	Material	Total energy consumption (KWh)	Value of change	Percentage of change
	Base case	5309		
Walls	Framed single fc or galvanized steel with 25 mm EPS or glass fiber	4086	-1223	-23.04%
	Framed single fc or galvanized steel with 50 mm EPS or glass fiber	3777	-1531	-28.85%
	Framed, 20mm timber boarding with 25 mm EPS or glass fiber	3988	-1321	-24.89%
	Framed, 20mm timber boarding with 50 mm EPS or glass fiber	3719	-1589	-29.94%
roof	Corrugated fibrous cement sheet with 50 mm EPS or glass fiber	5325	15	0.30%
	Tiles, sarking, 25 timber ceiling with 50 mm EPS or glass fiber	5286	-22	-0.43%
	Metal sheet + attic + plasterboard ceiling with 50 mm EPS or glass fiber	5325	15	0.30%
	25 Timber deck, bit. Felt, plasterboard ceiling with 50 mm EPS	5291	-17	-0.34%
Windows	Metal frame, single 6mm glass	5309	0	0.00%
	Metal frame, double glazing	5138	-171	-3.22%
	Vinyl frame, double, clear + clear glazing	5081	-228	-4.30%
	Vinyl frame, double, argon filled low-e clear + clear	5003	-306	-5.77%

Table (2) Effect of changing the envelope's materials on total energy consumption.

Category	Losses	Gains
Fabric	50.30%	16.80%
Sol-Air	0.00%	34.00%
Solar	0.00%	12.70%
Ventilation	37.30%	14.40%
Internal	0.00%	19.40%
Inter-Zonal	12.50%	2.60%

Table(3) breakdown percentage of heat gains and losses

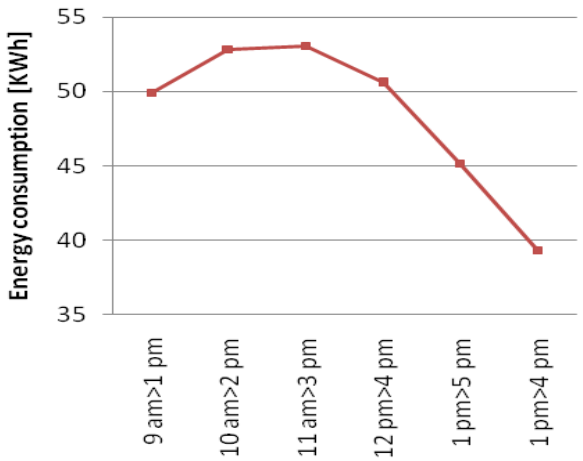


Fig (6) comparison of energy consumption per m^2 for alternative operation time schedules.

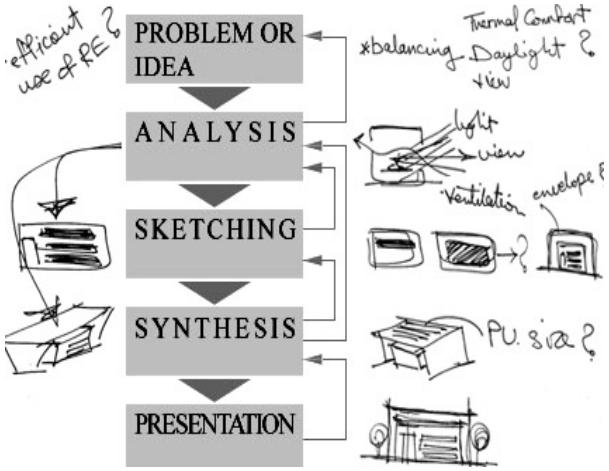
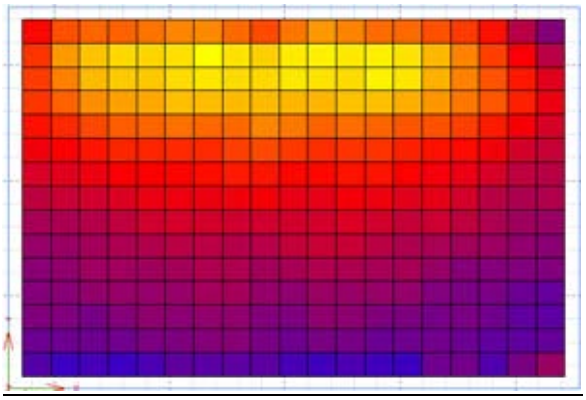
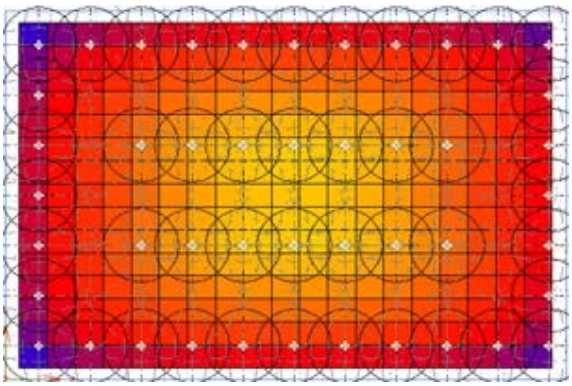


Fig (7) The interpretations of (IDP) approach through the context of the case study.



Value range: 210-1410 lux Average value: 735 lux

Fig (8) Day- lighting analysis of the case study after using the external envelope



Value range: 360-860 lux Average value: 640 lux

Fig (9) Electric lighting analysis of the case study.

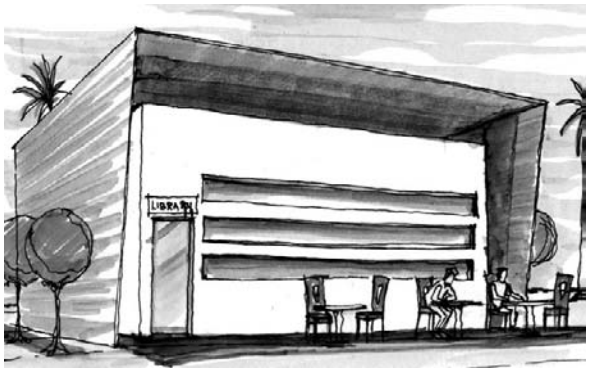


Fig (10) Conceptual sketch of the portable library.

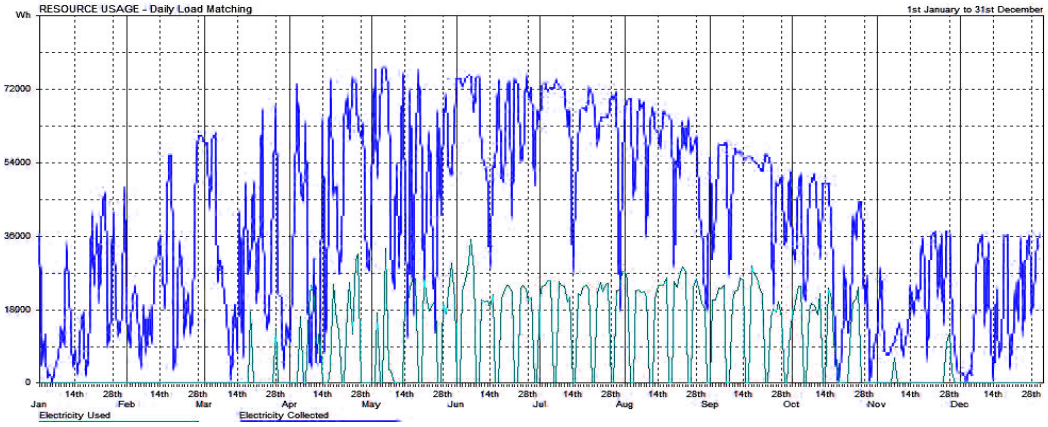


Fig (11) Daily load matching shows that electricity produced by PV system exceeds air-conditioning demand

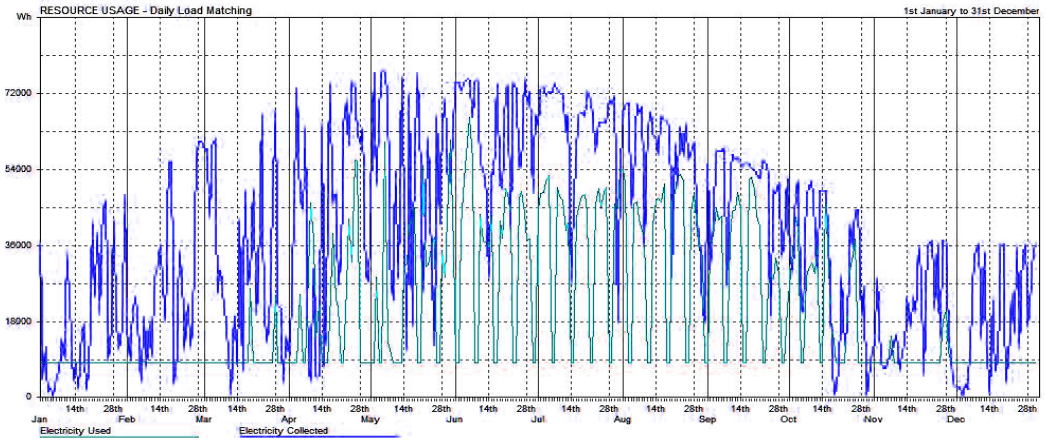


Fig (12) Daily load matching shows that electricity produced by PV system matches approximately air-conditioning and electric-lighting demand.

RESULTS

Using energy simulation software plays an important role in the formation of the building instead of personal preferences.

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

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

Day-lighting is more preferred than Electrical Lighting for both usage of energy consumption and heat emission.

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 creates cross-ventilation.

Insulating walls of the envelope has the major effect on the energy consumption, and then comes windows and roof in this case study.

Effect of materials use is relevant essentially with its surface area.

Also additional envelope - constructed using recycled materials - can enhance thermal performance but cost must be taken in consideration.

Roof of the envelope can be inclined either to minimize heat gains or, to face sun and maximize solar exposure in case of installing PV systems taking in consideration the long-term cost assessment.

Operating hours included in the day or night play an important role in energy consumption for many factors: day-lighting versus electrical lighting, also heating and cooling loads.

ACKNOWLEDGEMENTS

We would like to acknowledge and extend our gratitude to the following persons who have made the completion of this research paper possible:

Prof. Dr. Adel Deif, Dean, Faculty of Engineering.

Prof. Dr. Esmat El-Attar, Chair, Department of Architectural Engineering.

Prof. Dr. Mohammed Ghasob, Department of Mechanical Engineering.

Prof. Dr. Mohammed Eid, Department of Electrical Engineering.

Prof. Dr. Mounir Abd-El-Razek, Technology Center for Services and Communications in Mansoura University.

Mr. Omar ElSayed, Student Affairs in Faculty of Engineering.

Eng. Wafaa Ahmed, Engineering Administration in Mansoura University.

Hani Hassan, Student in 3rd grade 2009/2010, Department of Architectural Engineering.

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 analysing outputs of simulation processes.

In the case study presented in this paper a portable library is designed to fulfill its basic function in addition to reducing the overall energy consumption by 40% relative to its baseline case.

REFERENCES

Andarini R., Schranzhofer H., Streicher W., Pratiwi A.K. (2009) *Thermal Simulation And Cooling Energy Sensitivity Analysis Of A Typical Shophouse In Jakarta, Indonesia*, IBPSA conference.

Hansen H.T.R. and Knudstrup M.A. (2005), *The Integrated Design Process (IDP) - a more holistic approach to sustainable architecture*. Sustainable Building Conference 2005, Tokyo, Japan.

Harputlugil G.U., Hensen J.L.M.,Wilde P. (2007) *Simulation As A Tool To Develop Guidelines For The Design Of School Schemes For Four Climatic Regions Of Turkiye*, IBPSA conference.

Lam J.C. and Hui S.C.M. (1996) *Sensitivity Analysis of Energy Performance of Office Buildings.* Building and Environment, Vol 31, No. 1, pp. 27-39, Elsevier Science Ltd.

Lechner N., (2001) *Heating, Cooling, Lighting: Design Methods for Architects*, John Wiley & Sons, Inc.

Pollock M., Roderick Y., McEwan D., Wheatley C. (2009) *Building Simulation As An Assisting Tool In Designing An Energy Efficient Building: A Case Study*, IBPSA conference.

Stein B., Reynolds J.S. (2000) *Mechanical and Electrical Equipment for Building*, John Wiley & Sons, Inc.

Szokolay, S.V. (2004) *Introduction to Architectural Science the Basis of Sustainable Design*, Architectural Press.

Tavares P.F., Martins A.M. (2007) *Energy Efficient Building Design Using Sensitivity Analysis—A Case Study*, Energy and Buildings 39 23–31