An attempt to achieve efficient energy design for High-Income Houses in Egypt
Case Study: Madenaty City

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Received 27 April 2015; accepted 27 April 2016

Abstract

Taking into consideration the economic status in Egypt in recent years, especially the investment sector will demonstrate the enormous increase in the residential buildings sector, which created massive energy consumption that never was in proportion with the growth in generated power in Egypt. As the residential sector consumes around 42.3% of the total energy used in Egypt, one of the main factors that waste that energy is artificial lighting and electric ventilation. Meanwhile, the architects who design those buildings never pay enough attention to the energy in the design process. This paper tackles many strategies for the environmental control of building designs besides showing that now, it is essential to take into consideration energy performance efficiency and the compatibility of the building with the environment by optimizing the design of the building envelope elements such as a window to wall ratio (WWR), the glazing type. This paper will not cover the details of construction and structure, but it sheds light on many guidelines to help to raise the thermal and environmental quality of the envelope of the building. A computer-based simulation tool (Autodesk Ecotect) was used to measure current building energy and lighting performance in one of the modern cities like Madenaty city. By the end of this study, some of the characteristics of the building envelope will be concluded like the window wall ratio in the aim to reduce the energy waste in the case study, as well as the different criteria of designing process for residential buildings in Egypt in the near future.

Keywords: Low energy buildings; Energy and thermal performance; Simulation programs; Egypt

1. Background

In the last few decades, the rate of residential building investments has grown rapidly due to the general population growth and the concentration of the majority of the population in Nile Delta of Egypt. The Egyptian population now is 90,294,964 (Jan 2015 est.), with a population rate of 1.922% (2015) (Central Agency for Public Mobilization, 2015). To face this challenge many expansions have been made in the building investments to contain this population, with the focus on building quantities, not the quality of living there. In 2011 over 9.64 billion EGP were paid on residential building investments with a total increase in this much of paid money in 2010, as 8.01 billion

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Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2016.04.007
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EGP were paid with a rise of 20% in these investments (Central Agency for Public Mobilization, 2015). Most of these building were erected without paying attention to the environmental consideration at the early stages, which led to active air-conditioning to afford thermal comfort and well-lit indoor spaces (Fahmi and Sutton, 2008). As a result, building energy consumption has been increasing to meet the requirements of cooling and electric lighting, as 52% of total electricity consumption goes to residential spaces (check Fig. 1) (Ministry of Electricity and Energy, 2014). On the other hand, over 70% of buildings in Egypt are residential, so solving the problem of energy waste in these buildings will have positive effects on user outcome and will be a part of solving the energy crisis in Egypt (Info-times organization, 2013).

Moreover, the current building styles in Egypt do not take into consideration the climatic effects on the new buildings. The concrete and steel implementation in the construction technique, with not taking into account the climatic difference between each country would instantly lead to a significant loss of money, efforts and time. Many third world countries follow the structure rules and construction principles without thinking about weather differences (Mansour et al., 2007). Focusing on the last five years will demonstrate the local move among researchers in Egypt to develop guidelines for designing low energy usage residential buildings, which never affected the trend in real world constructions in Egypt. Among all these structures, there are only 26 buildings which are LEED certified, with zero residential buildings among them (USGBC, 2016).

An initiative established in 2011 by researchers at Mansoura University in Egypt was aimed to develop a residential building energy code with the help of the simulation tools by analyzing two imaginary plans for a single-family house and used sensitive analysis to study the effect of the change in input parameters on the output case study. The study focused on walls and roof insulation as well as glass upgrade and adding a renewable energy source for the unit. Without taking into consideration the ordination of the imaginary unit or its location which the researcher will try to avoid in this study with keeping the same methodology on the pre-built residential unit (Nabih et al., 2011).

Another research was done by a researcher in the housing and building national research center in 2013 named “Sustainable Energy Potential in the Egyptian Residential Sector”. Stated that power usage in the residential sector can be divided into nine parts (as shown in Fig. 2). As noticed the lighting and space cooling and heating represent almost 44% of total energy demand in the residential sector in Egypt, the study is trying to find guidelines to decrease the energy used for lighting, cooling and heating which is considered as a strengthening point (Hanna, 2013).

2. Research aims

This paper is 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 initial stages of design can ensure the performance of the end product. While thermal comfort, daylighting and view were identified as three main challenges to the design concept, the following strategies provide a key toward 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 construction at the preliminary design stage, this will allow critical choices to be made before the final work started.
- Sensitivity analysis (SA) was employed as a 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 (Andarini et al., 2009).

![Energy Distribution](image1)

**Figure 1.** Energy distribution based on building type in Egypt (Ministry of Electricity & Energy, 2014).

![Electricity Consumption Patterns](image2)

**Figure 2.** Sectorial Electricity Consumption Pattern/(Hanna, 2013).
3. 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 (check Fig. 3).

3.1. Case-study characteristics

(a) A case study building was selected in Madenaty city in New Cairo as an example of shelters for High-Income Houses in Egypt (Madenaty Co., 2015). The study chooses Madenaty city as a representative of this category of housing.

(b) The master plan of Madenaty was designed to have variables in each unit ordination, which gives a variety of thermal characteristics for each unit. In this study the researcher will focus on a single unit (as shown in Fig. 4) with true north orientation for the main view and the entrance directed to the true south.

(c) As seen in Fig. 5, the building volume is 16 (width) × 19 (length) × 8.40 (height).

(d) The building consists of two duplex residential flats with 130 m² furnished spaces divided on two floors 56 m² on the ground floor and 74 m² on the 1st floor.

(e) The building is planned to be occupied by 10:12 persons as 5:6 persons for each flat, as the standard number of the Egyptian family.
Figure 5. Case study characteristics (Madenaty Co., 2015).

Figure 6. The characteristics of base case study.

Figure 7. Integrated design process (Howell, 2008).
(f) Since the outdoor air temperature in the most of the summer season is higher than 40 °C (Ministry of Petroleum, 2010), 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.

(g) 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.

(h) All other factors such as occupancy schedules, orientation, operation schedules ventilation rates, infiltration rates and internal design conditions are the same as shown in Fig. 6.

3.2. Integrating design and simulation

According to the integrated design process (IDP) approach, it is so important to combine knowledge from engineering and architecture 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 and Knudstrup, 2005), in this paper the performance elements analyzed include Energy consumption, day-lighting and the view of interior space as an essential architectural quality, see Fig. 7.

3.3. 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 and Hui, 1996), critical input design parameters of the building systems are identified and analyzed from the points of view of:

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Figure 11. Model variations in WWR ratio and daylight distribution changes.
a. Annual building energy consumption.
b. Peak design loads.
c. Building load profiles.

The purposes of the analysis are:

1. Assessing the significance and impact of input design parameters.
2. To identify essential characteristics of the input and output variables.

3.4. Autodesk Ecotect 2011

All measures and empirical tests were done using the methods of simulation and analyzing the building’s energy with advanced software through Autodesk Ecotect 2011 software. From the comparison between many computer based programs, study chooses to use Ecotect program because of its facilities with respect to making a perfect induction about thermal performance of the building and pleasant user interface, which is easily used by architects (Crawley et al., 2008). All results are put into diagrams, tables, and charts, and then they were compared and analyzed to indicate what is concluded.

4. Analysis

**First stage**: constructing a computational model of the case study building on Ecotect and extracting some results like the internal daylighting, ventilation power usage and electric lighting power usage to edit many parameters in the building geometry to minimize these findings.

**Second stage**: many alternative models varied in windows size, location and arrangement were created to study the building’s thermal behavior and interior day-lighting. Informed by the fact that some design changes would improve one performance element and might hinder another these series of analyzes were performed, thereby an optimum solution can be selected to deliver the overall best solution for all three criteria.

**Third stage**: aiming at the definition of the best parameter values for 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, orientation, window size and number of building users.

**Fourth stage**: inspired by the integrated design process (IDP) and based on the results from the previous steps, the optimum solution was selected to perform an upgrading phase through which an efficient use of renewable energy can be achieved (See Fig. 8).

<table>
<thead>
<tr>
<th>Opening ratio</th>
<th>Daylight factor</th>
<th>Covered floor area</th>
<th>Cooling load</th>
<th>Heating load</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>6.75</td>
<td>90%</td>
<td>30.02</td>
<td>9.25</td>
</tr>
<tr>
<td>70%</td>
<td>5.49</td>
<td>90%</td>
<td>27.8</td>
<td>8.2</td>
</tr>
<tr>
<td>50%</td>
<td>5.29</td>
<td>80%</td>
<td>26.4</td>
<td>8.4</td>
</tr>
<tr>
<td>41% (case study)</td>
<td>4.75</td>
<td>38%</td>
<td>25.8</td>
<td>11</td>
</tr>
<tr>
<td>30%</td>
<td>4.16</td>
<td>40%</td>
<td>25.74</td>
<td>7.3</td>
</tr>
<tr>
<td>10%</td>
<td>3.18</td>
<td>20%</td>
<td>25.7</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Figure 12. Daylight factor and WWR changes.

Figure 13. Cooling loads and WWR changes.

4.1. First stage analysis (base model analysis)

4.1.1. Light analysis

At day time, the distribution of openings in both plans affords proper daylighting for only 38% of the total spaces. As the daylight factor is 4.75 overall the plan area and this is less than the required for human visual comfort in residential spaces and requires using electric lighting in most of the plans as shown in Fig. 9.
4.1.2. Cooling and heating loads analysis

Due to the wrong orientation and openings ratios and the lake of the south facade treatment, the cooling and heating loads are more all over the year as shown in (Fig. 10).

As calculated in Ecotect:

- Max Heating: 11 KW at 05:00 on 20th January.
- Max Cooling: 25.8 KW at 15:00 on 7th June.

4.2. Second stage analysis (the variations)

Many alternative models varied in window size were created to study the building’s thermal behavior and interior day-lighting see Fig. 11, as the change in opening percentage change many thermal characteristics of the building. Check Table 1 to notice the difference between model varieties. As noticed the more the opening percentage, the more the cooling and heating load but more daylight factor and covered floor area, see Figs. 12 and 13. So applying the sensitive analysis concept, choosing the optimum opening percentage will be by achieving the best day-lighting with the least cooling and heating load.

4.3. Third stage analysis (sensitive analysis)

The model design no. 3 which has opening ratio = 50%, has the lowest accepted daylight and covered floor area with daylight and achieving the most conventional cooling and heating loads, see Fig. 14.

So comparing model no three which has 50% opening ratio to the case study which has 41% opening ratio, see Fig. 15 we conclude that the increase in cooling loads is acceptable when compared to the decrease in heating loads and increasing daylight factor all over the floor area.

4.4. Third stage analysis (the optimum case analysis)

Analyzing the optimum case study that was selected based on achieving the maximum possible daylight factor

![Graph](image1)

Figure 14. Comparison between case study and suggested models in daylight and in thermal comfort loads.

![Graph](image2)

Figure 15. Comparison between case study and selected model for daylight, cooling and heating loads.
and distribution with the minimum cooling and heating loads

4.4.1. Daylight analysis

The openings at north and south facade help to increase daylight, as shown in Fig. 16, the solar exposure in EGYPT varies from 5.4: 7.1 KWh/m2/day, which helps on indoor daylight (British Standards Institution (BSI), 1992).

The daylight distribution on a (+.6, +3.9 m) level is shown next Fig. 17, showing that the average daylight factor is 5.92% with 1.17% more than the previous design and the minimum daylight is 321 lux and the minimum required for living spaces is 300 lux, except the corridor which has only 83 lux the necessary daylight for the corridors is 50 lux only, so there is no need to use artificial lights in the morning and hence save energy (The Engineering Toolbox, 2012).

4.4.2. Cooling and heating loads analysis

Due to the opening ratio change, the cooling and heating loads are less, see Fig. 18

- Max Heating: 1.5 KW at 05:00 on 23rd February.
- Max Cooling: 17 KW at 14:00 on 27th May.
5. Results and discussion

Different residential indicators refer to the fact that the major expansion rate in the sector will keep rising with no reduction in the near future and may lead to a crisis in the power generation industry in Egypt, (Ministry of Electricity and Energy, 2014). Since the energy waste in the residential sector should be decreased in some way or other, the primary objective of the study is to prove that including many simulation processes in the predesign phase will help in reducing the power waste in the residential sector. The study covered many results. For example, a small change in a single architectural element like the Window-to-Wall Ratio (WWR) may have a significant effect on either daylight sufficiency or cooling and heating loads. As the change in a single unit’s WWR led to increasing the daylight factor over the whole plan by .54, as the original model has a daylight factor of 4.75 and the modified model has a daylight factor of 5.29 which should certainly decrease the power usage implemented in artificial lighting. The same change led to a reduction in the power usage of cooling and heating by 10 KW over the year which is not considered to be a significant drop as both cooling and heating loads depending on other architectural elements like orientation and material properties too. However, the selection of the optimum case process was depending on achieving the maximum possible daylight with the minimum possible loads. In another research, there would be different criteria in the selection of the optimum case that could be the one with minimum loads and only based on saving the wasted power in heating and cooling. Besides taking into consideration other criteria, the optimum case could be the model with the best possible daylight. The change in WWR only led to ±3.75 in daylight factor and ±70.7 KW in heating and cooling loads over the year. However many architectural elements should be modified to reduce the power usage such as orientations in Master plans, architecture design of each residential unit plan, windows size, finishing materials and shading devices. The different cases and studies mentioned before resulted in huge gaps that should be filled shortly by other studies so as to measure how each architectural element could affect the power usage in each residential unit.

6. Conclusions

Putting into consideration the simulation results of many varieties would lead to conclude the following:

- Creating verities in WWR resulted in 6 different models with 67.142% increase and decrease with daylight factor in comparison to the base model.
- Another change in results was noticed in cooling and heating loads with a 88.109% decrease and an increase in comparison to the base model.
- Because both the artificial lighting and HVAC uses around 44% of the residential unit total power usage, the reduction of 88% and an increase of 109% led to an entire range of 94:105% change in the total residential unit power. Also, having all other parameters fixed should be taken into consideration.
- Changing the orientation led to different results of the expected range while bearing in consideration the factors of cooling, heating, and daylight.
- Many architectural elements were included in the research such as finishing material, opening material and transparency, usage hours and the number of users which should be considered as variables that affect visual and thermal comfort all over the studied unit.
- Including simulation in the design phase will help in solving many problems that are connected to the user’s visual and thermal comfort as well as contributing to decreasing the possibility of energy waste.

Author’s contributions

Kareem: data collection, study design, simulations, preparation of draft.
Wael: critical revision of draft.

References


