Affordable Housing Retrofitting Strategies through Coupling Simulation Method Criteria

Y. Magdy¹, W. Kamel², A. El Menshawy¹

ABSTRACT

Nowadays many of social housing in Alexandria are often obsolete with inadequate condition that represent through the comfort conditions, energy consumption and structural conditions moreover the lack of the minimum aspects of the architectural aesthetic elements. over 50% of the Egyptian population live in informal settlement. Alexandria has a great share of these slums, while it contains more than 36 informal settlements. The residential sector consume about 47% of all the electricity consumption. The government constructing a large concrete blocks without concerning about the environmental issues during the decision making or design buildings more energy efficient. Also this buildings with old energy technologies affects the overall energy consumption in the city. this research aims to state the significance of choosing the appropriate software in decision making for retrofitting strategies of building energy and micro climate simulation through formulating a strategic framework of concentration area, selection and assessment criteria applied of different architect friendly softwares, concluding by applying the passive design strategies reaching the most effective thermal comfort techniques through coupling method in order to simulate the building energy and micro climate by eQuest which employs DOE-2.2 and Designbuilder which employs Energyplus along with the micro-climate tools such as CityBES and ENVI-met respectively as the most architect friendly use softwares.

KEYWORDS: informal settlements, microclimate simulation, energy simulaiton, retrofitting systems, passive systems

1. INTRODUCTION

Informal settlements were described through a numerous varied definitions, and each of them was based on some of the characteristics that characterize slums, in terms of being illegal, unplanned and marginal areas. Recently the slums were frequently mentioned as it is a global concern to reflect the depth of this phenomenon in its housing and population dimensions.

Slum areas are described as areas that constructed by self-efforts, they are built in the absence of law in settlements which have not been planned. That can be environmentally and socially insecure which is characterized by a low level of basic services and lack of facilities. Resulted in a segment of society whose values and principles are decreasing in the face of the overwhelming need for food, housing, clothing and sense of security [1]. Over 50% of the population in Egypt lives in informal areas [2]. Alexandria has a great share of the informal settlements as over two third of the population lives in slums distributed through all the city districts as shown in table 1 [3].

¹ Architecture Engineering and Environmental Design Department, College of Engineering and Technology, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.
yousabmagdy94@gmail.com

² Construction and Building Engineering Department, College of Engineering and Technology, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.
The annual demand for residential units in Egypt ranges between 200 thousand to 300 thousand housing units, to meet the needs of population growth and internal migration, the government housing sector providing 27.4% of this requirement. The private sector also provides the same rate of 27.4%, while random housing fills 45.2% of this requirement, making the largest reliance on the need to meet the need for random housing [3].

Table 1. Informal settlements distribution in Alexandria [3]

<table>
<thead>
<tr>
<th>Name of the District</th>
<th>Size in Km²</th>
<th>Total population/year</th>
<th>Number of informal areas</th>
<th>Average Density P/Km²</th>
<th>Safe / unsafe</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Montaza</td>
<td>82</td>
<td>1,585,572/2018</td>
<td>9</td>
<td>19,336</td>
<td>Safe</td>
</tr>
<tr>
<td>Sharek (East)</td>
<td>35</td>
<td>1,158,822/2018</td>
<td>5</td>
<td>33,109</td>
<td>Safe</td>
</tr>
<tr>
<td>Wasat (Middle)</td>
<td>68</td>
<td>543,405/2018</td>
<td>2</td>
<td>7,991</td>
<td>Safe</td>
</tr>
<tr>
<td>El Gomerk</td>
<td>4.7</td>
<td>156,780/2018</td>
<td>2</td>
<td>33,357</td>
<td>Safe</td>
</tr>
<tr>
<td>Gharb (West)</td>
<td>20.1</td>
<td>356,613/2018</td>
<td>8</td>
<td>17,741</td>
<td>unsafe</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td><strong>209.8</strong></td>
<td><strong>2,801,192</strong></td>
<td><strong>26</strong></td>
<td><strong>13,351</strong></td>
<td></td>
</tr>
<tr>
<td>El Amriya+ El Agamy</td>
<td>1555.5</td>
<td>617,384+ 608,674/2018</td>
<td>5+</td>
<td>788</td>
<td>Safe + unsafe</td>
</tr>
<tr>
<td>Borg El Arab</td>
<td>534.7</td>
<td>133,543/2018</td>
<td>1</td>
<td>250</td>
<td>Safe</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2300</strong></td>
<td><strong>5,225,979/2019</strong></td>
<td><strong>36</strong></td>
<td><strong>2,272</strong></td>
<td></td>
</tr>
</tbody>
</table>

1.2 Problem Statement

By 2014 Egypt has a total electricity capacity of 174.9 Billion kWh, all the distributed amount is 146.6 Billion kWh, the residential sector consume 63.5 Billion kWh compared to 2018 the residential sector consume 83.4 Billion kWh with increasing ratio 7.6%. The total electricity of residential houses increases from 36.6% to 42.4% with loss of 7.7% of generated energy and 3.2% self-consumption by the station, with a total up to 53.3%. However the government implementing new electricity generation stations through renewable and non-renewable sources that only the whole consumption payback covers 63% of total cost while increasing the cost by average 30% between 2019-2020 in order to cut all the governmental financial support by 2025. The problem is the increasing gap between the energy consumption and energy production due to the new urban communities.

1.3 Research aim and objectives

This research aims to the significance of choosing appropriate software in decision making for retrofitting strategies of the building energy and micro climate simulation considering the occupants’ thermal comfort for the new residential complex determining the appropriate simulation software testing the retrofitting system, through the following objectives:

- Determining the meteorological parameters affecting the occupants’ thermal comfort.
- Considering the retrofitting strategies of building and micro-climate.
- Applying the energy simulation through different software by a concentration areas, selection and assessment criteria.
- Determining the architect friendly software.

2. The Meteorological Parameters Affecting The Occupants’ Thermal Comfort

The need to achieve a good indoor environmental quality (IEQ) as a result of thermal, visual, acoustic comfort and indoor air quality. The awareness increased that an adequate design of the indoor environment, where people work and live, requires a synergic approach to all facets involved in full compliance with sustainability. IEQ strictly affects the overall building energy performances and exhibits an antagonistic relationship with respect to the energy saving requirements [4].
Thermal comfort is defined by the opinion of people who occupy a space, depending on the subjective feeling related to temperature, it refers to the perception of occupants, and should be modified as possible to avoid situations of discomfort or thermal stress. Thermal comfort must be guaranteed as a neutral condition, thermal comfort described through seven points thermal sensation scale between the Predicted Mean Vote (PMV) and Occupants’ sensation as shown in Table 2 [5].

<table>
<thead>
<tr>
<th>PMV vote</th>
<th>+3</th>
<th>+2</th>
<th>+1</th>
<th>0</th>
<th>-1</th>
<th>-2</th>
<th>-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensation</td>
<td>Hot</td>
<td>Warm</td>
<td>Slightly warm</td>
<td>Neutral</td>
<td>Slightly cool</td>
<td>Cool</td>
<td>Cold</td>
</tr>
</tbody>
</table>

Physiological equivalent temperature (PET), where the exchange between human body and environment is evaluated and, in relation to the different equilibrium situations, is defined as a perceived equivalent temperature by a subject, PMV and Percentage People Dissatisfied (PPD%), which is related to the felling and judgment of people as shown in Fig.1 [5].

![Fig. 1 Thermal sensation scale][5]

Physical parameters of indoor environment is related to the air volume enclosed in the building, this is an open system that:
- Exchanges mass, because of the air passage through doors and windows, and air leakage, which causes as well the movement of indoor pollutants, such as dust and CO₂,
- Exchange energy, because of the difference in temperature between indoor and outdoor spaces, because of heating due to the sun or to the presence of people, or to the variation in latent heat due to absolute, specific and relative humidity as shown in Table 3 [6].

<table>
<thead>
<tr>
<th>The variables influencing indoor environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature, measured in °C</td>
</tr>
<tr>
<td>Mean radiant temperature (MRT) measured in °C</td>
</tr>
<tr>
<td>Absolute humidity, measure in g/m³</td>
</tr>
<tr>
<td>Specific humidity measured in g/kga</td>
</tr>
<tr>
<td>Relative humidity (RH), measured in percentage (%)</td>
</tr>
<tr>
<td>Air velocity (v), measured in m/s</td>
</tr>
</tbody>
</table>

3. STRATEGIES FOR ENERGY RETROFITTING

The design that maintains a comfortable temperature within the building using the climate and natural elements to get the optimum benefit and to reduce or eliminate the independence on mechanical systems for heating, cooling and lighting, is called ‘Passive Design’. There are two crucial measures for passive design to be beneficial and effective: climate and comfort. To get the maximum benefit of energy retrofitting for a building it’s needed to combine different strategies [7].

Analytical considerations to Design an Energy efficient Building in order to get the optimum benefit of the retrofitting strategy, needs to consider the following:

**A. Building orientation**

Building orientation governs the passive technologies implementation within the design. It also governs the window sizing and locations, which will affect both lighting space conditioning within a
building. Proper orientation can lead to significant reduction in lighting and space conditioning load if coupled with passive design technologies [8].

**B. Building shape**

Well-designed passive building produces less air pollution and greenhouse gasses, and thus it contributes to a more sustainable environment. Good passive buildings not only conserve energy, but also account for hidden environmental benefits. Massing of the building blocks help achieve thermal and visual comfort. Building blocks channelize or obstruct the wind flow, also act as shading devices for surroundings. Building blocks design and geometry can influence the wind flow and velocity [9].

**C. Material selection**

Choice of material depends on the outside climate around the building. However, the properties of material used, which governs their usage, can be noted as three different properties. Color, insulation property and assembly type. Finishes color will vary the amount of heat and light absorbed and reflected. Lighter the color greater reflectivity while darker the color more absorbing property. In addition, the insulation property plays an important role in material selection. Good insulation is required to reduce heat exchange between the internal and external space [10].

4. MICRO-CLIMATE LEVELS

Many urban and suburban areas experience elevated temperatures compared to their outlying rural surroundings, this difference in temperature is what constitutes an urban heat island (UHI) [11]. According to the characterization in different layers of urban heat island is divided into three categories surface urban heat island (SUHI), canopy urban heat island (CUHI) and boundary urban heat island (BUHI). The BUHI is relatively hard to detect due to temperature difference from sensors mounted on tall towers, balloons and aircraft and climate model simulation has been usually used to understand the characterization of BUHI. Canopy urban heat island is usually quantified by air temperature records from urban and rural stations The heterogeneous time series of air temperature records usually result in uncertainties of warming trend induced by urbanization process, Satellite-based land surface temperature (LST) is widely used in the monitoring of SUHI and can provide detailed information in regards to surface temperature variation over various land cover types as shown in Fig. 2 [12].

![Fig.2 Schematic depiction of the urban microclimate levels](image)

Elevated temperatures from urban heat islands, particularly during the summer, can affect a community’s environment and quality of life. Most impacts are negative and include:
- Increased energy consumption
- Elevated emissions of air pollutants and greenhouse gases
- Compromised human health and comfort
In order to set a strategic criteria to control urban heat island in micro scale for energy consumption reduction needs the following:

1. Providing green spaces and vegetation in different layers of buildings
2. Using albedo materials on external surfaces of buildings
3. Providing void decks at ground level or at mid-span, variation of building height and arrangement of openings in building to face the prevailing wind can create natural ventilation.
4. Providing appropriate orientation of building and site for preventing sun radiation, encouraging air movement and natural ventilation.

5. **BUILDING INFORMATION MODELING**

A limited number of building energy simulation tools are integrated with building information modeling (BIM) through Industry Foundation Class (IFC) and Green Building XML (gbXML), additional efforts such as manual model check and modification for defining thermal zones are requested to generate reliable energy models. Simulation results into the design decision is still considered difficult. Typically, energy simulation tools provide a large quantity of numerical results presented in tables or charts [13].

Existing building energy simulation tools aim to evaluate energy performance and thermal comfort during a building’s life cycle. Specifically, DOE-2 and EnergyPlus have been widely used at multiple stages of a building’s life cycle due to their functionality of exchanging data with other tools through standard data formats as described in the “Building Energy Software Tools Directory”.

The research surveyed more than two hundred software about evaluation of the performance of each tool in different categories such as graphical representation of results, easy learnability, short learning curve, flexibility of use and navigation, simple input options, flexible data storage, providing online support and training courses, providing weather data within the tool, and interoperability.

5.1 **Selection Criteria for Energy Simulation Softwares**

Developed criteria for assessing the architect-friendliness of the building information modeling (BEM) tools, this evaluation criteria consisted of five concentration areas as shown in table 4 [13].

<table>
<thead>
<tr>
<th>Concentration areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Input</td>
</tr>
</tbody>
</table>

The first part focused on achieving quick and straightforward data input, as well as graphical representation of the geometry, while the second part focused on the interpretation of output results and the capabilities of parametric analysis. The third section stressed the importance of the Graphical User Interface (GUI) through clear and flexible navigation instead of using command line interface (CIL), the fourth section incorporated the usability for minimal and quick feedback, and a general section based on the overview of most commonly used BEM tools and the different developed selection criteria as shown in table 5 [14].

<table>
<thead>
<tr>
<th>Selection criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability and Information Management of Interface</td>
</tr>
</tbody>
</table>

---

Page 15
The selected BEM tools for this research have higher penetration within the architectural practice, in addition to their integration with BIM tools. Also, defined the following assessment criteria from as shown in table 6 [15].

**Table 6 Assessment criteria for BEM tools [15]**

<table>
<thead>
<tr>
<th>Assessment criteria</th>
<th>Usability</th>
<th>Interoperability</th>
<th>Support Options</th>
<th>Information Management</th>
<th>Computing Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 5.2 User friendly energy Softwares for architects

These software helping choose the most applicable software to be used by architects, depends on the software source availability, and the results validation. Using more than one software covering the microclimate simulation and building energy simulation combined together to give a holistic overview of energy performance. Emphasizing on test and assess the performance of the most commonly used BEM tools, by applying the previous criteria for (concentration areas, selection criteria, and assessment criteria) as shown in table 7.

**Table 7 User friendly software for building energy simulation. Source: the researcher**
The US department of energy formerly hosted over two hundred energy simulation tools, the previous table 7 shows the user friendly software for building energy simulation, also there are more software like eQuest, Autodesk Insight Solar, Indoor Climate and Energy, and more selected according to the previous criteria. Reliably generating high quality BEM using current tools remains difficult. Although much of the process has been automated, intervention by the user to simplify models, choose among representations with subtle differences, and correct errors. Also there are software dedicated for the micro-climate simulation as shown in table 8.

Table 8 User friendly software for Micro-climate simulation. Source: the researcher

<table>
<thead>
<tr>
<th>Energy simulation Softwares</th>
<th>(IES-VE) Integrated Environmental Solution – Virtual Environment</th>
<th>ENVINFO _MET</th>
<th>CityBES (City Building Energy Saver)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Input</strong></td>
<td>Ability to import building geometrical data from a commonly used BIM tools in addition to gBXML, IFC, and DXF files, includes 11 modules, ModelIT for geometry creation and editing, SunCast for shading visualization, ApacheCalc for loads analysis, ApacheSim for thermal analysis, Apache HVAC, MacroFlo for natural ventilation, MicroFlo for 3D CFD, FluxPro for radiation for lighting design, DEFT for model optimization, LifeCycle for LC energy and cost analysis, and Simulex for building evaluation.</td>
<td>The new ENVINFO _MET plugin for Rhinoceros 3D has been developed in the Ladybug Tools. By the use of this plugin, the user is able to convert Rhinoceros 3D designs into ENVINFO _MET model areas and run ENVINFO _MET simulations without even opening the ENVINFO _MET software suite. This makes the usage, especially for architects who commonly utilize Rhinoceros 3D for their designs in the first place, much easier. - Modeling 3D buildings with Rhinoceros and Grasshopper to - Integration with plugins of Grasshopper such as Gismo (GIS plugin for Grasshopper).</td>
<td>Three layers of the software first the data layer, the Algorithmic and software layer including weather data, and combined data in 3d city models (CityGML, GORSYS) that includes building stock data, geographical information system (GIS), Database for a selected location (ECMs, utility rates, codes and Regulations), secondly the software layer includes EnergyPlus, OpenStudio and CityBES, finally the use case layer provides examples of potential applications related to energy.</td>
</tr>
<tr>
<td><strong>Data Output</strong></td>
<td>(IES-VE) provide a variety of output data formats such as tabular, graphical, photorealistic images and detailed populated reports that match green building rating systems templates</td>
<td>Solar analysis, Air pollutant dispersion, Building Physics (Facade, temperatures, vegetated walls) interactions between the outdoor microclimate with indoor climate Green &amp; blue technologies</td>
<td>Provides a set of features to support building energy efficiency analyses including energy retrofit analysis, energy benchmarking, urban energy planning, and building operation improvements.</td>
</tr>
<tr>
<td><strong>Graphical User Interface</strong></td>
<td>(IES-VE) is one of the hardest to learn tools, which require training to master because of its relatively complex suite</td>
<td>The new NetCDF converter allows users to visualize simulation results using a wide range of different visualization tools in addition to the well-known LEONARDO application.</td>
<td>CityGML as the data schema to represent and exchange 3D city models. Also provides 2D building footprint GeoJSON format, building height, type, and year of built.</td>
</tr>
<tr>
<td><strong>Usability</strong></td>
<td>(IES-VE) employs Apache dynamic simulation engine for its thermal and energy simulation, Radiance for lighting simulation, MacroFlo and MicroFlo for airflow and CFD simulation.</td>
<td>ENVINFO _MET only simulates part of the spatial environment, boundary conditions are required for the lateral and vertical borders of the 3D model.</td>
<td>CIBES allows users export the retrofit analysis results to CSV format for further analysis. Also generates approximately load profiles to support the analysis of district energy systems.</td>
</tr>
<tr>
<td><strong>General</strong></td>
<td>an integrated suite of in-depth building performance analysis tools, linked together by a common user interface and centralized integrated data model.</td>
<td>Allows to create living conditions in a constantly changing environment. With interactive tools deep-seated of the microclimate complex and analyze how designs perform.</td>
<td>A free user friendly web app modeling urban buildings using detailed EnergyPlus models Excellent 3D GIS visualization.</td>
</tr>
</tbody>
</table>

6. CONCLUSION

Energy efficient buildings aim to reduce the overall energy consumption necessary for their operation. High-performance buildings are designed to improve the overall building performance, besides energy usage, such as improving occupants’ thermal, visual and acoustic comfort. Quantifiable
predictions can help in identifying strategies and methods to improve building energy efficiency and the overall building performance.

Passive design is about taking advantage of natural energy flows to maintain thermal comfort. Passive technologies are systems which rely on natural resources and help to achieve comfort levels without relying on artificial energy. Choice of passive design techniques is majorly dependent on local climate where the project is located. The techniques are sustainable and use abundantly available natural resources. Integration of such techniques help transform building envelops into living organic creations to sustain human life within.

Urban heat islands refer to the elevated temperatures in developed areas compared to more rural surroundings. UHI are caused by development and the changes in radiative and thermal properties of urban infrastructure as well as the impact buildings can have on the local micro-climate.

7. RECOMMENDATIONS

In order to test the retrofitting systems to reach the most energy efficient scenarios required to use the coupling simulation method by combining the results from the building energy simulation and micro-climate simulation based on the selection, assessment criteria and concentration areas in order to choose the most appropriate simulation software providing the relatively most accurate results for the occupants’ thermal comfort through passive design strategies by using eQuest which employs DOE-2.2 and Designbuilder which employs Energyplus along with the micro-climate tools such as CityBES and ENVI-met respectively as the most architect friendly use software.

8. REFERENCES

استراتيجيات التعديل التحديثي للإسكان بأسعار معقولة من خلال معايير أسلوب محاكاة الاقتران

بواسط ماجد، وائل كامل، عادل المنشاري

الملخص

في الوقت الحاضر، غالبًا ما يكون العديد من المساحات الاجتماعية في محافظة الإسكندرية تأثراً بظروف غير مناسبة تمثل من خلال الشعور بالراحة داخل المباني واستهلاك الطاقة والميزانيات الطاقة للمباني علاوة على عدم وجود الحد الأدنى من العناصر الجمالية المعمارية. يعيش أكثر من 50% من سكان مصر في مناطق مشابهة، الإسكندرية فيها نصيب كبير من هذه الأحياء الفقيرة، في حين أنها تحتوي على أكثر من 36 موقعاً غير مختار. يتضمن القطاع السكني حوالي 47% من إجمالي استهلاك الطاقة، ويقوم به الحكومة بناء كائناً خرسانيًا كبيراً دون الفرق بين التكلفة والبيئة. أثناء اتخاذ القرار، تم تصميم المباني بشكل أكثر كفاءة في استخدام الطاقة. كما أن هذه المباني ذات تقنيات الطاقة القليلة تؤثر على الاستهلاك الكلي للطاقة في المدينة. يهدف هذا البحث إلى توضيح أهمية اختيار المباني المناسب في اتخاذ القرار للإستراتيجيات التحديثي. لبناء الطاقة ومحاكاة المناخ من خلال صياغة إطار استراتيجي لعملية تعمق وتنفيذ الاختبار والتقديم للمشروع. برامج معمارية مختلفة، واستخدام إستراتيجيات التصميم تعتمد على مصادر طبيعية للطاقة تصل إلى تقليل الراحة الحرارية الأكثر فعالية من خلال طريقة الاقتران من أجل محاكاة طاقة المبنى والم לשريحة من خلال الاقتران من خلال طريقة الاقتران من أجل محاكاة طاقة المبنى والم

كلماتใครش: العشراويات، محاكاة المناخ، محاكاة الطاقة، أنظمة التحسين لاستهلاك الطاقة. الأنظمة العصبية للبيئة.

الكلمات المفتاحية: الإسكان، طاقة، محاكاة، المحافظة على البيئة، الطاقة، الاستهلاك.

1. قسم الهندسة المعمارية والتصميم البيئي، كلية الهندسة والتكنولوجيا، الأكاديمية العربية للعلوم والتكنولوجيا، ونيل البحري، الإسكندرية، مصر.
yousabmagdy94@gmail.com.

2. قسم هندسة التشييد والبناء، كلية الهندسة والتكنولوجيا، الأكاديمية العربية للعلوم والتكنولوجيا، ونيل البحري، الإسكندرية، مصر.