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FULL LENGTH ARTICLE

Using simulation tools for optimizing cooling loads and daylighting levels in Egyptian campus buildings

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Abstract This article presents a case of heuristic optimization of cooling loads and daylighting levels in deep halls of Egyptian Universities, using DesignBuilder software, with EnergyPlus and Radiance engines, in order to show the vital role of simulation tools in architects' hands. Generally speaking, campus buildings in Egypt reflect real problems of energy efficiency and indoor environmental quality of the overcrowded educational spaces. The case, studied in the article, is for three drawing halls of different specifications, located in the main building of the Faculty of Engineering at Mansoura University. The simulation work is processed along a road map of three consequent phases: simulating the existing situation of thermal and visual comfort inside the three halls; optimizing cooling loads by testing various alternatives of design parameters; and including daylighting levels in the optimization process. The study found that optimizing windows shading of overhangs and louvers, low-transmittance characteristics of glazing, and ventilation system would provide from 26% to 31% reduction of cooling loads compared to base case, without taking into account daylighting requirements. While, opening skylight strips, perpendicular to the external facade, with 8% window–roof-ratio, would provide required daylighting levels with minimum increase of cooling loads. The principle objective, attained through this article, is to underline the significance of using building performance simulation (BPS) tools in the architectural educational and research work.

Introduction

Sustainability and built-environment

While sustainability is defined in the global point of view for a green planet, encouraging the present development and assuring future one [1], it is always required to focus on the performance of planet components. When all elements on earth are being greened in an integrative collective manner, wider sustainable goals could be then achieved, where one of the most vital elements is the building [2].

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A good building design was defined by Vitruvius, long centuries ago, as the one that fulfills main three aspects: durability, convenience and beauty [3]. Nowadays, in the beginning of the third millennium, the American Society of Refrigeration, Heating and Air-Conditioning Engineers (ASHRAE) has defined the good building design as the one that fulfills five main characteristics [2]: meeting owner and occupants requirements; meeting all applicable codes and standards; providing indoor environmental quality; respecting surroundings historical and cultural features; and achieving intended emotional impact on viewer.

Sustainable buildings and simulation tools

In general, buildings consume energy, water and materials resources in order to fulfill the minimum requirements of a good design. A good designed building must meet the ASHRAE previous five qualifications, but not any building will meet them in an exceptional innovative way. To achieve the energy efficiency goal, architects and building designers require effective design tools for analyzing and understanding the complex behavior of building energy use. With the advance in computing technology, computer simulation and modeling has been widely used for providing accurate and detailed appraisal of building energy performance.

Building energy simulation is important for the study of energy efficiency in buildings. Computer simulation programs are effective analytical tools for building energy research and evaluation of architectural design [4].

Such tools work on accurate modeling for all details whether related to the building design, construction, systems and internal loads, or the outdoor environmental boundaries [5]. All these inputs are processed in the simulation engine, which is the software core calculators, to provide user with outputs defining thermal comfort degree and energy demand rates.

BPS tools have been used in the literature in many various scopes and concepts. These uses can be categorized according to main aim, methodology, inputs' variables and constants, and outputs' objectives and constraints. As shown in Table 1, methodologies can be classified according to three criteria [6–10]: intuitive or computerized optimization, parametric or whole design optimization, and single or multi-objective optimization.

The case of campus buildings in Egypt

Because of the fact that a large portion of educational buildings in Egyptian campuses does not meet the minimum requirements of indoor environmental quality and energy efficiency, simulation tools have a lot to do, providing architects the mechanism to optimize their designs and renovation plans.

While annual rates of enrolling students in Egyptian universities are significantly increasing due to general population growth [11], most of campuses' built facilities are not developed to host them. Accordingly, the higher education spaces, especially in public universities, do not meet minimum requirements of thermal and visual comfort standards. At the same time, when active systems are used, high rates of energy are consumed in air-conditioning and artificial lighting [12–15].

One of the research institutions, concerned with energy-efficient buildings in Egypt, is the Architectural Engineering Department at Mansoura University [16,17]. This is promoted through the main research themes of the Egyptian Sustainable Urbanism (ESU) Laboratory, of which this study was conducted under its umbrella, getting special support for the first author by the teams of Prof. Dr. John Grunewald at Dresden University of Technology and Prof. Dr. Wallied Orabi at Florida International University. In order to conduct a deeper discussion about using BPS tools in optimizing the educational spaces at the Egyptian universities, the main building of the Faculty of Engineering at Mansoura University (Fig. 1a) was selected to be the research case study. This is for various reasons, as follows:

- It represents most of educational buildings in Egyptian universities in general and engineering learning spaces in particular.
- Its spaces and halls are overcrowded for the high growth rates of enrolling students every year without providing new enough extensions; and

Table 1 Summary of optimization concepts developed in previous studies using BPS.

Methodology	Concept of study
Parametric intuitive single objective optimization	Lee et al. processed a series of parametric sensitivity analysis for the impacts of design variables on energy consumption for heating, cooling and lighting in order to define optimal cases for five Asian cities [6]
Parametric intuitive multi-objective optimization	Ochoa et al. processed graphical optimization for Window Wall Ratio (WWR) to meet minimum requirements of energy performance in buildings codes (cooling, heating, lighting and ventilation) and achieve > 50% of visual comfort hours (daylighting level > 500 lux, uniformity < 3.5 and glare < 22 DGI) [7]
Parametric computerized single objective optimization	Attia et al. developed a simulation-based decision support tool for Net Zero Energy Buildings design relying on parametric sensitivity analysis. The tool is based on EnergyPlus simulation engine and uses the feature of parametric testing. The tool provides architects, in early stages of design, the capability to explore the impact of orientation, envelope and systems alternatives on the thermal performance of building [8]
Whole design computerized multi-objective optimization	Manu & Rawal used parametric simulation in EnergyPlus for processing sensitivity analysis for four design variables (floor area, orientation, Window–Wall Ratio (WWR) and aspect ratio) in a typical commercial building [9]
Parametric computerized multi-objective optimization	Zemella et al. used Evolutionary Neural Networks (ENN) for optimization processes of façade design. The study used multi-objective optimization for minimizing cooling load and maximizing daylighting levels, where the only design variable is the glazing type [10]

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