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Article

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Comparative energy performance simulation for passive and conventional design: A case study in Cairo, Egypt

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Abstract

Buildings design at the time of climate change must enhance their energy performance and in turn to minimize the undesired impacts on our environment. In this work, a comparative simulation analysis has been conducted to an administration building in Cairo, Egypt, to assess its performance after the application of passive design features in comparison to its conventional construction. The proposed passive design features include courtyards, double walled envelope, shading devices, and cross ventilation whereas the base case include none. To do so, Design Builder simulations were made using the generated weather data for the site using Meteonorm. Results show the superiority of applying the passive design, which lead to 11 % reduction in the annual energy consumption.

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Keywords: Energy simulations; Environmental performance; Green buildings; Climate change; Passive design

1. Introduction

The building sector has a direct impact on the social, environmental and economic aspects [1,2]. It consumes 19% of the global energy consumption and 50% of global electricity that is needed for construction and operation of buildings, which leads to 33% of total carbon dioxide emissions through the whole life cycle of buildings [3,4]. These emissions have the major responsibility of the global climate change, especially the rise in temperatures [5,6]. Accordingly, the deliberate design of buildings is not only a form and aesthetic concept, but also a holistic process that includes a precise choice of the building materials can minimize the energy consumption of buildings and implementing passive design strategies [7,8]. These strategies opt to increase the utilization of natural lighting, decreasing the heat gain through the building envelope (walls and fenestration), and increase the natural cross ventilation by using architectural elements such as courts and wind catchers [9,10].

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Moreover, these strategies can have a direct influence on the energy performance of buildings that are being considered one of the important aspects, which needs a precise attention [11]. From this point of view, this research will introduce two different designs of a case study building: the first design used a conventional design and construction; the second adopts the passive design strategies for ventilation, thermal insulation and shading. Furthermore, comparisons between the two strategies were conducted to proof the effect of the passive design strategy on minimizing the energy consumption of buildings.

2. Methodology

A comparative analysis of a case study building in Cairo, Egypt was conducted through simulations for the following: the as-built building (base-case); and the conceptual passive design for the same building (modified-case). This analysis aimed to stand for the effect on the passive design on the reduction of the energy consumption of the case study building. The case study building is an administrative building, which is in Kobri Al-Kobba, Cairo, Egypt. The gross area of the building is 1750 m² that comprises four floors each are divided into administrative spaces with different sizes. The base case consists of one court, whereas the modified case comprises two courts. The methodology is divided into two steps: (1) utilizing Meteororm software [12] and (2) perform simulation using Design builder software [13]; analysis.

2.1. Utilizing meteororm software

Meteororm software was used to extract the actual climatic data for the location Kobri Al Kobba from Cairo weather data files. The rationale for extracting the weather data is to get the precise climate data for this specific location rather than using the general climate data for Cairo city.

2.2. Energy performance simulation

The energy performance simulation was conducted for the base-case and the modified-case using different construction materials. Both cases are the same in the foot-print area, which is 1750 m², also, both cases comprise four above-grade floors. The first case is the as-built case that used traditional Egyptian construction material as follows: the roof was made of typical Egyptian roof layers (0.15 m reinforced concrete, 0.02 m betomine damp insulation, 0.04 m heat insulation roofing board, 0.05 m sand, 0.02 m cement mortar, and 0.01 m concrete tiles) as shown in Fig. 1(a); the typical floor layers were made of 0.12 reinforced concrete, 0.05 m sand, 0.02 m cement

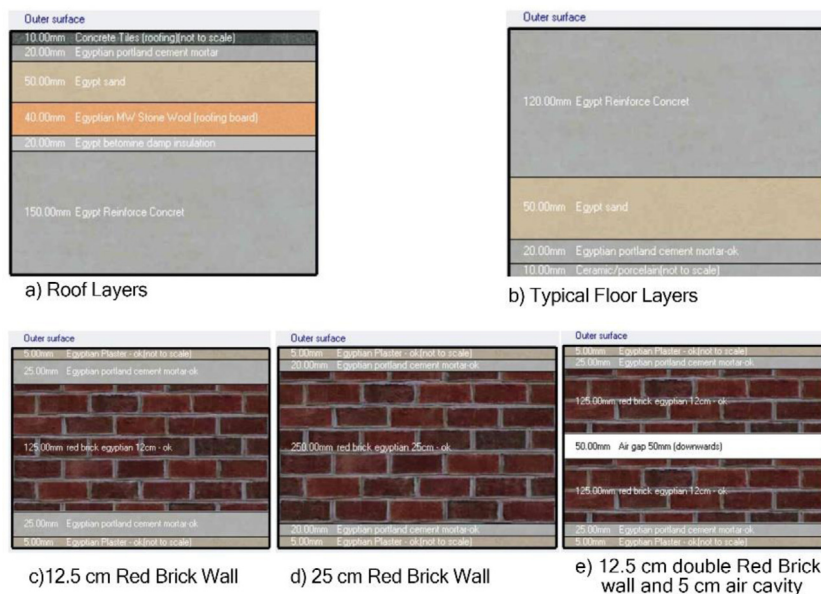


Fig. 1. Construction layers for simulation.

mortar, 0.01 m ceramic as shown in Fig. 1(b); the envelope walls are made of 125 mm thick red brick as shown in Fig. 1(c); and the outer fenestration was made of 6 mm clear glass.

The modified case used the following construction materials: 125 mm double wall with air gap 5 cm in between as shown in Fig. 1(e); the roof layers and the typical floor layers are the same as the base case, the outer fenestration is made of 6 mm reflective glass. Moreover, this case enclosed two courts and used reinforced concrete sunshades over each window in the south and west elevation as shown in Fig. 2(b). The simulation process is based on two interactive groups: (1) building envelope group; and (2) fenestration group as illustrated in Table 1. The wall group consists of 125 mm red brick wall, 250 mm red brick wall, and 125 mm double wall with 5 cm air cavity in between. The fenestration group comprised of 6 mm clear glass, 6 mm reflective glass, and 6 mm double glass with 6 mm air cavity. Ten simulations were performed using alternations of the two groups each of which are five simulations as shown in Fig. 3 as follows: (1) base case simulation group, and (2) modified-case simulation group.

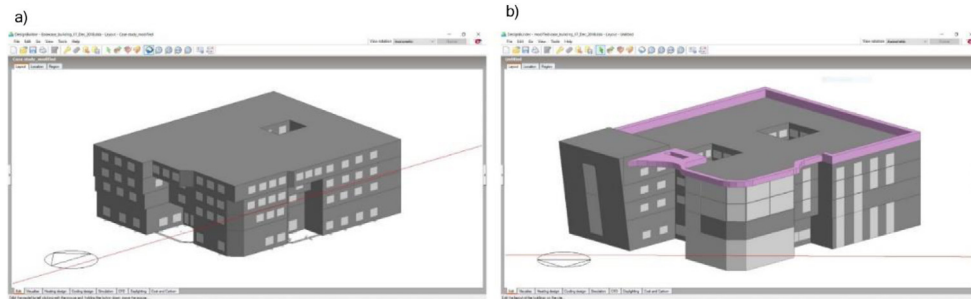


Fig. 2. The graphical user interface of eQuest having the simulation model of the case study.

Table 1. Thermal properties of the exterior envelopes and the fenestration types.

Wall			
Thermal data	First case	Second case	Third case
	125 mm Egyptian red Brick	250 mm Egyptian red Brick	125 mm Egyptian red Brick double wall with 5 cm air cavity in between
U-value ($W/m^2 \text{ } ^\circ K$)	2.548	1.914	1.384
R- value ($m^2 \text{ k/W}$)	0.392	0.522	0.722
R- value surface to surface ($m^2 \text{ k/W}$)	4.494	2.837	1.810
Fenestration			
	6 mm clear glass	6 mm double glazing	6 mm reflective glass
Total solar transmission (SHGC)	0.710	0.660	0.180
Light transmission	0.650	0.590	0.060
U-value ($W/m^2 \text{ } ^\circ K$)	5.760	3.710	5.360

3. Results

The output energy performance was a combination of lighting energy, heating energy, air conditioning energy, and office instrument energy. The overall energy consumption is measured in kWh. The output was analysed and compared mainly for the base-case and the modified-case by using monthly and total energy consumption. Furthermore, other simulations were performed for using the two cases by changing the materials of the building envelope and the fenestration material as previously discussed.

As shown in Fig. 4, the modified-case, which uses sun shadings, two courts, double wall with an air cavity, and reflective glass, performs better than the base-case through the twelve months of the year. Moreover, from the annual energy consumption graph as in Fig. 5, the base-case consumes 708 MWh, whereas the modified-case consumes 629.5 MWh that is 11% reduction in the annual energy consumption. In case of the other four simulations of the base-case by altering materials can be arranged ascendingly according to energy consumption as follows: (1) double wall with reflective materials; (2) 250 mm wall with reflective glass; (3) double wall with double glass; and (4) 250 mm wall with 6 mm clear glass, in which these cases consume 614.7 MWh, 631.6 MWh, 662.5 MWh, and 687 MWh respectively. Similarly, by arranging the other four simulations ascendingly as follows: (1) double wall

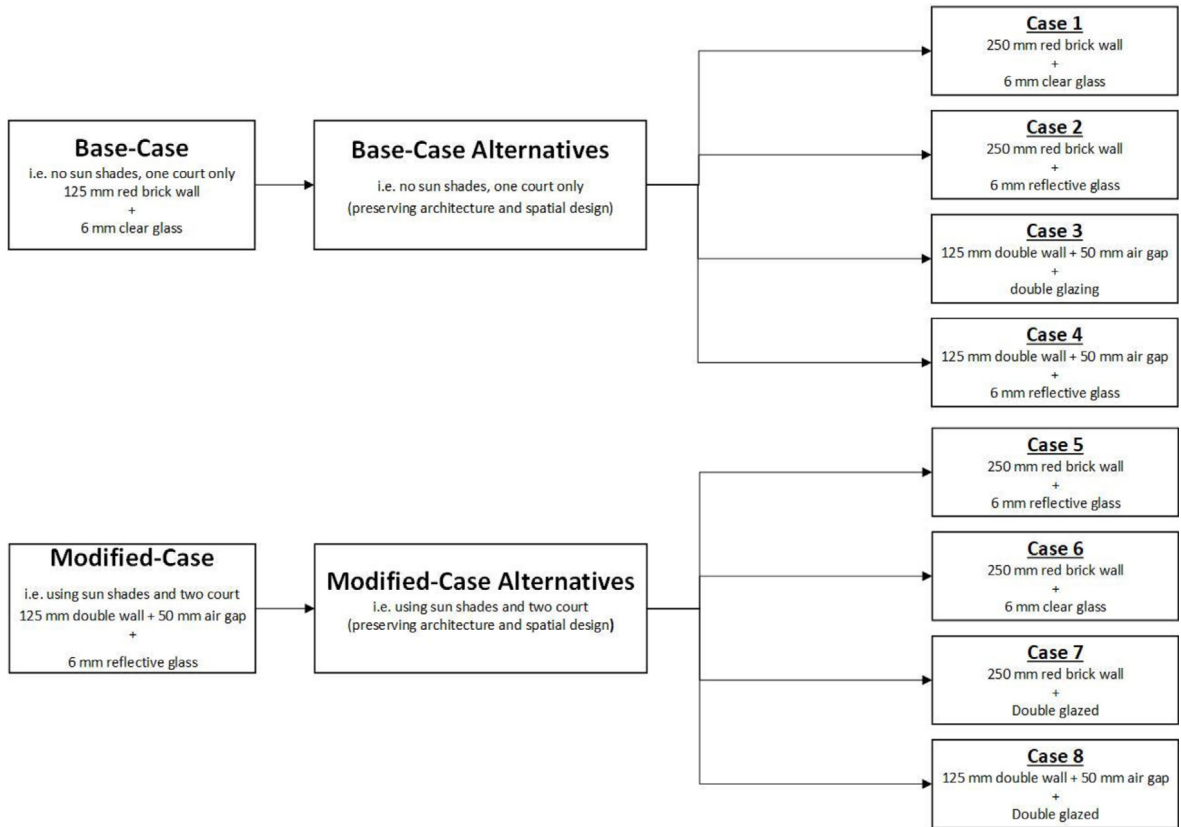


Fig. 3. Simulation alternatives.

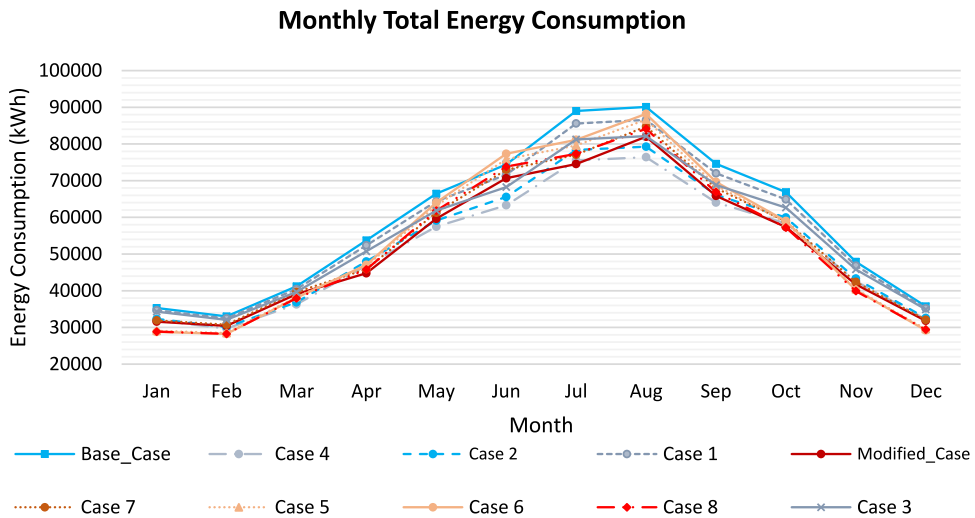


Fig. 4. Monthly simulation energy consumption records for the six construction materials.

with double glazing, (2) 250 mm wall with double glazing; (3) 250 mm wall with reflective glass; and (4) 250 mm wall with clear glass. These cases consume 631 MWh, 645 MWh, 646 MWh, and 651 MWh respectively.

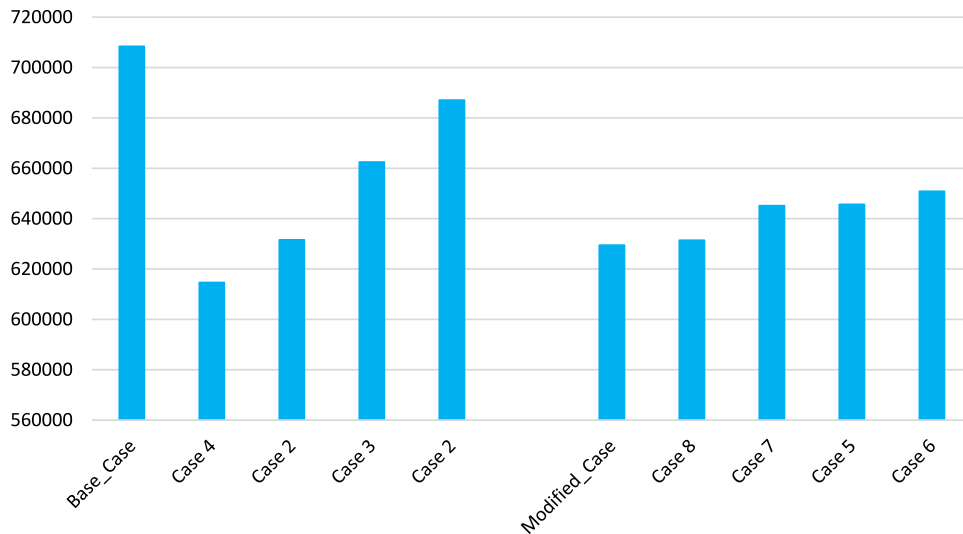


Fig. 5. Annual energy consumption.

4. Discussion and conclusion

This research opts to shed light on the advantage of adopting passive design in buildings rather than using the traditional materials in construction, which will save more energy that in turn, will decrease the harmful emissions of gasses in the surrounding environment, and decrease the financial burdens on the building owners and users.

This research utilized two primary principles in the conducted methodology: (1) using Meteororm software to get the actual weather data for the case-study location (Kobri Al Kobba) that will be used in the simulation to give accurate results rather than using the generic Cairo weather data files; and (2) utilizing the Design Builder simulation software to illustrate the impact of adopting passive design in a case study building, as well as, to demonstrate the effect of the diverse construction material materials on the monthly and annual energy consumption.

The results, according to simulations, showed that the as-built base-case consumes 708 MWh, which is greater with 11% than the modified-case that adopts passive design concepts, which consumes 629.5 MWh. Furthermore, using 125 mm double wall with a 5 cm air cavity and single 6 mm reflective glass can improve dramatically the energy performance of the as-built building (base case) to be 614.7 MWh, in which the energy consumption is reduced by 13%. Therefore, selecting the construction materials is a serious issue that can change the energy performance of the building drastically. Also, using deliberate studies in the design stage can prevent a lot of environmental, social and economic impacts through the whole life cycle of the buildings that is the main aim of sustainable construction.

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