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# Comparative Analyses Based on Simulations to Improve Energy Consumption in Office Buildings in Egypt

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**KEYWORDS:**
***Simulation; Comparative Analyses; Building Envelope; Energy Consumption; Finishing Materials***

***Abstract*—A growing attention has been paid to building envelope features for achieving lower energy consumption especially in large office buildings and hot climate zones, since these features and their variables are affecting energy consumption widely and with different sensitivity. Therefore, this paper conducts simulation-based comparative analyses between main envelope features with their internal variables; the selected features for this study are building geometry ratios, orientations and common envelope finishing materials (FMs). Two applications have been conducted (comparing cases with either a same or different building volumes), and more than 500 cases/simulations have been conducted and studied in total. Accordingly, sensitive features and variables have been determined to enrich design decisions for different cases, along with best variables' integrations that achieve best energy consumption through the proposed applications and cases. Cubic office buildings in Egypt have been used to demonstrate the study, and energy simulations have been achieved using eQuest (DOE-2). Results show that lower height with wider roof achieves best energy consumption if building volume is fixed via comparisons, and vice versa. Gravel and galvanized steel represent best studied roof and walls' FMs, while roofing shingles is the worst one. If building volume is varied via comparisons, horizontal dimensions are the most sensitive feature that affects energy consumption per m$^2$, while FMs and height represent lowest sensitivity among studied features. Ranking of cases, features, variables along with sensitive features in details have been analyzed and discussed through the paper.**

### LIST OF SYMBOLS

| | |
|---|---|
| ***FM/s*** | Finishing Material/s |
| ***WWR*** | Window-to-Wall-Ratio |
| ***eQuest*** | The QUick Energy Simulation Tool (a software tool) |
| ***Case (Xxi*)*** | In one of the proposed applications, case (Xxi*) denotes to a studied case with specific dimensions and orientation, where: (X) is an uppercase/capital letter from (A) to (E) referring to the length that ranges from 20m to 100m with 20m intervals, (x) is a lowercase/small letter from (a) to (e) denotes the width with the same range and intervals, (i) represent a number from 1 to 3 referring to the height that ranges from 20m (5 stories) to 60 (15 stories) with 20m (5 stories) intervals, and (*) denotes to the cases oriented 45 degrees from azimuth, if any. For example, case (Ce3) refers to the building with dimensions: 60m (length), 100m (width) and 60m (height), while case (Ce3*) refers to the previous dimensions with orienting the whole building 45 degrees from the azimuth. |

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## I. INTRODUCTION

Building envelope is one of the main domains that can be utilized towards developing net zero energy buildings, especially in hot climate zones. A lot of envelope features can be tracked to reduce energy consumption such as building geometry ratios and others. For instance, changing the geometry ratios of a cubic building (as a feature) from 1:1:1.5 (width: length: height) to 1.75: 1.75: 0.5 with a same volume (e.g., 96000 m$^3$) can reduce the energy consumption from 158.5 to 149.6 kWh/(m$^2$.year) in a hot climate zone (2A) [1], predicted using eQuest simulation tool [1], and more energy savings per m$^2$ can be reached if the building volume are varied via comparisons. This study aims at determining the sensitivity of envelope

[1] Based on ASHRAE 90.1 standard, the international climate zones are defined and classified using letters and numbers; letters (A), (B) and (C) denote to moist, dry and marine climate zones, respectively, while numbers (from 1 to 8) denote to the temperature (from the hottest to the coldest climate zones), respectively (ASHRAE 2007).

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features and their variables along with determining sensitive features and variables that achieves best energy consumption; building geometry ratios, orientations and Finishing materials (FMs) (either covering the roof and/or walls) are the main features to be studied in this paper. However, office buildings have been selected to be studied due to their flexible geometric features, wide façade areas and high energy consumption, and different volumes have been analyzed. Cairo in Egypt, as a hot climate zone, has been used to demonstrate the study outcomes.

Numerous studies conducted analyses on building envelope parameters and design methods towards better energy performance in different climate zones. Ihm and Krarti [2] determined optimal values for the design features of single-family residential buildings in Tunisia to increase their energy efficiency; orientation, window location, Window-to-Wall Ratio (WWR), glazing type, insulation and others systems have been tested. Qian and Lee [3] tested materials and insulations applied on building envelope components (walls, windows, doors and others) in small commercial building using Minitab 17 and TRACETM 700. Ferrara et al [4] developed a framework to find the cost-optimal building configuration for the French single-family building using TRNSYS simulation and GenOpt program. Harmati and Magyar [5] compared glazing influence, preferable WWR and window geometry for better indoor daylight quality and annual energy demand in offices using Radiance simulations. Aksamija [6] discussed design methods for developing sustainable high-performance facades; this include different building treatments, orientations, WWR, shading elements and materials to improve daylighting, energy efficiency and thermal comfort. Hu and Wu [7] analyzed the influence of exterior walls, roof, exterior windows and other features for a public building in Beijing to determine sensitive properties.

Moreover, Raji et al [8] studied energy-saving solutions for the envelope design of high-rise office buildings; glazing type, WWR and other strategies through an existing office building in the Netherlands have been studied using DesignBuilder. Barozzi et al [9] reviewed contemporary envelopes via different design approaches for reducing energy consumptions in several examples of spaces, materials and others. Balter et al [10] conducted thermal and energy assessment of different envelope materiality on different residential buildings with massive and light envelopes. Liu et al [11] studied the effect of different orientations, WWR and floor geometric features on artificial lighting in office buildings in Tianjin, China; single and multi-parameter evaluations have been conducted using DesignBuilder. Liu et al [12] conducted energy consumption simulation analyses for a large amount of office buildings; each parameter influence on the energy consumption and optimal combinations have been analyzed. D'Agostino et al [13] demonstrated a decision support framework of building designs that includes different building types, materials and technologies through both environmental and economic criteria. As detailed before, majority of features are relevant to the specific cases or climate zones and should be tested to suit different design cases.

Other studies were focusing on other features such as building geometry (such as shape, ratios and dimensions) reach better energy performance. Tuhus-Dubrow and Krarti [14] developed an approach to minimize energy consumption by optimally selecting shapes, dimensions and other envelope parameters of residential buildings. Zerefos et al [15] examined energy consumption of buildings that have polygonal, orthogonal and prismatic building envelopes located in Mediterranean climates. Finishing and construction materials have been also widely focused for optimization purposes. Al-Nuaimi and Khamis [16] simulated different interior FMs in a single room for reducing its energy consumption in Bahrain; around 7% energy saving could be achieved. Pukhkal [17] studied protective FMs of exterior walls, structure and others with their effect on heat insulating. Huang et al [18] proposed two most popular retrofitting methods for cooling building wall surfaces in different orientations and climates. Alonso et al [19] studied outer façade FMs' effect on the buildings' energy balance in different thermal conditions; color, solar reflectance and emissivity have been focused on three different construction systems in Madrid, Spain. Echarri-Iribarren et al [20] compared cast recycled aluminium panels with large-format ceramic panels based on their energy savings using EnergyPlus. Khoukhi et al [21] studied retrofitting an office buildings in UAE towards lower energy consumption via building orientation, ventilation, walls and roof construction; wall construction can achieve 4.4% energy saving in the best case.

In Egypt climate zone in specific, many studies focused on optimizing building envelope features for better energy performance. For example, Albadry [22] proposed a method that combines both retrofitting building envelope with renewable energy strategies that suit the Egyptian context, not new designs. Khalil et al [23] analyzed some design variables and skin configurations of buildings' envelopes in residential buildings' cases in Alexandria, Egypt using Energy Plus simulation, not office buildings, also William et al [24] evaluated the energy efficiency using DesignBuilder simulation in Egyptian existing hospitals. Mahmoud et al [25] conducted a comparative simulation analyses to an administration building in Cairo to assess its performance after applying passive design features such as courtyards, double walled envelope, shading devices and other different features than proposed in this study. Abd El-Rahman et al [26] optimized thermal performance of office buildings through building shape, orientation and WWR on a fully glazed office building, not energy consumption. Previous studies did not outline the proposed features on different office buildings in the Egyptian context or highlight relevant guidelines to generic design cases. On the other hand, ASHRAE 90.1 - 2007 standard is applicable for Cairo climate zone [27], such standards can be utilized to classify features to which can be set to the standards and others to be tested and scoped as detailed in the following section 2.

Based on the conducted literature, no studies were found providing detailed performance of envelope features and variables in generic cases; some features of building envelope are needed to be studied in their context, such as building geometry that suits different design cases specifically. FMs in different orientations have been also focused to reach better energy performance, while WWR and story height are excluded from the studied variations to be set to the relevant standards as detailed before. To suit different design cases and supports designers' decision, analyses have been conducted via two different applications: application (A) compares energy consumption in cases with a same volume, and application (B) compares energy consumption per m$^2$ in cases with different volumes. The paper has been structured to include details of the proposed features, their variables and relevant classifications in section 2. Section 3 presents two applications ((A) and (B)) to demonstrate the comparison analyses of cases with either the same and different volumes, respectively. Section 4 presents the ranking of best variables' integrations in both applications and most sensitive features/variables. Finally, the discussion and conclusion are detailed in section 5 and 6, respectively, along with the whole simulation results in the appendices.

## II. MAIN FEATURES AND VARIABLES OF BUILDING ENVELOPE AFFECTING ENERGY CONSUMPTION

Main features of building envelope and their internal variables, that may affect energy consumption, have been selected as shown in Figure 1. Some of these features' variables have been fixed based on ASHRAE 90.1 - 2007 standard; it recommends 10% to 40% WWR for office buildings in Cairo climate zone to achieve less energy consumption [27], while high WWR is also recommended from the architectural perspective for providing view visibility and facades attractiveness. Therefore, 40% WWR has been selected in this study as an medium value that fits ASHREA standards and architectural recommendations. The study focuses on: a) building geometry ratios; b) orientations (every 45 degrees); and c) nine FMs (either covering the roof and/or walls) that have been selected from the common practice and available materials in local markets (detailed in Table 1). All alternatives obtained from different integrations of these features and their variables have been simulated via DOE-2 (eQuest) as detailed below.

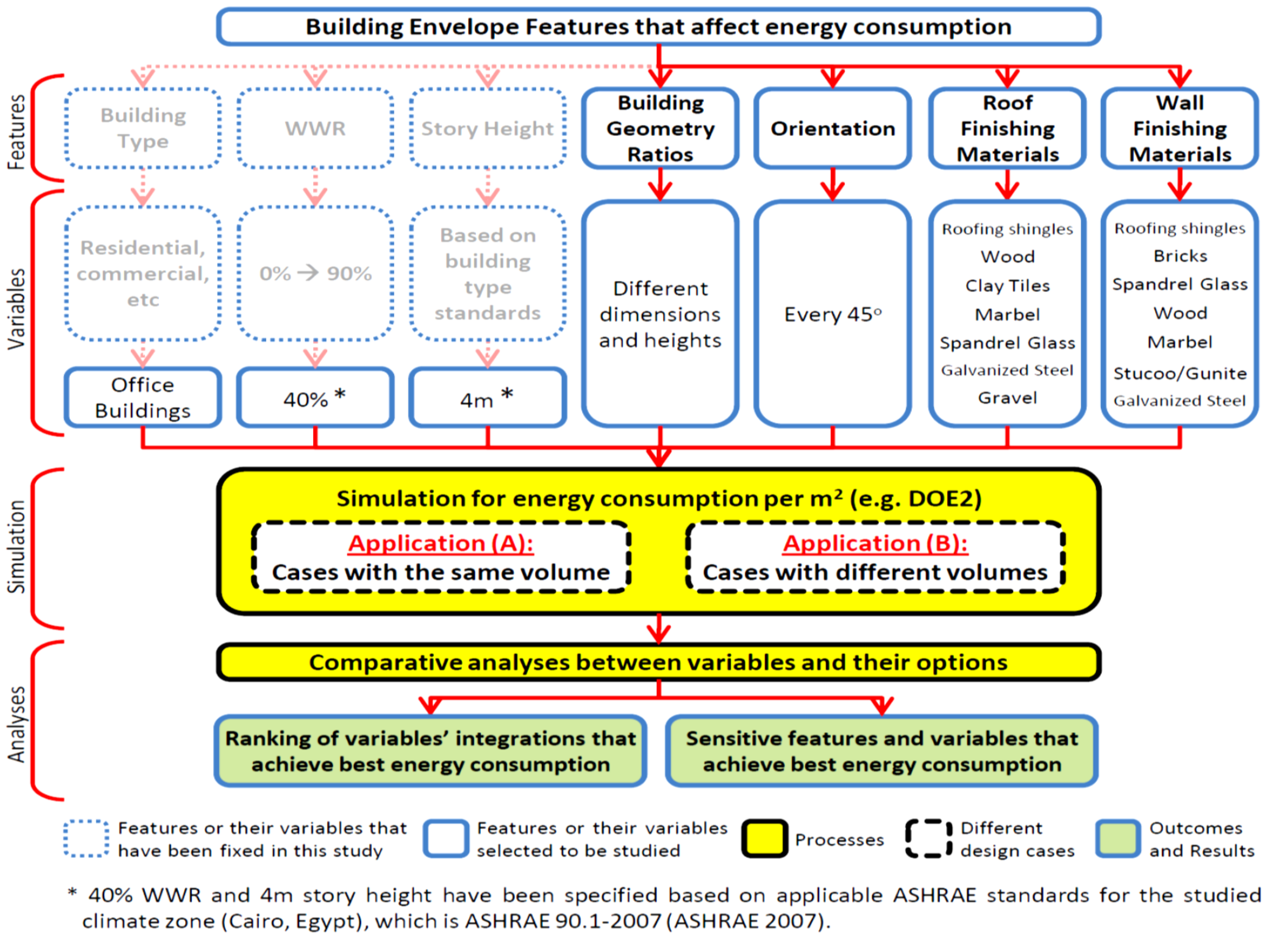


Fig. 1: Main features and variables of building envelope affecting energy consumption

TABLE 1
FINISHING MATERIALS' SPECIFICATIONS AND CHARACTERISTICS [1]

| | Finishing Materials | Name (Code) In DOE-2 | Thickness (Cm) | Density (Kg/M$^3$) | Specific Heat (Kj/Kg-K) | Resistance (K-M$^2$/W) | Roofs | Walls |
|---|---|---|---|---|---|---|---|---|
| 1 | Gravel | Gravel (RG02) | 2.5 | 881 | 1674 | 0.018 | √ | |
| 2 | Roofing shingles | Wood Shingle (WS01) | 1.7 | 513 | 1255 | 0.153 | √ | √ |
| 3 | Wood | Plywd (PW04) | 1.9 | 545 | 1213 | 0.22 | √ | √ |
| 4 | Galvanized Steel | Steel Siding (ASo1) | 0.15 | 7690 | 480 | $3.3x10^{-5}$ | √ | √ |
| 5 | Stucoo / Gunite | Stucco (SC01) | 2.5 | 2659 | 837 | 0.035 | | √ |
| 6 | Clay Tiles | Clay Tile Paver (CT11) | 1 | 1922 | 837 | 0.005 | √ | |
| 7 | Bricks | Face Brick 4in (BK05) | 10.1 | 2083 | 921 | 0.078 | | √ |
| 8 | Marbel | Terrazzo (TZ01) | 2.5 | 2243 | 837 | 0.014 | √ | √ |
| 9 | Spandrel Glass | 1/4 in Spandrel Glass | 0.625 | 2752 | 840 | - | √ | √ |

## III. ENERGY CONSUMPTION SIMULATION OF THE ENVELOPE FEATURES IN CUBIC OFFICE BUILDINGS IN EGYPT

Simulation processes have been conducted on cubic office building in Egypt via two applications as detailed below; the outcome in each application is determining the sensitive features and variables in achieving best energy consumption via a comparative analyses, along with ranking these alternatives.

### *1.1. Application (A): Buildings with a same volume*

In this application, previous illustrated features have been simulated using different geometric ratios with the same volume, this is to support designers in comparing different cases that have a fixed architectural program, number of spaces and accordingly a specific context to be formed; a medium volume (96000 m$^3$) have been proposed and outlined in 3 different ratios as shown in Figure 2, and accordingly 8 cases have been conducted after applying possible orientations. The total number of alternatives/simulations conducted using DOE-2 equals 392 alternatives as presented in Figure 3.

By analyzing and ordering the simulation results, it is obvious that cases can be ordered based on energy consumption ascending to case 7, case 8, case 3, case 6 or 4, case 5, case 1 and then case 2. Roof FMs can be also ordered based on energy consumption in the majority of cases ascending to gravel, galvanized steel, glass (spandrel) or marble, clay tiles, wood then roofing shingles, while walls' FMs can be ordered using their energy consumption ascending to galvanized steel, stucoo/gunite, marble, wood, spandrel glass, bricks then roofing shingles. The best alternative through the whole features and variables studied is case 7 with gravel roof and galvanized steel or stucoo walls, while worst alternative is case 2 with roofing shingles in its roof and walls. Appendix (A) shows all the simulation results along with best and worst 10 roof and walls' FMs to be used for each case. As a result, cases 1-2, 3, 4-6 and 7-8 achieve around 3810, 3707, 3722 and 3610 MWh/year in average (+/- 0.6%), respectively.

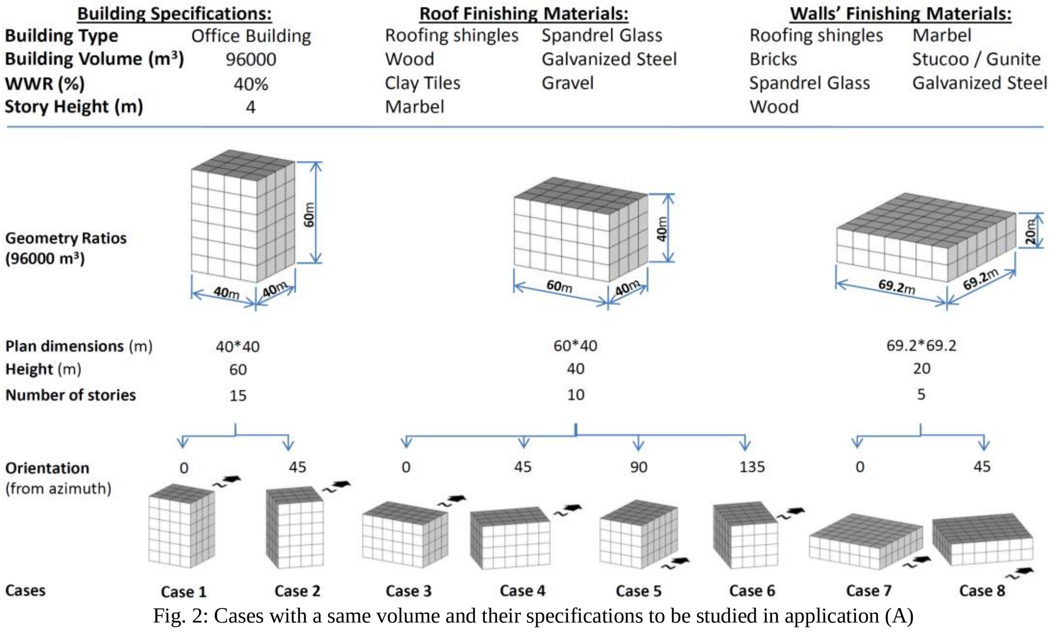

Fig. 2: Cases with a same volume and their specifications to be studied in application (A)

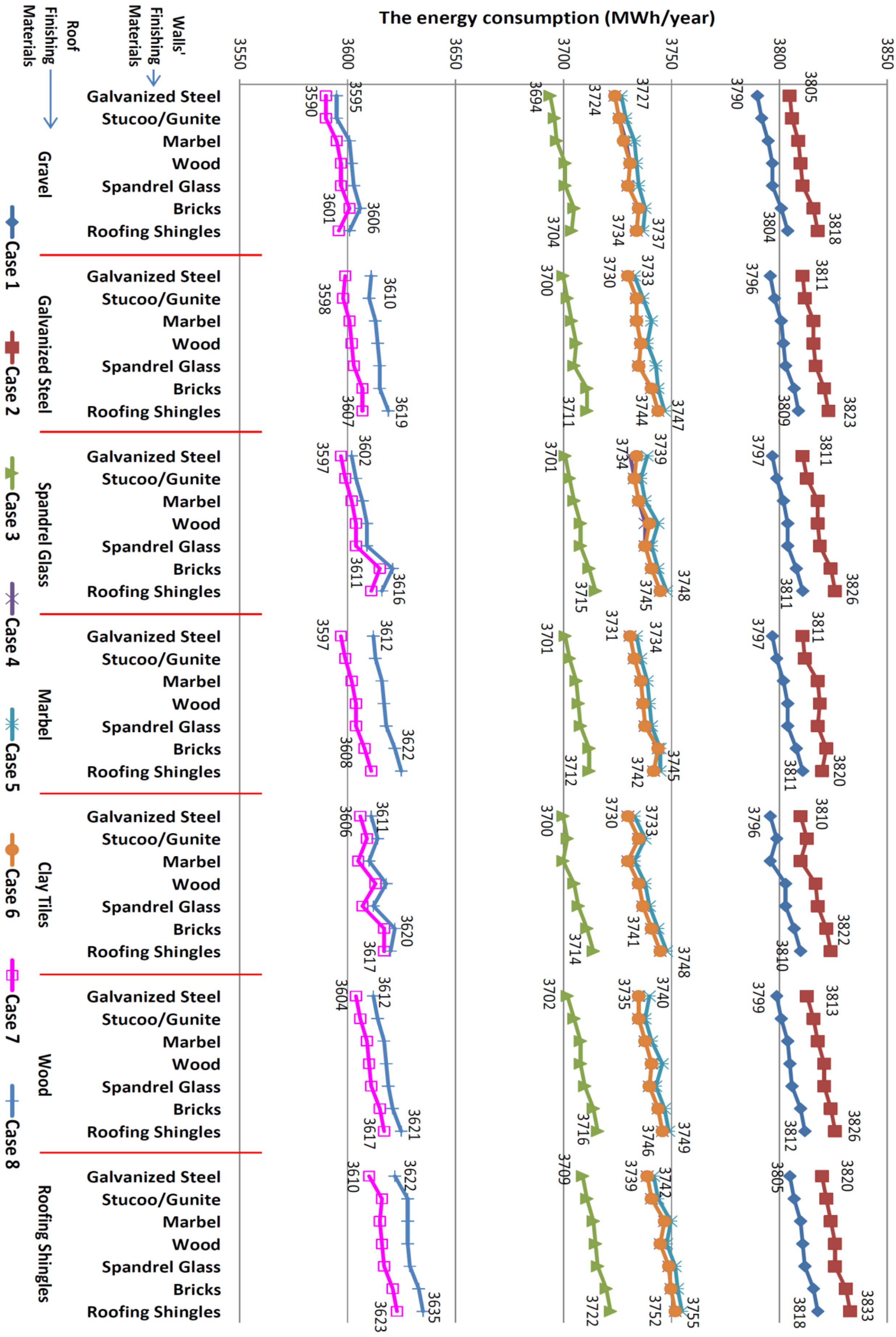


Fig. 3: The energy consumption of the cases, features and variables studied in application (A) (simulated by eQuest 3.65)

### *1.2. Application (B): Buildings with different volumes*

In this application, buildings with different volumes have been tested in different orientations, while FMs' effect on both roof and walls have been ignored due to their weak effect regardless building ratios and orientations as presented in previous application (A). The tested cases in this application are buildings with cubic dimensions starting from 20m (length, width or height) with 20m intervals in each direction till reaching 100m (length or width) and 60m (height), also both 0 and 45 orientations from the azimuth have been included (150 total cases). As shown in Figure 4, cases in this application have been denoted to reflect their dimensions and orientation, for example, case (Ce3) refers to the case with dimensions: 60m (length C), 100m (width e) and 60m (height 3), while case Ce3* refers to the same previous case with orienting the building 45 degrees from the azimuth. Figure 5 shows the analyses of the energy consumption of cases per m$^2$ in each case, while the simulation results are detailed in Appendix (B).

The results' analyses presented that case (Ee3) achieved the less /energy consumption among all cases and cases (Ee) in different orientations and heights are also the best 6 alternatives, while cases (Aa3) and (Aa3*) have the highest energy consumption. In other words, increasing building length and width causing reducing the energy consumption per m$^2$ in all cases, for example, increasing the width (the side facing east/west direction) from 20m (case Ca1) to 100m (case Ce1) reduces 27 (kWh/(m$^2$.yr)) - around 15.7%, and increasing the length (the side facing north/south direction) from 20m (case Ae3) to 100m (case Ee3) reduces 20 (kWh/(m$^2$.yr)) - around 12.1%. On the other hand, the orientation shows no significant difference in all cases while the majority of cases oriented towards 45 from azimuth have a higher energy consumption per m$^2$ compared to the same cases oriented orthogonally. Figure 6 presents the energy consumption of the three proposed heights (each 5 stories) per m$^2$ in all cases; the height effect can be ignored in the majority of cases since each 5 stories represents around one third of the energy consumption per m$^2$ within a range less than +/- 4%.

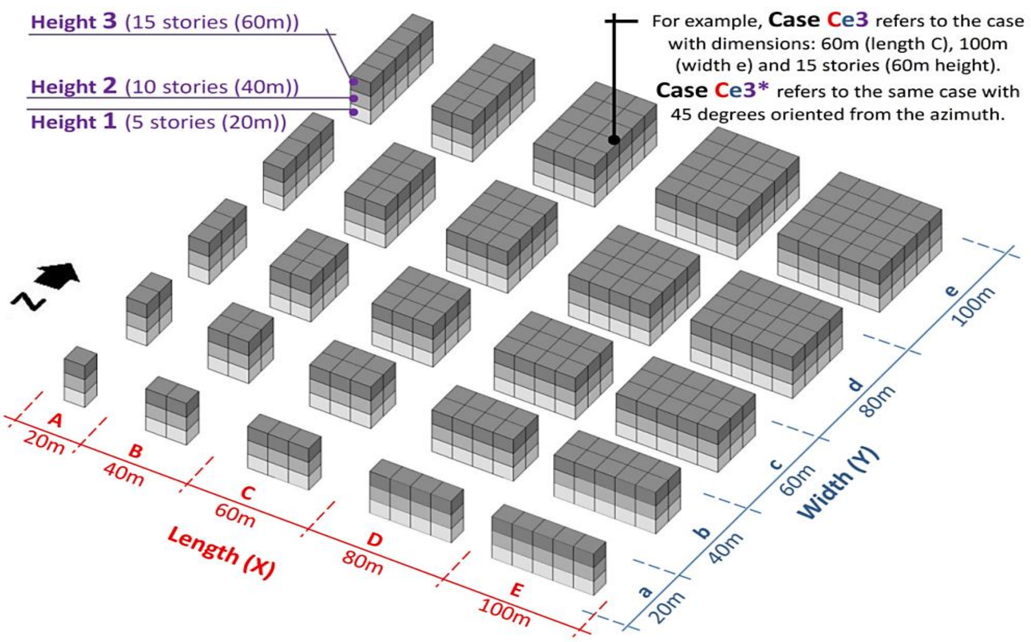


Fig. 4: Cases with different volumes and their specifications to be studied in application (B)

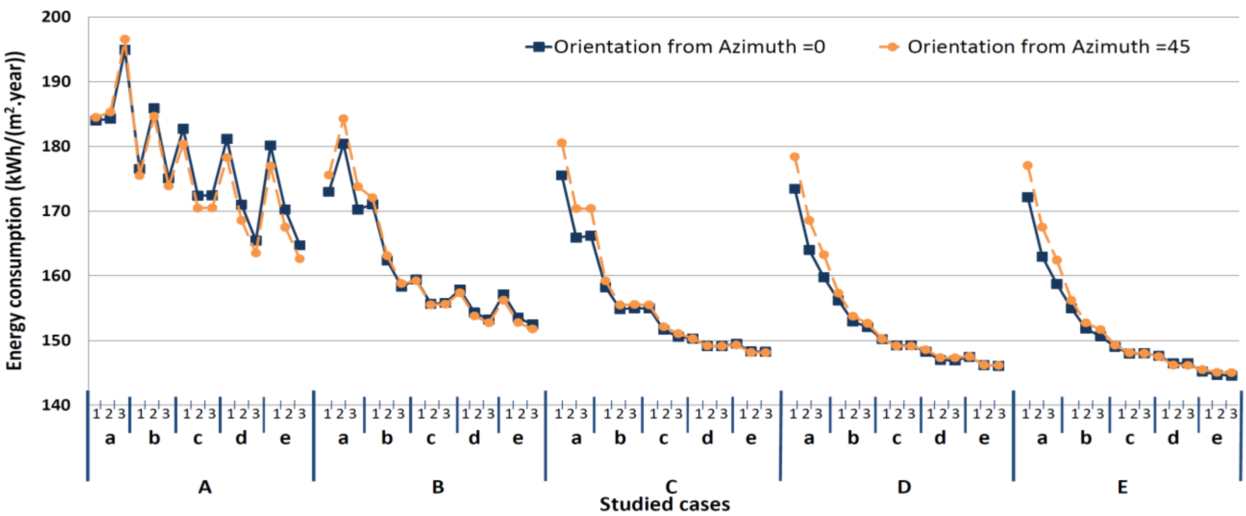


Fig. 5: The energy consumption of cases studied in application (B)

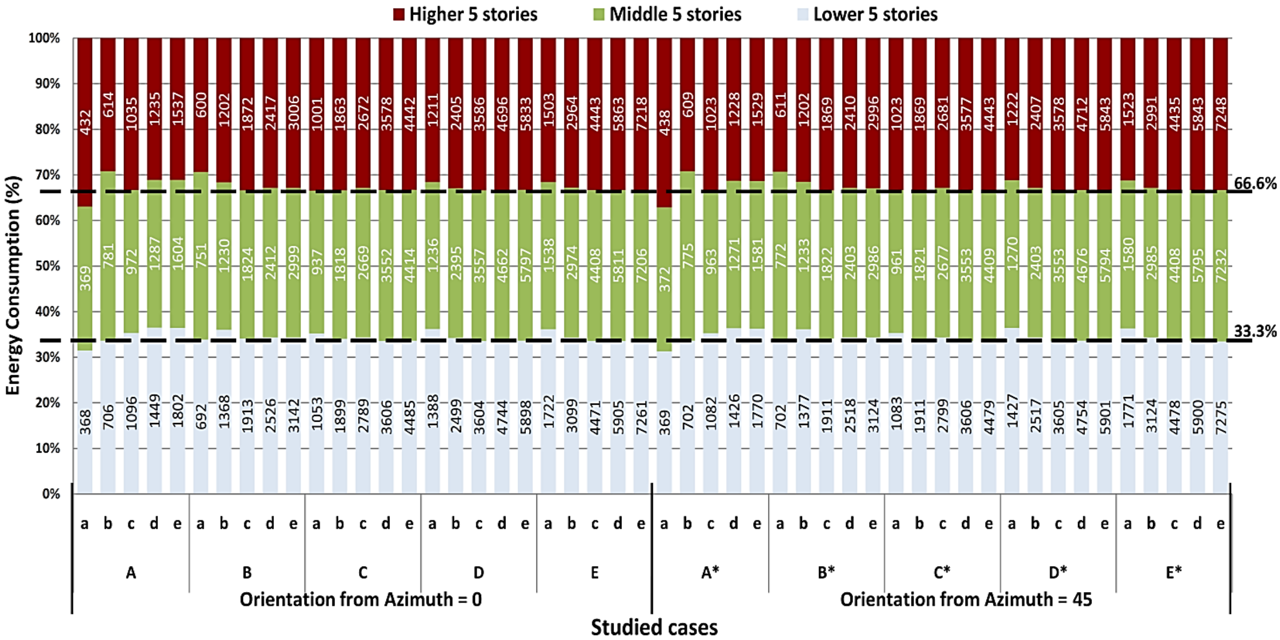


Fig. 6: The effect of building height on the energy consumption of cases studied in application (B)

## IV. SENSITIVE FEATURES AND VARIABLES OF BUILDING ENVELOPE AFFECTING ENERGY CONSUMPTION

It is obvious that the main features and variables studied in both applications have different sensitivity in achieving best energy consumption. As shown in Figure 7, building ratios are the most sensitive feature among studied ones in both applications (A) and (B) (regardless compared cases have the same or different volumes). In applications (A), 9 kWh/(m$^2$.year) energy saving (around 5.7%) can be reached with changing building ratios only in extreme cases, while changing both roof and walls FMs only can reach 1.8 kWh/(m$^2$.year) in case 2 (around 1.1%). Application (B) presents wider possibility in energy saving due to the flexibility of cases' volume and accordingly ratios; 50 kWh/ (m$^2$.year) can be reached by changing the building ratios only. Ranking of cases included in applications (A) and (B) are detailed in appendices (A) and (B), respectively.

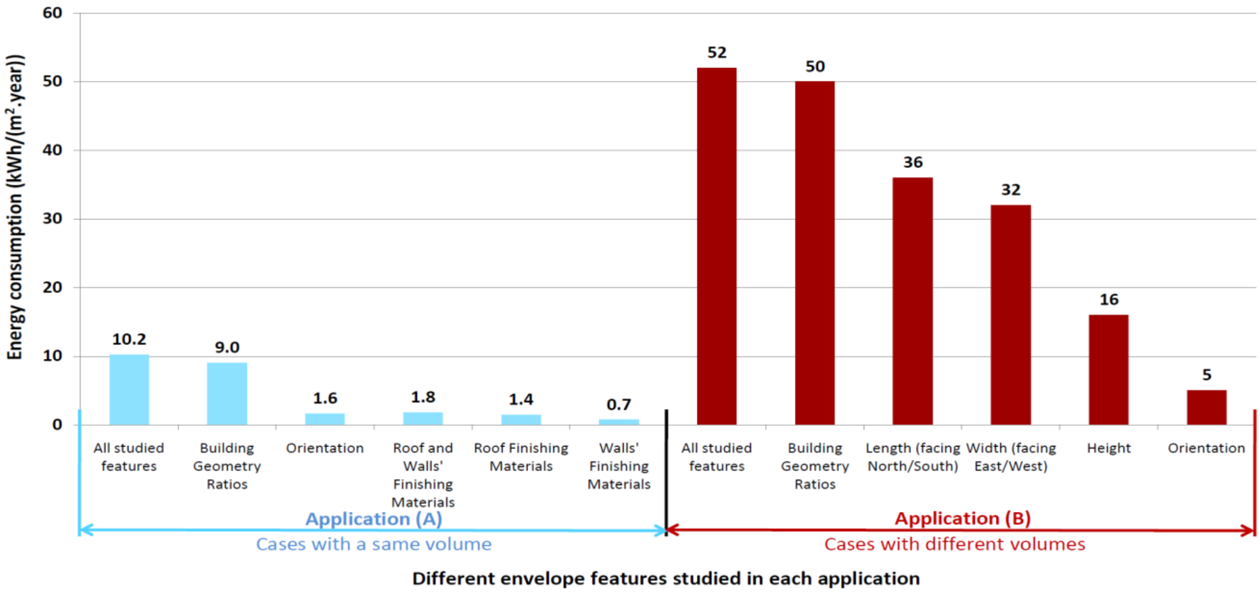


Fig. 7: Maximum energy saving achieved by different building envelope features

## V. DISCUSSION

The paper illustrated the sensitivity of envelope features for different design cases, and this help designers with a clear suggestions and supportive recommendation while developing their designs. For instance, it can be stated that one complex building with wider dimensions as possible achieves better energy consumption than dividing it to smaller ones; adapting the design in one complex case with 96000 m$^3$ volume (such as cases 1-8, case Ad3, case Bc2 separately) achieves within 3600 - 3900 MWh/year, while using 5 small cases with the same total volume (such as Aa1-3 together with Ab1-2) achieves more than 4400 MWh/year in total. In flexible design problems such as new buildings in wider layouts, it is recommended to focus building geometry, dimensions and ratios to achieve better energy consumption, while orientation and FMs comes later. More specifically regarding building dimensions, the side that faces north/south direction is more sensitive than the other side, while the height and orientation have very less sensitivity in affecting energy consumption as detailed in application (B). FMs can be used in designs with lower flexibility such as existing buildings, and in such cases, using FMs in roofs have around the double sensitivity compared to FMs in walls especially in cases with wider roofs, for example, altering roof FM in case 7 and 8 in application (A) may reach 29 MWh/year (around 1%), while altering wall FMs in the same cases can reach only 13 MWh/year. However, best FM achieving energy consumption in roofs and walls are gravel and galvanized steel, respectively, while worst one is roofing shingles among both roof and walls' FMs; it is recommended to use other systems besides FMs for more energy savings then. Changing FMs can achieve only 1.1% energy saving in case 8 due its large volume compared to the envelope area; reducing that ratio increases the probable energy saving since the effect of the envelope features in general and FMs in specific will be increased. In other words, the sensitivity of FMs effect is inversely proportional with the building volume; this is why FMs effect is low although it reaches in a single room (as shown in the literature) to around 4%. Also, the effect of the other features such as building ratios have higher effects in small cases (such as cases Aa, Ab, Ba and others) as shown in previous Figure 5.

However, the study limitations can be outlined in: a) cubic building shapes: sensitive features should be studied within other shapes in future works, such as courtyard dimensions in U shapes, wings length in L shapes and others, although some features were found in the literature as stated before; b) Hot climate zones: the study can be extended easily towards other climates such as humid and dry zones with less climate temperature; sensitive features and variables may be altered then; c) Applying single FMs in facades: although different integrations of FMs in single facades have not been focused in the study, the performance of applying two or three FMs can be predicted easily from the analyses, since FMs' ranking is clear but not sensitive in the majority of cases, however, aesthetic, thermal and other parameters may be needed then to apply FMs in facades for having better architectural appearance.

## VI. CONCLUSION

This paper presents a simulation-based comparative analyses on building envelope features and their variables from energy consumption perspective. Three main envelope features in cubic office buildings in Egypt have been focused, they are: a) building geometry ratios; b) orientations (every 45 degrees); and c) common envelope finishing materials (FMs): roofing shingles, galvanized steel, wood, marbel and spandrel glass for both roof and walls, also gravel and clay tiles for roofs in addition to stucoo/gunite and bricks for walls. WWR has been set as detailed in ASHRAE 90.1 - 2007 standard for office buildings for Cairo climate zone. However, different cases either with the same or different volumes have been simulated and compared as application (A) and (B), respectively. In application (A), 8 different building cases with the same volume (96000 $m^3$), different ratios and orientations have been prepared along with applying nine FMs on them, hence, 392 simulations have been performed using DOE-2 via eQuest as a simulation tool. In application (B), cubic office buildings have been simulated starting from 20m as a unit and repeated intervals. The study outcomes are ranking of features' variables to be used in different cases along with determining sensitive features and best variables; comparative analyses have been conducted accordingly.

By analyzing and ranking the simulation results of cases, best energy consumption can be achieved in application (A) is case 7 (lower height with wider roof oriented by 45 degrees from azimuth), and worst case is case 2 (higher height with narrower roof oriented by 45 degrees from azimuth). Roof FMs can be ordered using their energy consumption ascending to gravel, galvanized steel, spandrel glass or marble, clay tiles, wood then roofing shingles, while walls' FMs can be ordered using their energy consumption ascending to galvanized steel, stucoo/gunite, marble, wood, spandrel glass, bricks, roofing shingles. However, best alternative in application (A) through the whole features studied is case 7 with gravel roof and galvanized steel or stucco walls, while worst alternative is case 2 with roofing shingles in its roof and walls. In application (B), dimensions are also the most sensitive feature as in application (A), while the side that faces north/south direction is more sensitive than the other side. In general, the longer building dimensions the better energy consumption; cases (Ee) in different orientations and heights are the best 6 alternatives, while cases (Aa3) and (Aa3*) have the highest energy consumption. The majority of cases orientated towards 45 from azimuth have a higher energy consumption per $m^2$ compared to the same cases oriented orthogonally, and height effect can be ignored in the majority of cases since each 5 stories represents around approximately one third of the energy consumption per $m^2$.

This comparative and sensitivity analyses are useful in selecting main features to be focused from architects during designing their envelope cases, since not all building envelope features have the same energy effect. More building envelope features and options can be added through to extend the study, beyond what are presented in this paper, such as different building shapes, facade tilting, positions of windows, shades and others. The effect of the economic parameter of such features' integration (e.g. FMs' cost) should be also studied in future works; this parameter may alter the sensitivity and recommendations accordingly. In addition, other evaluation criteria, design preference or priority could extend the study widely, such as cooling, daylighting, energy generation and architectural creativity. A complete computational tool can been developed based on that to present best features' variables to fit a set of requirements inserted by an architect to suit a design case with different limitations.

## APPENDICES

APPENDIX (A):
THE SIMULATION RESULTS (ENERGY CONSUMPTION (MWH/YEAR)) OF THE STUDIED CASES IN APPLICATION (A): CASES WITH A SAME VOLUME

| Serial Number | Roofs | Walls | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 | Case 8 | Average (MWh/ year) | Average Ranking (from 1/best to 49/worst alternative) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gravel | Galvanized Steel | 3790 | 3805 | 3694 | 3724 | 3727 | 3724 | 3590 | 3595 | 3706.1 | 1 |
| 2 | | Stucoo/Gunite | 3792 | 3806 | 3696 | 3726 | 3729 | 3726 | 3590 | 3595 | 3707.5 | 2 |
| 3 | | Marbel | 3795 | 3809 | 3697 | 3729 | 3733 | 3728 | 3595 | 3601 | 3710.9 | 3 |
| 4 | | Wood | 3797 | 3810 | 3701 | 3731 | 3734 | 3731 | 3597 | 3602 | 3712.9 | 4 |
| 5 | | Spandrel Glass | 3797 | 3811 | 3701 | 3730 | 3735 | 3730 | 3597 | 3603 | 3713 | 5 |
| 6 | | Bricks | 3801 | 3816 | 3705 | 3735 | 3738 | 3735 | 3601 | 3606 | 3717.1 | 15 |
| 7 | | Roofing shingles | 3804 | 3818 | 3704 | 3734 | 3737 | 3734 | 3596 | 3601 | 3716 | 13 |
| 8 | Galvanized steel | Galvanized Steel | 3796 | 3811 | 3700 | 3730 | 3733 | 3730 | 3599 | 3611 | 3713.8 | 6 |
| 9 | | Stucoo/Gunite | 3798 | 3812 | 3702 | 3734 | 3737 | 3734 | 3598 | 3610 | 3715.6 | 12 |
| 10 | | Marbel | 3801 | 3816 | 3704 | 3734 | 3741 | 3734 | 3601 | 3613 | 3718 | 18 |
| 11 | | Wood | 3802 | 3816 | 3706 | 3736 | 3739 | 3736 | 3602 | 3614 | 3718.9 | 21 |
| 12 | | Spandrel Glass | 3803 | 3817 | 3705 | 3735 | 3743 | 3735 | 3603 | 3615 | 3719.5 | 23 |
| 13 | | Bricks | 3807 | 3821 | 3711 | 3741 | 3744 | 3741 | 3607 | 3615 | 3723.4 | 32 |
| 14 | | Roofing shingles | 3809 | 3823 | 3711 | 3744 | 3747 | 3744 | 3607 | 3619 | 3725.5 | 35 |
| 15 | Spandrel Glass | Galvanized Steel | 3797 | 3811 | 3701 | 3731 | 3739 | 3734 | 3597 | 3602 | 3714 | 7 |
| 16 | | Stucoo/Gunite | 3799 | 3813 | 3703 | 3733 | 3736 | 3733 | 3599 | 3604 | 3715 | 11 |
| 17 | | Marbel | 3802 | 3818 | 3705 | 3735 | 3738 | 3735 | 3602 | 3607 | 3717.8 | 17 |
| 18 | | Wood | 3804 | 3818 | 3708 | 3738 | 3744 | 3740 | 3604 | 3609 | 3720.6 | 27 |
| 19 | | Spandrel Glass | 3804 | 3819 | 3708 | 3738 | 3741 | 3738 | 3604 | 3609 | 3720.1 | 24 |
| 20 | | Bricks | 3808 | 3824 | 3712 | 3741 | 3744 | 3741 | 3615 | 3621 | 3725.8 | 38 |
| 21 | | Roofing shingles | 3811 | 3826 | 3715 | 3745 | 3748 | 3745 | 3611 | 3616 | 3727.1 | 41 |
| 22 | Marbel | Galvanized Steel | 3797 | 3811 | 3701 | 3731 | 3734 | 3731 | 3597 | 3612 | 3714.3 | 8 |
| 23 | | Stucoo/Gunite | 3799 | 3812 | 3703 | 3733 | 3736 | 3733 | 3599 | 3613 | 3716 | 14 |
| 24 | | Marbel | 3802 | 3818 | 3706 | 3736 | 3739 | 3736 | 3602 | 3616 | 3719.4 | 22 |
| 25 | | Wood | 3804 | 3819 | 3707 | 3737 | 3740 | 3737 | 3604 | 3617 | 3720.6 | 28 |
| 26 | | Spandrel Glass | 3804 | 3818 | 3708 | 3738 | 3741 | 3738 | 3604 | 3618 | 3721.1 | 29 |
| 27 | | Bricks | 3808 | 3822 | 3712 | 3744 | 3745 | 3744 | 3608 | 3622 | 3725.6 | 36 |
| 28 | | Roofing shingles | 3811 | 3820 | 3712 | 3742 | 3745 | 3742 | 3611 | 3625 | 3726 | 39 |
| 29 | Clay Tiles | Galvanized Steel | 3796 | 3810 | 3700 | 3730 | 3733 | 3730 | 3606 | 3611 | 3714.5 | 10 |
| 30 | | Stucoo/Gunite | 3799 | 3813 | 3702 | 3735 | 3738 | 3735 | 3609 | 3614 | 3718.1 | 19 |
| 31 | | Marbel | 3796 | 3810 | 3700 | 3730 | 3733 | 3730 | 3605 | 3610 | 3714.3 | 9 |
| 32 | | Wood | 3803 | 3817 | 3705 | 3735 | 3738 | 3735 | 3613 | 3618 | 3720.5 | 26 |
| 33 | | Spandrel Glass | 3803 | 3818 | 3707 | 3737 | 3740 | 3737 | 3607 | 3612 | 3720.1 | 25 |
| 34 | | Bricks | 3807 | 3822 | 3711 | 3741 | 3744 | 3741 | 3617 | 3622 | 3725.6 | 37 |
| 35 | | Roofing shingles | 3810 | 3824 | 3714 | 3745 | 3748 | 3745 | 3617 | 3620 | 3727.9 | 43 |
| 36 | Wood | Galvanized Steel | 3799 | 3813 | 3702 | 3735 | 3740 | 3735 | 3604 | 3612 | 3717.5 | 16 |
| 37 | | Stucoo/Gunite | 3801 | 3816 | 3705 | 3735 | 3738 | 3735 | 3606 | 3614 | 3718.8 | 20 |
| 38 | | Marbel | 3804 | 3818 | 3708 | 3738 | 3741 | 3738 | 3609 | 3617 | 3721.6 | 30 |
| 39 | | Wood | 3805 | 3821 | 3708 | 3741 | 3746 | 3741 | 3610 | 3618 | 3723.8 | 33 |
| 40 | | Spandrel Glass | 3806 | 3821 | 3710 | 3740 | 3743 | 3740 | 3611 | 3619 | 3723.8 | 34 |
| 41 | | Bricks | 3810 | 3824 | 3714 | 3744 | 3747 | 3744 | 3615 | 3621 | 3727.4 | 42 |
| 42 | | Roofing shingles | 3812 | 3826 | 3716 | 3746 | 3749 | 3746 | 3617 | 3625 | 3729.6 | 46 |
| 43 | Roofing shingles | Galvanized Steel | 3805 | 3820 | 3709 | 3739 | 3742 | 3739 | 3610 | 3622 | 3723.3 | 31 |
| 44 | | Stucoo/Gunite | 3807 | 3822 | 3711 | 3741 | 3744 | 3741 | 3616 | 3628 | 3726.3 | 40 |
| 45 | | Marbel | 3810 | 3824 | 3714 | 3747 | 3750 | 3747 | 3615 | 3628 | 3729.4 | 45 |
| 46 | | Wood | 3811 | 3826 | 3715 | 3745 | 3748 | 3745 | 3616 | 3628 | 3729.3 | 44 |
| 47 | | Spandrel Glass | 3812 | 3826 | 3716 | 3749 | 3752 | 3749 | 3617 | 3629 | 3731.3 | 47 |
| 48 | | Bricks | 3816 | 3831 | 3720 | 3750 | 3753 | 3750 | 3621 | 3633 | 3734.3 | 48 |
| 49 | | Roofing shingles | 3818 | 3833 | 3722 | 3752 | 3755 | 3752 | 3623 | 3635 | 3736.3 | 49 |
| Average (MWh/ year) | | | 3803 | 3818 | 3707 | 3737 | 3741 | 3737 | 3606 | 3614 | | |

| | | | | | |
|---|---|---|---|---|---|
| (light blue) | Best 10 values in each case/ column (lower energy consumption) | (red) | Worst 10 values in each case /column (higher energy consumption) | (white) | Values between top and worst 10 ones |

## APPENDIX (B)

THE SIMULATION RESULTS (ENERGY CONSUMPTION) OF THE STUDIED CASES IN APPLICATION (B): CASES WITH DIFFERENT VOLUMES

**Orientation from Azimuth = 0 (Orthogonally)**

| Serial Number | Case ID | Length/X (m) | Width/Y (m) | Height(m) | Number of Stories | Total (MWH/year) | Energy Consumption (kWh/($m^2$.year)) | Ranking (from 1/best to 150/worst alternative) |
|---|---|---|---|---|---|---|---|---|
| 1 | Aa1 | 20 | 20 | 20 | 5 | 368 | 184 | 142 |
| 2 | Aa2 | 20 | 20 | 40 | 10 | 737 | 184.3 | 144 |
| 3 | Aa3 | 20 | 20 | 60 | 15 | 1170 | 194.9 | 149 |
| 4 | Ab1 | 20 | 40 | 20 | 5 | 706 | 176.5 | 131 |
| 5 | Ab2 | 20 | 40 | 40 | 10 | 1487 | 185.9 | 148 |
| 6 | Ab3 | 20 | 40 | 60 | 15 | 2101 | 175.1 | 127 |
| 7 | Ac1 | 20 | 60 | 20 | 5 | 1096 | 182.7 | 141 |
| 8 | Ac2 | 20 | 60 | 40 | 10 | 2069 | 172.4 | 121 |
| 9 | Ac3 | 20 | 60 | 60 | 15 | 3104 | 172.4 | 122 |
| 10 | Ad1 | 20 | 80 | 20 | 5 | 1449 | 181.2 | 140 |
| 11 | Ad2 | 20 | 80 | 40 | 10 | 2736 | 171 | 117 |
| 12 | Ad3 | 20 | 80 | 60 | 15 | 3970 | 165.4 | 104 |
| 13 | Ae1 | 20 | 100 | 20 | 5 | 1802 | 180.2 | 136 |
| 14 | Ae2 | 20 | 100 | 40 | 10 | 3405 | 170.3 | 112 |
| 15 | Ae3 | 20 | 100 | 60 | 15 | 4942 | 164.7 | 103 |
| 16 | Ba1 | 40 | 20 | 20 | 5 | 692 | 173 | 123 |
| 17 | Ba2 | 40 | 20 | 40 | 10 | 1443 | 180.4 | 138 |
| 18 | Ba3 | 40 | 20 | 60 | 15 | 2043 | 170.2 | 111 |
| 19 | Bb1 | 40 | 40 | 20 | 5 | 1368 | 171 | 118 |
| 20 | Bb2 | 40 | 40 | 40 | 10 | 2598 | 162.4 | 95 |
| 21 | Bb3 | 40 | 40 | 60 | 15 | 3799 | 158.3 | 88 |
| 22 | Bc1 | 40 | 60 | 20 | 5 | 1913 | 159.4 | 93 |
| 23 | Bc2 | 40 | 60 | 40 | 10 | 3736 | 155.7 | 78 |
| 24 | Bc3 | 40 | 60 | 60 | 15 | 5608 | 155.8 | 79 |
| 25 | Bd1 | 40 | 80 | 20 | 5 | 2526 | 157.9 | 86 |
| 26 | Bd2 | 40 | 80 | 40 | 10 | 4938 | 154.3 | 68 |
| 27 | Bd3 | 40 | 80 | 60 | 15 | 7355 | 153.2 | 64 |
| 28 | Be1 | 40 | 100 | 20 | 5 | 3142 | 157.1 | 83 |
| 29 | Be2 | 40 | 100 | 40 | 10 | 6141 | 153.5 | 65 |
| 30 | Be3 | 40 | 100 | 60 | 15 | 9148 | 152.5 | 58 |
| 31 | Ca1 | 60 | 20 | 20 | 5 | 1053 | 175.5 | 129 |
| 32 | Ca2 | 60 | 20 | 40 | 10 | 1991 | 165.9 | 105 |
| 33 | Ca3 | 60 | 20 | 60 | 15 | 2991 | 166.2 | 106 |
| 34 | Cb1 | 60 | 40 | 20 | 5 | 1899 | 158.2 | 87 |
| 35 | Cb2 | 60 | 40 | 40 | 10 | 3716 | 154.9 | 69 |
| 36 | Cb3 | 60 | 40 | 60 | 15 | 5579 | 155 | 72 |
| 37 | Cc1 | 60 | 60 | 20 | 5 | 2789 | 154.9 | 70 |
| 38 | Cc2 | 60 | 60 | 40 | 10 | 5458 | 151.6 | 52 |
| 39 | Cc3 | 60 | 60 | 60 | 15 | 8130 | 150.6 | 49 |
| 40 | Cd1 | 60 | 80 | 20 | 5 | 3606 | 150.3 | 47 |
| 41 | Cd2 | 60 | 80 | 40 | 10 | 7158 | 149.1 | 37 |
| 42 | Cd3 | 60 | 80 | 60 | 15 | 10737 | 149.1 | 34 |
| 43 | Ce1 | 60 | 100 | 20 | 5 | 4485 | 149.5 | 44 |
| 44 | Ce2 | 60 | 100 | 40 | 10 | 8899 | 148.3 | 31 |
| 45 | Ce3 | 60 | 100 | 60 | 15 | 13341 | 148.2 | 29 |
| 46 | Da1 | 80 | 20 | 20 | 5 | 1388 | 173.4 | 124 |
| 47 | Da2 | 80 | 20 | 40 | 10 | 2624 | 164 | 102 |
| 48 | Da3 | 80 | 20 | 60 | 15 | 3834 | 159.8 | 94 |
| 49 | Db1 | 80 | 40 | 20 | 5 | 2499 | 156.2 | 80 |
| 50 | Db2 | 80 | 40 | 40 | 10 | 4894 | 152.9 | 63 |
| 51 | Db3 | 80 | 40 | 60 | 15 | 7299 | 152.1 | 56 |
| 52 | Dc1 | 80 | 60 | 20 | 5 | 3604 | 150.2 | 45 |
| 53 | Dc2 | 80 | 60 | 40 | 10 | 7161 | 149.2 | 40 |
| 54 | Dc3 | 80 | 60 | 60 | 15 | 10747 | 149.3 | 42 |
| 55 | Dd1 | 80 | 80 | 20 | 5 | 4744 | 148.2 | 30 |
| 56 | Dd2 | 80 | 80 | 40 | 10 | 9406 | 147 | 16 |
| 57 | Dd3 | 80 | 80 | 60 | 15 | 14102 | 146.9 | 15 |
| 58 | De1 | 80 | 100 | 20 | 5 | 5898 | 147.5 | 19 |
| 59 | De2 | 80 | 100 | 40 | 10 | 11695 | 146.2 | 12 |
| 60 | De3 | 80 | 100 | 60 | 15 | 17528 | 146.1 | 7 |
| 61 | Ea1 | 100 | 20 | 20 | 5 | 1722 | 172.2 | 120 |
| 62 | Ea2 | 100 | 20 | 40 | 10 | 3259 | 163 | 98 |
| 63 | Ea3 | 100 | 20 | 60 | 15 | 4762 | 158.7 | 89 |
| 64 | Eb1 | 100 | 40 | 20 | 5 | 3099 | 155 | 71 |
| 65 | Eb2 | 100 | 40 | 40 | 10 | 6074 | 151.8 | 55 |
| 66 | Eb3 | 100 | 40 | 60 | 15 | 9038 | 150.6 | 50 |
| 67 | Ec1 | 100 | 60 | 20 | 5 | 4471 | 149 | 33 |
| 68 | Ec2 | 100 | 60 | 40 | 10 | 8878 | 148 | 23 |
| 69 | Ec3 | 100 | 60 | 60 | 15 | 13321 | 148 | 25 |
| 70 | Ed1 | 100 | 80 | 20 | 5 | 5905 | 147.6 | 22 |
| 71 | Ed2 | 100 | 80 | 40 | 10 | 11716 | 146.4 | 13 |
| 72 | Ed3 | 100 | 80 | 60 | 15 | 17579 | 146.5 | 14 |
| 73 | Ee1 | 100 | 100 | 20 | 5 | 7261 | 145.2 | 5 |
| 74 | Ee2 | 100 | 100 | 40 | 10 | 14467 | 144.7 | 2 |
| 75 | Ee3 | 100 | 100 | 60 | 15 | 21685 | 144.6 | 1 |

**Orientation from Azimuth = 45**

| Serial Number | Case ID | Length/X (m) | Width/Y (m) | Height(m) | Number of Stories | Total (MWH/year) | Energy Consumption (kWh/($m^2$.year)) | Ranking (from 1/best to 150/worst alternative) |
|---|---|---|---|---|---|---|---|---|
| 76 | Aa1* | 20 | 20 | 20 | 5 | 369 | 184.5 | 145 |
| 77 | Aa2* | 20 | 20 | 40 | 10 | 741 | 185.3 | 147 |
| 78 | Aa3* | 20 | 20 | 60 | 15 | 1180 | 196.6 | 150 |
| 79 | Ab1* | 20 | 40 | 20 | 5 | 702 | 175.5 | 128 |
| 80 | Ab2* | 20 | 40 | 40 | 10 | 1477 | 184.7 | 146 |
| 81 | Ab3* | 20 | 40 | 60 | 15 | 2087 | 173.9 | 126 |
| 82 | Ac1* | 20 | 60 | 20 | 5 | 1082 | 180.4 | 137 |
| 83 | Ac2* | 20 | 60 | 40 | 10 | 2046 | 170.5 | 115 |
| 84 | Ac3* | 20 | 60 | 60 | 15 | 3069 | 170.5 | 116 |
| 85 | Ad1* | 20 | 80 | 20 | 5 | 1426 | 178.3 | 134 |
| 86 | Ad2* | 20 | 80 | 40 | 10 | 2697 | 168.6 | 109 |
| 87 | Ad3* | 20 | 80 | 60 | 15 | 3924 | 163.5 | 101 |
| 88 | Ae1* | 20 | 100 | 20 | 5 | 1770 | 177 | 132 |
| 89 | Ae2* | 20 | 100 | 40 | 10 | 3350 | 167.5 | 107 |
| 90 | Ae3* | 20 | 100 | 60 | 15 | 4879 | 162.6 | 97 |
| 91 | Ba1* | 40 | 20 | 20 | 5 | 702 | 175.6 | 130 |
| 92 | Ba2* | 40 | 20 | 40 | 10 | 1474 | 184.3 | 143 |
| 93 | Ba3* | 40 | 20 | 60 | 15 | 2086 | 173.8 | 125 |
| 94 | Bb1* | 40 | 40 | 20 | 5 | 1377 | 172.1 | 119 |
| 95 | Bb2* | 40 | 40 | 40 | 10 | 2610 | 163.1 | 99 |
| 96 | Bb3* | 40 | 40 | 60 | 15 | 3811 | 158.8 | 90 |
| 97 | Bc1* | 40 | 60 | 20 | 5 | 1911 | 159.2 | 91 |
| 98 | Bc2* | 40 | 60 | 40 | 10 | 3732 | 155.5 | 75 |
| 99 | Bc3* | 40 | 60 | 60 | 15 | 5601 | 155.6 | 77 |
| 100 | Bd1* | 40 | 80 | 20 | 5 | 2518 | 157.4 | 85 |
| 101 | Bd2* | 40 | 80 | 40 | 10 | 4921 | 153.8 | 67 |
| 102 | Bd3* | 40 | 80 | 60 | 15 | 7331 | 152.7 | 60 |
| 103 | Be1* | 40 | 100 | 20 | 5 | 3124 | 156.2 | 82 |
| 104 | Be2* | 40 | 100 | 40 | 10 | 6110 | 152.8 | 62 |
| 105 | Be3* | 40 | 100 | 60 | 15 | 9107 | 151.8 | 54 |
| 106 | Ca1* | 60 | 20 | 20 | 5 | 1083 | 180.5 | 139 |
| 107 | Ca2* | 60 | 20 | 40 | 10 | 2045 | 170.4 | 113 |
| 108 | Ca3* | 60 | 20 | 60 | 15 | 3067 | 170.4 | 114 |
| 109 | Cb1* | 60 | 40 | 20 | 5 | 1911 | 159.2 | 92 |
| 110 | Cb2* | 60 | 40 | 40 | 10 | 3731 | 155.5 | 73 |
| 111 | Cb3* | 60 | 40 | 60 | 15 | 5600 | 155.6 | 76 |
| 112 | Cc1* | 60 | 60 | 20 | 5 | 2799 | 155.5 | 74 |
| 113 | Cc2* | 60 | 60 | 40 | 10 | 5476 | 152.1 | 57 |
| 114 | Cc3* | 60 | 60 | 60 | 15 | 8157 | 151.1 | 51 |
| 115 | Cd1* | 60 | 80 | 20 | 5 | 3606 | 150.3 | 48 |
| 116 | Cd2* | 60 | 80 | 40 | 10 | 7160 | 149.2 | 39 |
| 117 | Cd3* | 60 | 80 | 60 | 15 | 10737 | 149.1 | 35 |
| 118 | Ce1* | 60 | 100 | 20 | 5 | 4479 | 149.3 | 43 |
| 119 | Ce2* | 60 | 100 | 40 | 10 | 8888 | 148.1 | 28 |
| 120 | Ce3* | 60 | 100 | 60 | 15 | 13331 | 148.1 | 27 |
| 121 | Da1* | 80 | 20 | 20 | 5 | 1427 | 178.4 | 135 |
| 122 | Da2* | 80 | 20 | 40 | 10 | 2697 | 168.6 | 110 |
| 123 | Da3* | 80 | 20 | 60 | 15 | 3918 | 163.3 | 100 |
| 124 | Db1* | 80 | 40 | 20 | 5 | 2517 | 157.3 | 84 |
| 125 | Db2* | 80 | 40 | 40 | 10 | 4920 | 153.7 | 66 |
| 126 | Db3* | 80 | 40 | 60 | 15 | 7327 | 152.6 | 59 |
| 127 | Dc1* | 80 | 60 | 20 | 5 | 3605 | 150.2 | 46 |
| 128 | Dc2* | 80 | 60 | 40 | 10 | 7159 | 149.1 | 38 |

continued on the next page

APPENDIX (B):: continued

Orientation from Azimuth = 45

| Serial Number | Case ID | Length/X (m) | Width/Y (m) | Height(m) | Number of Stories | Total (MWH/year) | Energy Consumption (kWh/(m².year)) | Ranking (from 1/best to 150/worst alternative) |
|---|---|---|---|---|---|---|---|---|
| 129 | Dc3* | 80 | 60 | 60 | 15 | 10737 | 149.1 | 36 |
| 130 | Dd1* | 80 | 80 | 20 | 5 | 4754 | 148.6 | 32 |
| 131 | Dd2* | 80 | 80 | 40 | 10 | 9430 | 147.3 | 18 |
| 132 | Dd3* | 80 | 80 | 60 | 15 | 14142 | 147.3 | 17 |
| 133 | De1* | 80 | 100 | 20 | 5 | 5901 | 147.5 | 21 |
| 134 | De2* | 80 | 100 | 40 | 10 | 11695 | 146.2 | 10 |
| 135 | De3* | 80 | 100 | 60 | 15 | 17538 | 146.1 | 8 |
| 136 | Ea1* | 100 | 20 | 20 | 5 | 1771 | 177.1 | 133 |
| 137 | Ea2* | 100 | 20 | 40 | 10 | 3350 | 167.5 | 108 |
| 138 | Ea3* | 100 | 20 | 60 | 15 | 4873 | 162.4 | 96 |
| 139 | Eb1* | 100 | 40 | 20 | 5 | 3124 | 156.2 | 81 |
| 140 | Eb2* | 100 | 40 | 40 | 10 | 6109 | 152.7 | 61 |
| 141 | Eb3* | 100 | 40 | 60 | 15 | 9101 | 151.7 | 53 |
| 142 | Ec1* | 100 | 60 | 20 | 5 | 4478 | 149.3 | 41 |
| 143 | Ec2* | 100 | 60 | 40 | 10 | 8886 | 148.1 | 26 |
| 144 | Ec3* | 100 | 60 | 60 | 15 | 13321 | 148 | 24 |
| 145 | Ed1* | 100 | 80 | 20 | 5 | 5900 | 147.5 | 20 |
| 146 | Ed2* | 100 | 80 | 40 | 10 | 11695 | 146.2 | 11 |
| 147 | Ed3* | 100 | 80 | 60 | 15 | 17538 | 146.1 | 9 |
| 148 | Ee1* | 100 | 100 | 20 | 5 | 7275 | 145.5 | 6 |
| 149 | Ee2* | 100 | 100 | 40 | 10 | 14507 | 145.1 | 4 |
| 150 | Ee3* | 100 | 100 | 60 | 15 | 21755 | 145 | 3 |

| | |
|---|---|
| (blue) | Best 20 values (lower energy consumption) |
| (red) | Worst 20 values (higher energy consumption) |

## REFERENCES


[1] DOE-2 (2020) DOE-2 based software homepage, eQuest. Available via http://www.doe2.com/equest.Accessed at 20 June 2020.

[2] P. Ihm, M. Krarti (2013) Design Optimization of Energy Efficient Office Buildings in Tunisia. Building and Environment 58(4):81–90. https://doi.org/10.1016/j.buildenv.2012.06.012.

[3] X. Qian, S.W. Lee (2014) The Design and Analysis of Energy Efficient Building Envelopes for the Commercial Buildings by Mixed-Level Factorial Design and Statistical Methods. Proceeding of Fall 2014 Middle Atlantic American Society of Engineering, Swarthmsore College in Swartz Creek, US. Available via: https://www.semanticscholar.org/paper/. Accessed at 1 Apr 2021.

[4] M. Ferrara, E. Fabrizio, J. Virgone, M. Filippi (2014) A Simulation-Based Optimization Method for Cost-Optimal Analysis of Nearly Zero Energy Buildings. Energy and Buildings 84:442–457. https://doi.org/10.1016/j.enbuild.2014.08.031.

[5] N. Harmati, Z. Magyar (2015) Influence of WWR, WG and Glazing Properties on The Annual Heating and Cooling Energy Demand in Buildings. Energy Procedia78: 2458-2463. https://doi.org/10.1016/j.egypro.2015.11.229.

[6] A. Aksamija (2015) High-performance building envelopes: design methods for energy efficient facades. Proceedings of: BEST4 Conference, USA.

[7] J. Hu, J. Wu (2015) Analysis on the Influence of Building Envelope to public buildings energy consumption based on DeST simulation. Procedia Engineering 121: 1620-1627 https://doi.org/10.1016/j.proeng.2015.09.192.

[8] B. Raji, M.J. Tenpierik, A. Van den Dobbelsteen (2016) An assessment of energy-saving solutions for the envelope design of high-rise buildings in temperate climates: A case study in the Netherlands. Energy and Buildings124: 210-221. https://doi.org/10.1016/j.enbuild.2015.10.049.

[9] M. Barozzi, J. Lienhard, A. Zanelli, C. Monticelli (2016) The Sustainability of Adaptive Envelopes: Developments of Kinetic Architecture. Procedia Engineering 155: 275-284. https://doi.org/10.1016/j.proeng.2016.08.029.

[10] J. Balter, C. Ganem, C. Discoli (2016) On High-rise Residential Buildings in an Oasis-City: Thermal and Energy Assessment of Different Envelope Materiality Above and Below Tree Canopy. Energy and Buildings 113: 61-73. https://doi.org/10.1016/j.enbuild.2015.11.011.

[11] L. Liu, D. Wu1, X. Li, Sh. Hou, C. Liu, Ph. Jones (2017). Effect of Geometric Factors on The Energy Performance of High-rise Office Towers in Tianjin, China. Building Simulation, 10: 625–641. https://doi.org/10.1007/s12273-017-0359-y

[12] Y. Liu, S. Zou, H. Chen, X. Wu, W. Chen (2019) Simulation Analysis and Scheme Optimization of Energy Consumption in Public Buildings. Advances in Civil Engineering 2019: 6326138. https://doi.org/10.1155/2019/6326138.

[13] D. D'Agostino, D. Parker, P. Melià (2019) Environmental and Economic Implications of Energy Efficiency in New Residential Buildings: A Multi-Criteria Selection Approach. Energy Strategy Reviews26: 100412 https://doi.org/10.1016/j.esr.2019.100412.

[14] D. Tuhus-Dubrow, M. Krarti (2010). Genetic-Algorithm Based Approach to Optimize Building Envelope Design for Residential Buildings. Energy and Buildings 45: 1574–1581. https://doi.org/10.1016/j.buildenv.2010.01.005.

[15] S.C. Zerefos, C.A. Tessas, A.M. Kotsiopoulos, D. Founda, A. Kokkini (2012) The Role of Building Form in Energy Consumption: The Case of A Prismatic Building in Athens. Energy and Buildings 48: 97-102. https://doi.org/10.1016/j.enbuild.2012.01.014.

[16] S.F. Al-Nuaimi, Kh.A. Khamis (2014) Thermal Impact Of Different Interior Finishing Materials On Energy Consumption in Bahrain. Journal of Energy Technologies and Policy 4:3: 30-49. Available via: https://www.iiste.org/Journals/index.php/JETP/article/view/11663. Accessed at July 2021.

[17] V. Pukhkal (2015) Humidity Conditions for Exterior Walls Insulation (Case Study of Residential Housing Development in Saint-Petersburg). Procedia Engineering 117: 616-623. https://doi.org/10.1016/j.proeng.2015.08.222.

[18] Y. Huang, R. Qi, L. Mi (2017) Investigation on Energy-Efficient Retrofitting Measures on Commercial Building External Walls in Cooling-Dominate Cities. Energy and Buildings 205: 2973-2979. https://doi.org/10.1016/j.proeng.2017.10.115.

[19] C. Alonso, F. Martín-Consuegra , I. Oteiza, E. Asensio, G. Pérez, I. Martínez, B. Frutos (2017) Effect of Façade Surface Finish on Building Energy Rehabilitation. Solar Energy 146: 470-483. https://doi.org/10.1016/j.solener.2017.03.009.

[20] V. Echarri-Iribarren, F. Echarri-Iribarren, C. Rizo-Maestre (2019) Ceramic Panels Versus Aluminium in Buildings: Energy Consumption and Environmental Impact Assessment with a New Methodology. Applied Energy233–234: 959-974. https://doi.org/10.1016/j.apenergy.2018.08.091.

[21] M. Khoukhi, A.F.Darsaleh, S. Ali (2020) Retrofitting an Existing Office Building in the UAE Towards Achieving Low-Energy Building. Sustainability 12: 2573. https://doi.org/10.3390/su12062573.

[22] S. Albadry (2016) Feasibility of Converting Existing Residential Buildings to Net Zero-Energy Buildings in Egypt. M.Sc, Center for Sustainable Development, The American University of Cairo, Egypt. Available via: http://dar.aucegypt.edu/handle/10526/4771. Accessed at: 1 Jan 2021.

[23] A. Khalil, M. Fikry, W. Abdeaal (2018) High Technology or Low Technology for Buildings Envelopes in Residential Buildings in Egypt. Alexandria Engineering Journal57(4): 3779-3792. https://doi.org/10.1016/j.aej.2018.11.001.

[24] M.A. William, A.M. El-Haridi, A.A. Hanafy, A.A. El-Sayed (2019). Assessing The Energy Efficiency Improvement for Hospitals in Egypt Using Building Simulation Modeling. Engineering Research Journal 42 (1): 21-34. https://doi.org/10.21608/erjm.2019.66266.

[25] S. Mahmoud, M. Fahmy, M. Mahdy, I. Elwy, M. Abdelalim (2019). Comparative Energy Performance Simulation for Passive and conventional Design: A Case Study in Cairo, Egypt. Energy Reports6 (1): 699-704. https://doi.org/10.1016/j.egyr.2019.09.052

[26] S.M. Abd El-Rahman, S.I. Esmail, H.B. Khalil, Z. El-Razaz (2020). Sustainable Optimization for Thermal Comfort and Building Energy Efficiency in Cairo. Engineering Research Journal 166: A18-A34. https://doi.org/10.21608/erj.2020.135278

[27] ANSI/ASHRAE/IESNA Standard 90.1-2007.Final Qualitative Determination, ASHRAE (2007).


***Title Arabic:***

**تحليل مقارن معتمد علي المحاكاة لتحسين استهلاك الطاقة في المباني الإدارية في مصر**

***Arabic Abstract:***

زاد الاهتمام بسمات أغلفة المباني لتحقيق أقل استهلاك طاقة خاصة في المباني الإدارية الكبرى والبيئات المناخية الحارة، حيث أن هذه السمات ومتغيراتها تؤثر في استهلاك الطاقة علي نطاق واسع ومستويات مختلفة. تقدم الورقة البحثية تحليل مقارن معتمد علي المحاكاة لأهم السمات الرئيسية لأغلفة المباني ومتغيراتها، والسمات التي سيتم دراستها هي نسب المبني وتوجيهه بالإضافة مواد التشطيب الخارجية الشائعة. تمت الدراسة من خلال تطبيقين (مقارنة نماذج ذات حجم ثابت وأخرى متغيرة)، وعليه تم دراسة أكثر من ٥٠٠ نموذج (عملية محاكاة). بناءً علي ما سبق، تم تحديد السمات والمتغيرات المؤثرة لدعم اتخاذ القرار في الحالات التصميمية المختلفة، وكذلك أفضل دمج للمتغيرات وصولاً لأفضل استهلاك للطاقة في الحالات والنماذج المقترحة. تم تطبيق الدراسة على المباني الإدارية في مصر، وتم اختيار برنامج eQuest (DOE-2) لعمل المحاكاة. من أهم نتائج الدراسة أن تقليل الارتفاع مع زيادة مسطح المبني يحقق أفضل استهلاك طاقة في حالة مقارنة نماذج مباني ذات حجم ثابت والعكس صحيح، الأرضيات المكونة من الحصى والحديد المجلفن في الحوائط يمثلان أفضل المواد التي تم دراستها من منظور تقليل استهلاك المبني للطاقة، بينما ألواح تكسية الأسطح هي أقلها. في حالة مقارنة مباني ذات حجم متغير، فإن الأبعاد الأفقية للمبني تمثل أكثر السمات تأثيراً علي استهلاك الطاقة للمتر المربع الواحد، بينما مواد التشطيب والارتفاع تمثل أقلها تأثيراً.تم تحليل ومناقشة ترتيب النماذج والسمات والمتغيرات المختلفة بالإضافة إلي تحديد فعالية السمات المختلفة وأفضل متغيراتها بنهاية الدراسة.