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Amr Youssef
Assistant Professor., Architectural Engineering Department., Faculty of Engineering., Assiut University., Assiut 71518., Egypt., amr.ma.youssef@aun.edu.eg

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

Amr Mamdoh Ali Youssef *

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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***Corresponding Author:** Amr Mamdoh Ali Youssef, Assistant Professor in Department of Architectural Engineering, Assiut University, Assiut 71518, Egypt. (email: amr.ma.youssef@aun.edu.eg)*

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).

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.

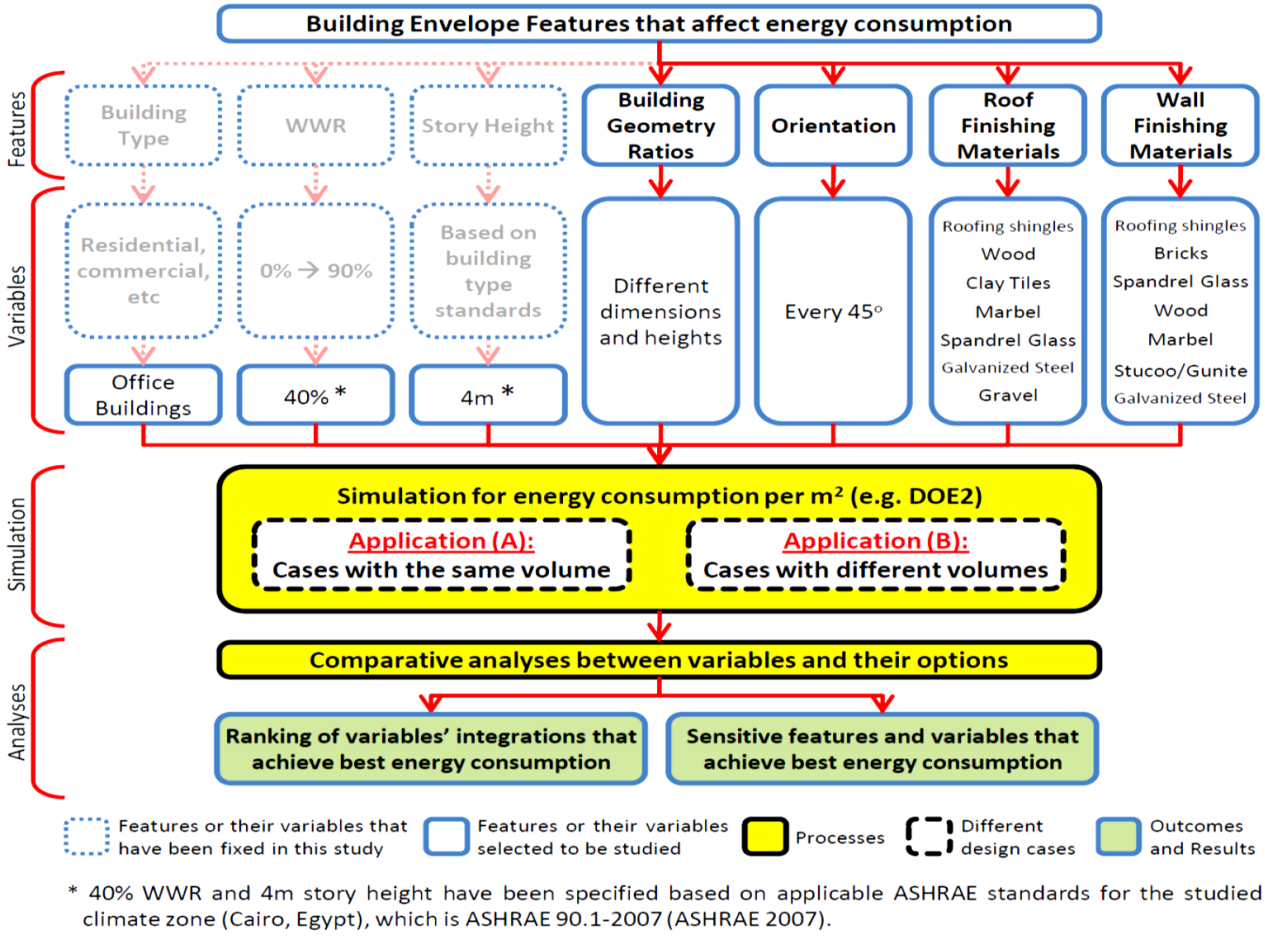

Fig. 1: Main features and variables of building envelope affecting energy consumption

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 ($K\text{-}M^2/W$)	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.

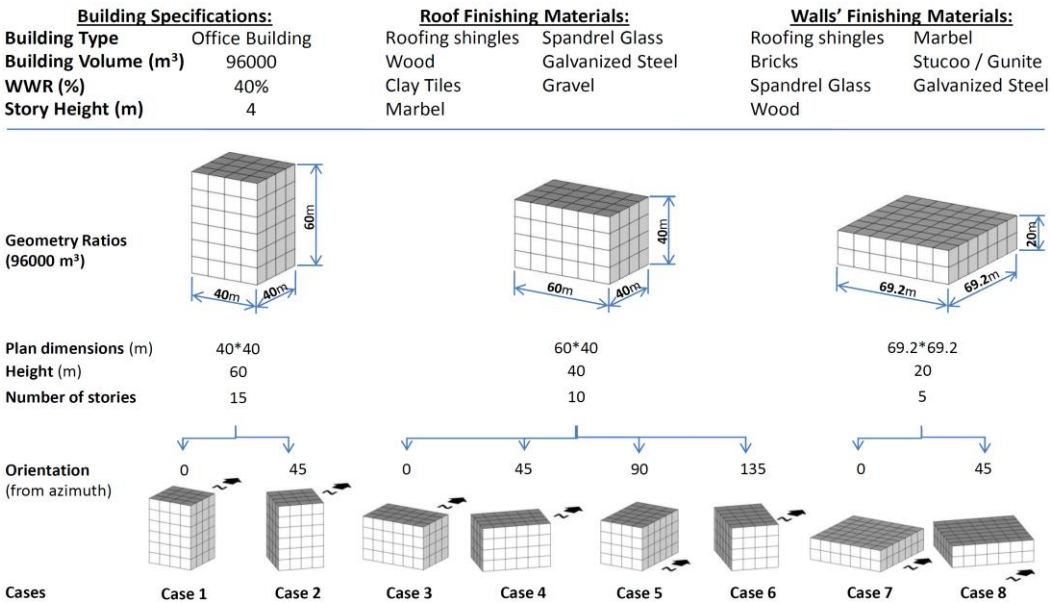

Fig. 2: Cases with a same volume and their specifications to be studied in application (A)

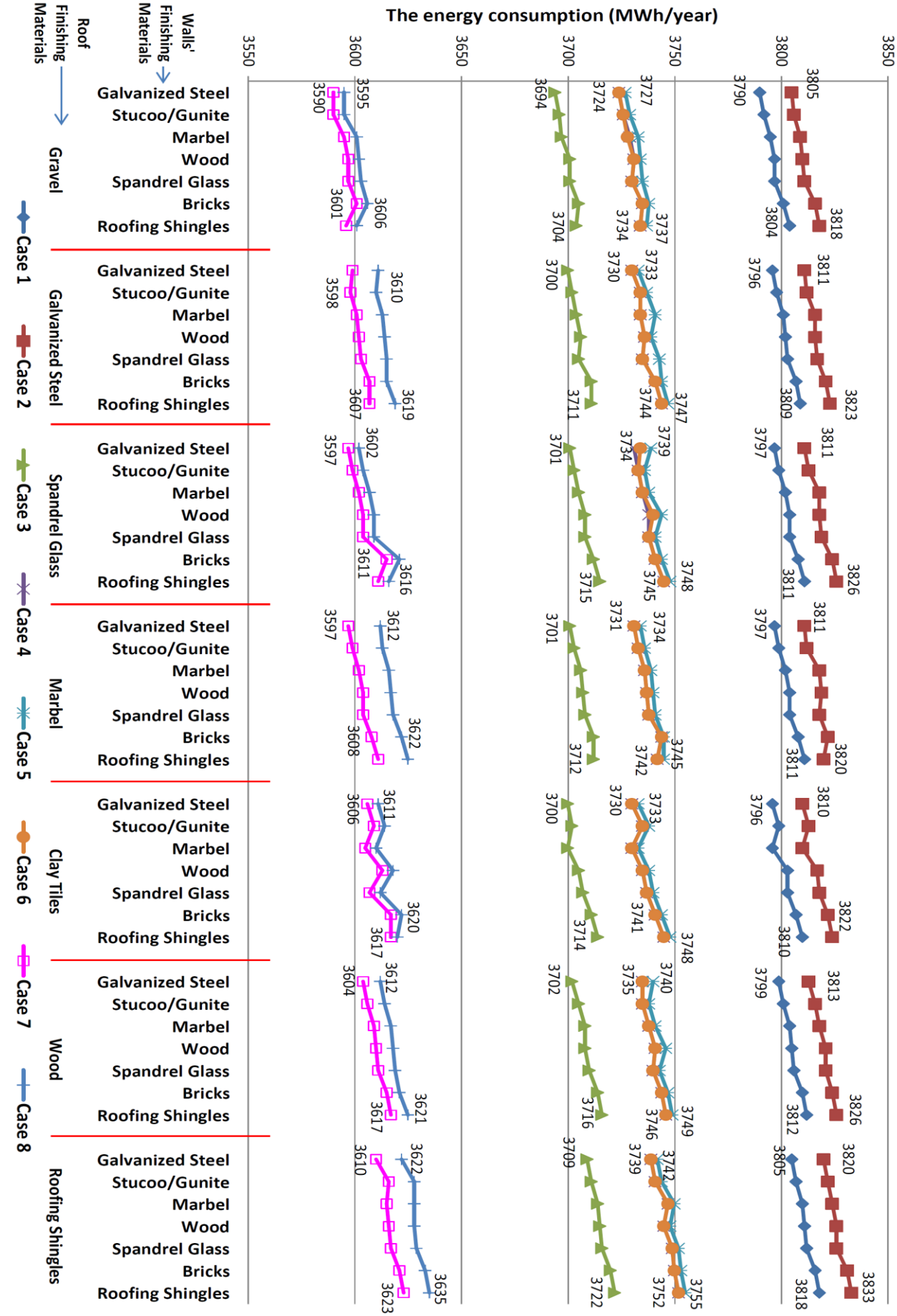

Fig. 3: The energy consumption of the cases, features and variables studied in application (A) (simulated by eQuest 3.65)

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%.

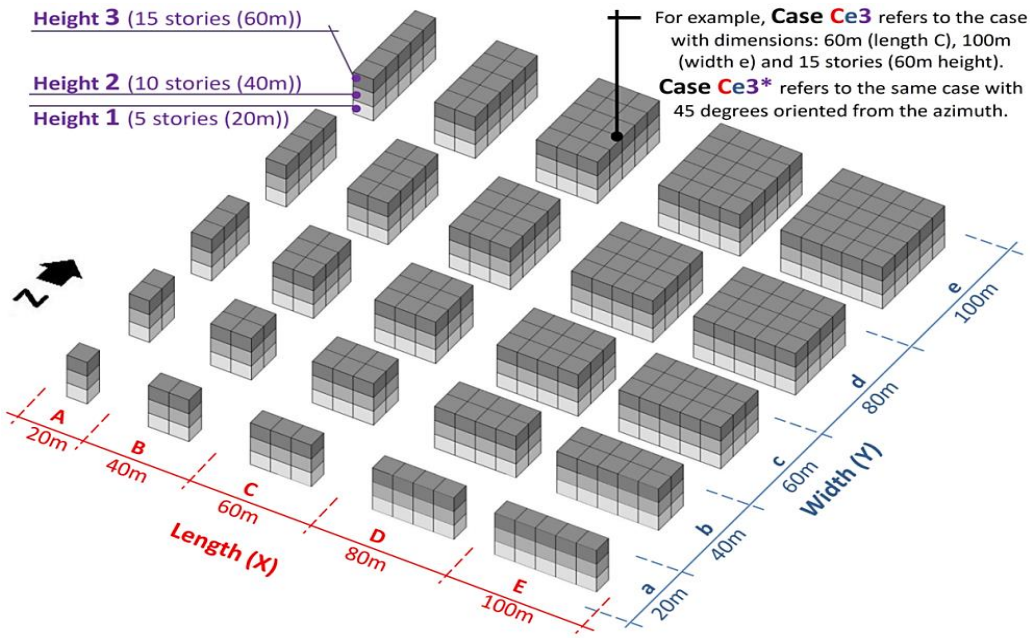

Fig. 4: Cases with different volumes and their specifications to be studied in application (B)

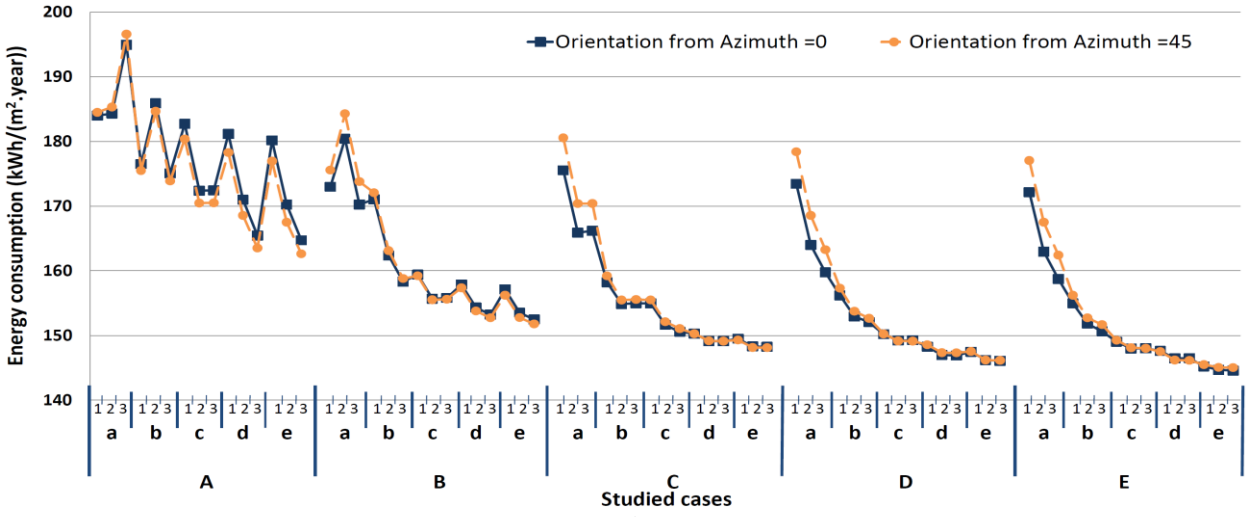

Fig. 5: The energy consumption of cases studied in application (B)

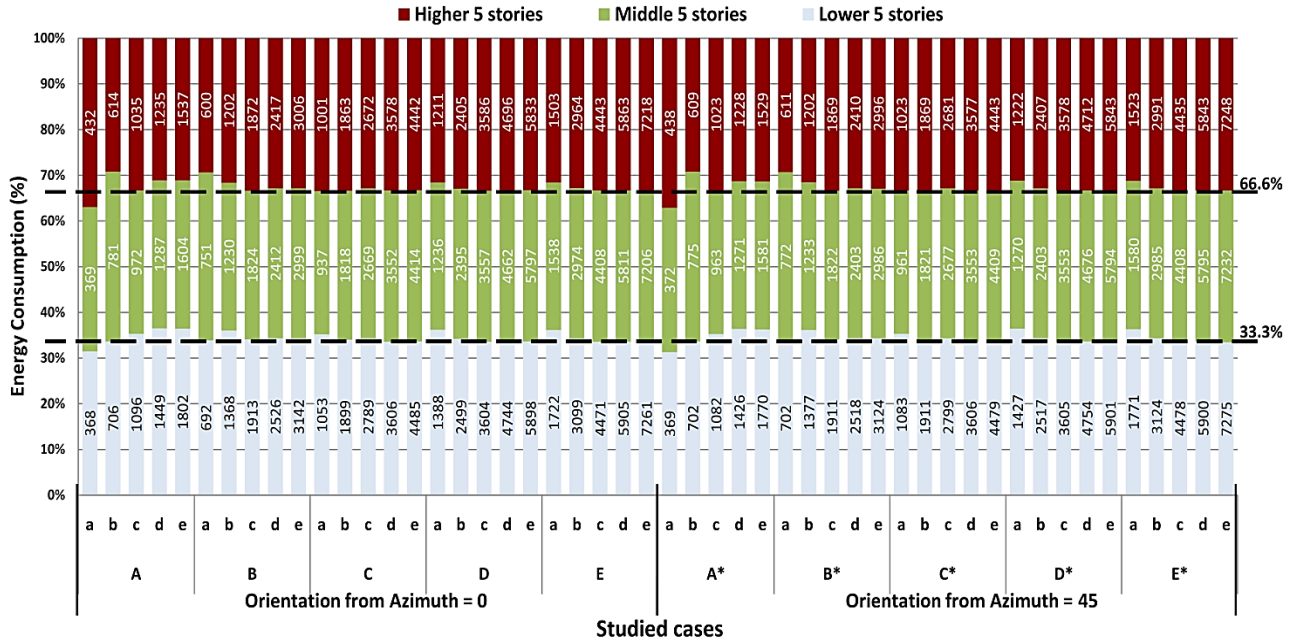

Fig. 6: The effect of building height on the energy consumption of cases studied in application (B)

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.

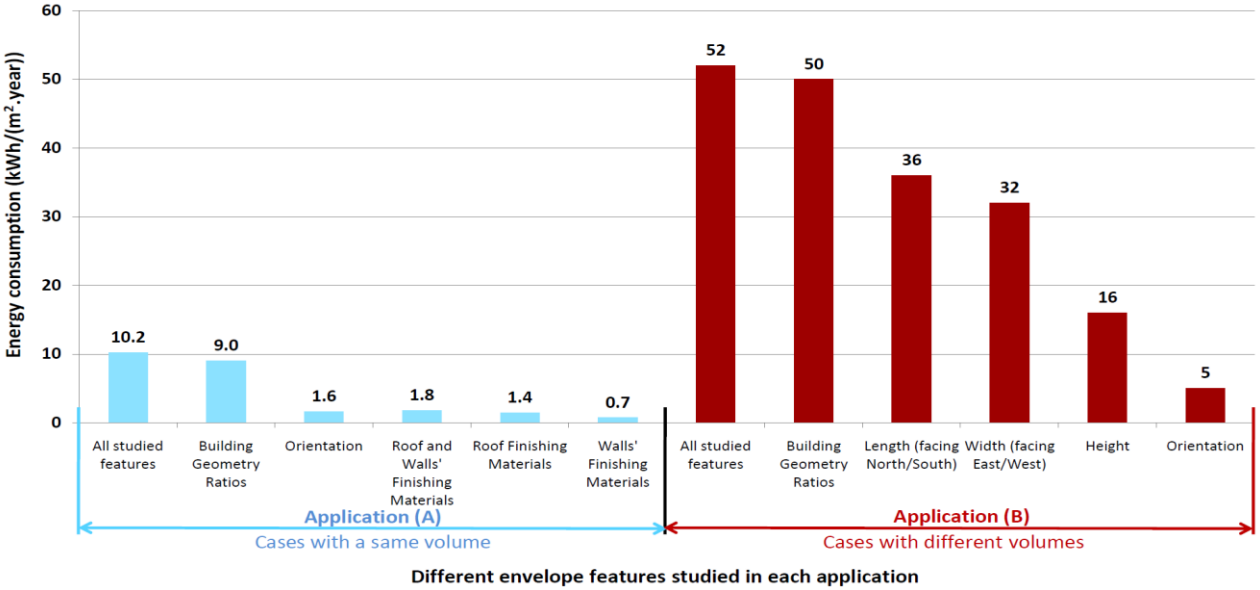

Fig. 7: Maximum energy saving achieved by different building envelope features

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		

	Best 10 values in each case/ column (lower energy consumption)		Worst 10 values in each case /column (higher energy consumption)		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/(m^2.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

	Best 20 values (lower energy consumption)
	Worst 20 values (higher energy consumption)

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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.