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INTEGRATING LAYOUT GEOMETRY WITH ARCHITECTURAL REQUIREMENTS TO ACHIEVE ENERGY-EFFICIENT OFFICE BUILDINGS IN EGYPT

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ABSTRACT

Office buildings consume energy intensively for HVAC to maintain their thermal condition. As the form typology is a factor that affects the building's energy consumptions, this research focuses on the impact of form layout on office building energy consumption in hot desert climate. An extensive simulation process takes place to optimize the integration between energy-efficiency and design needs. The different tested design alternatives are the window to wall ratios, shading devices, and building orientations. The results exposed that building orientation has a significant role in improving the energy efficiency of longitudinal forms, while complex forms have a remarkable response to fenestration size and shading devices.

In addition, the results found that the design alternatives optimization can play a significant role in improving the energy performance of high energy consumption forms.

INTRODUCTION

One of the cities sustainable energy paths is the focus on energy-efficiency and providing support and information to users (UN-Habitat, 2009). Therefore, the Arab world cities work to introduce stronger standards for green building and promote sustainable communities to tackle climate change (Kibert, 2016). Achieving energy-efficient buildings is one of the ways of promoting sustainable communities, as they represent the highest electricity consumption in Egypt according to the latest official annual electricity report (residential 42.4%, commercial 12.2% and governmental entities 4.5%) (MEHC, 2017). Offices title as heavy energy consumer buildings, as they depend on HVAC systems during the day working hours.

A previous study on hot arid climate tracked the total energy used for office buildings, and it found that the energy used by HVAC and split units was about double that for lighting and equipment. Thus decreasing the cooling loads for the HVAC system shows a great opportunity to total saving energy (Abd-allah et al., 2014).

Energy-saving in building consumption can be achieved by controlling different design parameters, for instance: building geometry, orientation, materials, window to wall ratio (WWR). By way of, building geometry is the first stage in building design process, it comes before selecting building materials or WWR. Therefore, geometry plays an essential role in controlling energy-efficiency in the earlier design phases.

Building geometry has a significant factor in controlling energy-efficiency. In a hot arid climate, basic geometric shapes like a circural layout found that it receives the lowest amount of solar insolation followed by square shape for high-rise buildings (Ling, Ahmad, & Ossen, 2007). Different forms do not perform in the same patterns across differ desert regions. In place of residential buildings in hot desert climate, courtyarded forms consume more energy rather than squared forms in a higher way than hot-arid desert regions (El-Deeb, El-Zafarany, & Sherif, 2012). That means that the gap in energy consumption between squared and courtyard forms is increased in hot desert climate.

Besides, form compactness plays a role as an indicator to help buildings in achieving energy-efficiency in hot and arid regions for residential buildings. The compactness of a building indicates the ratio between the external surface area and the internal volume of a building. It has a considerable influence on the overall energy demand (McLeod, Mead, & Standen, n.d.). Compact shapes can result in reducing building energy consumption in hot and cold climates. Generally, a smaller compactness ratio of the building indicates a lower probability of heat loss and more efficient energy consumption. It is recommended that the compactness ratio has to be less than 0.7m²/ m³ (McLeod et al., n.d.). Regarding the building shape compactness, the building performance is varying in different climate conditions. In a cold climate, compact forms suggested cutting the heat loss, while they use beside courtyards to minimize heat gain in hot-dry climate and help in providing shading (Yüksek & Karadayi, 2017).

Previous studies showed different results of building geometries preferences according to the climatic regions and building activities. So, this research focuses on illustrating the case of office buildings in hot desert region resembled in the Egyptian case.

STUDY OBJECTIVES

The main aim of the study is to evaluate the power of form geometry on buildings' energy consumption rates. The research tests different geometries with different orientations to compare their energy consumption values for heating, and cooling. Consequently, an optimized approach discussed the influence of integrating design requirements for developing different low-efficient forms by reducing their energy consumption.

SIMULATION METHODOLOGY

To investigate the relation between building form and its cooling and heating energy load in office buildings, a computer simulation study proceeds for four Egyptian cities that resemble different local climatic zones. Egypt's climate considers being a hot desert climate according to the Köppen-Geiger climate classification (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). Table 1 shows the climatic conditions for each studied city, according to the Egyptian climatic zones classification (HBRC, 2005).

Table 1: Climate characterizations for the four studied Egyptian cities

	Cairo	Alex.	Aswan	Al Tor
Climatic Region	Cairo and Delta	North Coast	South Egypt	Highlands
Latitude	30.13 °N	31.2 °N	23.97 °N	28.20 °N
Longitude	31.4 °E	29.95 °E	32.78 °E	33.63 °E
Dry-bulb temp.	Min. 13 °C Max. 28 °C	Min. 13 °C Max. 27 °C	Min. 15 °C Max. 34 °C	Min. 18 °C Max. 28 °C
Relative humidity	45 – 68%	64 – 74 %	17 – 45 %	51 - 63 %

A hypothetical open office plan simulated by DesignBuilder software that simulated internally using EnergyPlus. The analysis performed for building forms by comparing the annual energy consumption per square meter. The change in saving percentages always returned to a base case which changes from phase to another depending on the target of the analysis.

The simulation examined 10 different forms which are commonly found in office buildings design, and they are illustrated in Figure 1. All forms facades have openings with 30% WWR. The forms simulated as a prototype of an open office plan building equipped with a full air conditioning system. For all the floor area of forms, the open office plan is limited to 6.25m depth and any excessive space would be turned to a main core. For the difference in the total floor area, all mentioned annual consumption united to the square meter.

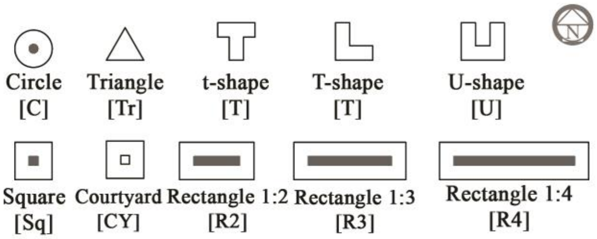

Figure 1: The selected layout of office plan.

The simulation analysis passes within three phases;

- Phase I: Energy performance of "form variations";
- Phase II: Energy performance of "different orientations";
- Phase III: "Architectural design" optimization.

Phase I: it stands on the impact of building different forms on the cooling and heating energy loads. The investigation takes place in four Egyptian cities [Cairo, Alexandria, Aswan, Al Tor].

Phase II: it shows the effect of form orientations on energy consumptions. Eight diverse rotation angles take place with 45° interval clockwise.

Phase III: it targets to achieve forms' optimum design through parametric simulation, an optimization for WWRs and window shading types are ran. These results are followed by study for the optimum number of outer building facades that can decrease energy consumption rates.

Checking different alternatives for fenestrations design for improving forms energy-efficiency to achieve the optimum design for WWRs and shading types. The WWR alternatives vary between 10% to 30% with 5% intervals. Moreover the local shading devices parameter with seven alternatives from no shading to louvers, overhand, and side fins. Figure 2 shows the different alternatives for each phase.

This phase studies the architectural alternatives that are related to the number of exposed building facades, and how to be energy-effiecent in each case. It starts with one exposed facade (north), followed by two facades (north, and east), three exposed facades (north, east, and south), ended with the exposure of whole outer facades.

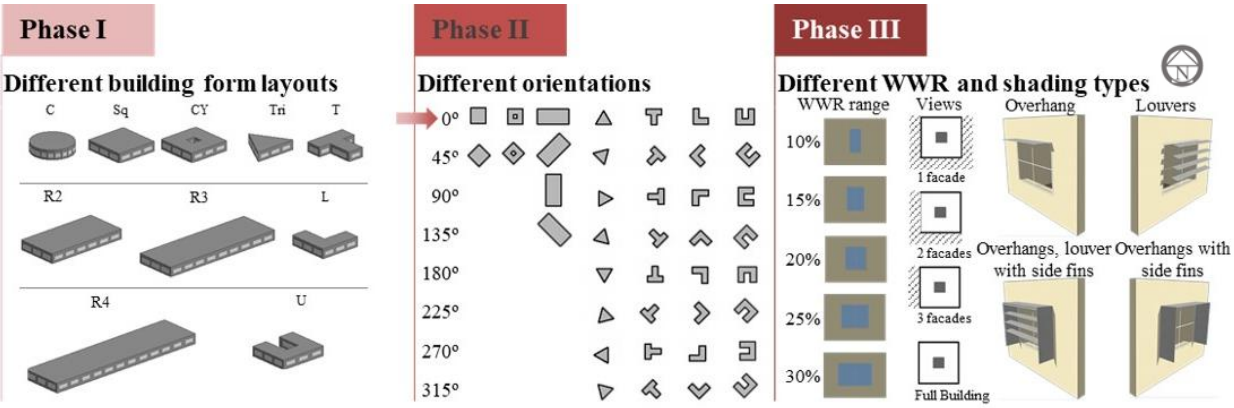

Figure 2: Different alternatives for each phase

DISCUSSION AND RESULTS

The results discussed through phases to stand on the effect of each parameter. In general terms, the results showed that the tested cities have the same energy consumption pattern with differences in the efficiency rates. So, in some phases, the discussion takes into account Cairo city only as a representitive for the rest cities. As it is the capital of Egypt, beside having the enormousnumber of office buildings in Egypt.

Energy performance of "form variations"

For the longitudinal forms showed more efficiency representing in the rectangular form with a ratio of 1:4. While forms as T, U, and L-shapes beside the triangle caused an increase in energy consumptions. Furthermore, the compact forms as square, circle, and courtyard showed balanced energy consumption.

As the ratio of longitudinal of the rectangle increase, the energy demands decrease. R4 could reduce the consumed energy for heating and cooling by a percentage between 13.9%, 15.4%, 16%, and 17.9% in Alexandria, Al Tor, Cairo, and Aswan respectively in comparison with the circle form as shown in Figure 3.

Among the basic forms -as circular, triangular, square, and square court-yard- the square shape consumed the lowest energy, while the triangular had the highest energy consumption due to side inclination to several orientations of its faces.

In comparison with a circular shape, the square achieved a range between 1.2% to 1.7% of energy-efficiency to the tested cities, while the triangular shape consumes energy more than the base case by values around 20.2% to 22.9%. As noticed the energy performance of a circle, square, and courtyard shape were convergent, with a preference for square form.

Energy performance of "different orientations"

Cairo selected to be discussed in detail as a resemble of the Egyptian climate for the pattern similarity in energy performance for office buildings in Egypt.

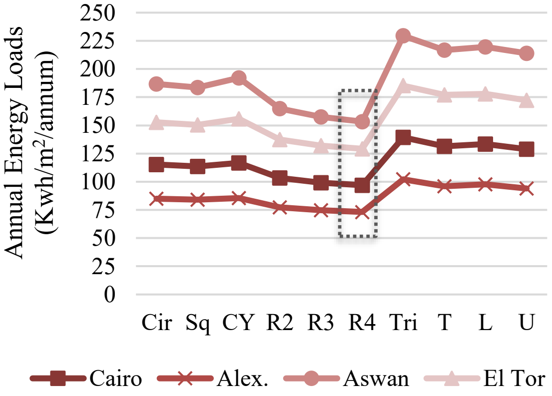

Figure 3: Annual heating and cooling energy consumption for squared meter for tested cities

Orientation plays an important part as it relates to the sun path diagram. Generally, layouts faced the north orientation had the best energy performance with 0° angle for regular shapes as square, courtyard, triangle, and rectangular shapes. While orienting advanced shapes to 90° or 270° had the best performance.

The regular shapes reached an unvarying performance to change in different orientations, as the energy consumption did not exceed 3% between the worst and superlative orientation. Otherwise, longitudinal shapes had sensitivity towards orientations, as the difference exceeded 10% in some cases. A discussion around each form detailed in the following section.

i. **Square, and Courtyard:** courtyards usually thought as a suitable form at hot desert climate, but results showed that it was less efficient than square form for air-conditioned office buildings. Though, Figure 4 showed an increase in consumption of court-yard by 2.5% for cooling and heating loads in comparison with the square. The inclined shapes by 45° consumed more energy for both square and court-yard forms by values 1%, and 1.5% representatively.

And that returns to facing south-east, and west orientations lead to an increase in the solar absorptance period from the sun as many more surfaces facing it for a long time.

ii. **Triangle:** angle 0º and 135º have the best performance for energy consumption as indicated in Figure 5, while the 90º and 315º has the worst performance. This returnes to the increased percentage of exposed wall to solar radiation. Although the reduction in energy loads was not exceeded by 2.5% in annual heating and cooling energy loads. (Figure 5)

iii. **Rectangle:** For all tested rectangle ratios, the north-south orientation (0º angle), it performed efficiently. among all directions. In comparison to the circular form (base case), the rectangulare shapes reduce the energy consumption by 5-10%, 16% for R2, R4 respectively. The worst angle to this shape was the 90º angle as the longitudinal surfaces face the east and west orientation (Figure 6).

iv. **T, L, and U-shaped:** form rotation had minor impact on energy consumption, as the difference between the best and worst orientation was ranging between 2.7%, 3.5%, and 4.6% to T, U, and L-shaped respectively (Figure 7). U-shaped forms had more efficient performance among others. These forms showed effectual performance while they lied towards east or west directions, as the ability to form itself-shading increased against the sun path.

Overall, in hot-arid climates such as Egypt, the linear longitudinal forms held an efficient potential, with the best orientation while facing the north-south for office buildings. This finding relates to the performance of geometries for the residential building (El-Deeb et al., 2012), although the occupants' patterns and air-conditioning needs very differ. Besides, proving the significant role of orientation to longitudinal forms as a rectangle in controlling energy loads of heating and cooling, while having a minor effect in other advanced forms like T, U, and L shapes.

As well as selecting the building form and orientation are not related only to the energy-efficiency, but for other architectural factors like the site location, surrounding urban context, and available views. A further study had been made to reach the optimal energy-efficient case for each form, besides investing in the impact of WWR and shading on enhancing the thermal performance of office building.

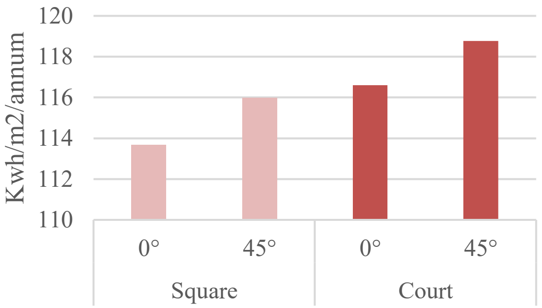

Figure 4: Annual energy consumption of square and courtyard for different rotations angles in Cairo

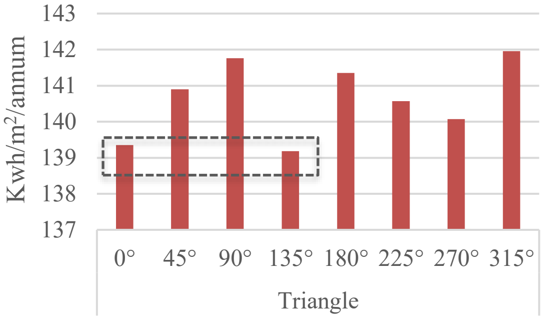

Figure 5: Annual energy consumption of triangle for different rotations angles in Cairo

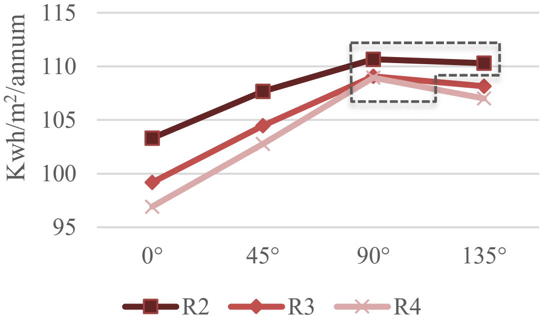

Figure 6: Annual energy consumption of different rectangle ratios for different rotations angles in Cairo

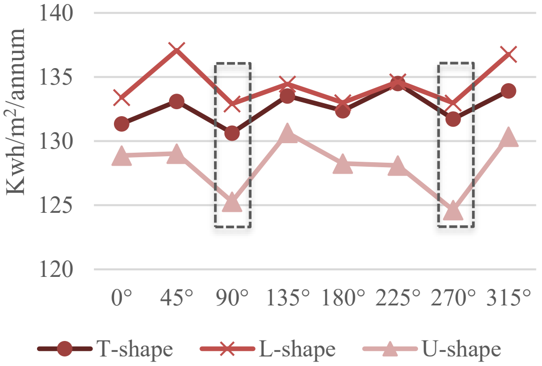

Figure 7: Annual energy consumption of T, L, and U-shaped for different rotation angles in Cairo

“Architectural design” optimization

This phase explores the optimal WWR and local shading devices for selected forms that performed as intensive energy consumption forms. The tested forms are the triangle, T, U and L shapes, with a comparison with R4 form as a base case as this form was the most efficient performance. For this phase, the total energy consumption calculated with the addition of the lighting and equipment’s energy loads. This is for tracing the effect of WWR and for optimization limitations.

The study also examined the role of exposed facades numbers allowed to open windows in.

Selecting the optimal WWR and shading devices have a major impact on controlling the energy loads of internal spaces. As well as the optimization helped the high energy consumption forms to enhance their performance in an efficient way than that of the rectangular shape. Figure 8 shows the saving percentage that reached 25.6% for rectangular form at the time it ranged between 41% to 44.3% for T, U, and L-shaped.

To explore the effect of WWR on energy consumption forms with different view facades numbers simulated by diverse WWRs without shading. Generally, the smallest WWR achieved the least energy consumption cases when the numbers of opened facades are two or more. In the case of one façade with a north orientation, the 10% WWR was not always the prime choice, for the rectangular and T-shape the choice was 15% WWR for allowing efficient performance with a small saving difference. Table 2 shows the saving percentage of each case in comparison to the base case of 30% WWR without shading for each alternative of presence the form in the site.

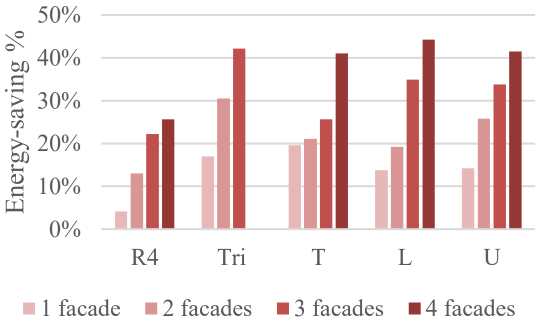

Figure 8: Energy-saving percentage of the optimal design of WWR and shading device

Table 2: Energy-saving percentage of different WWR without shading (base case: 30% without shading)

	WWR%															
WWR	N Façade				N,E Facades				N,E,S Facades				4 Facades			
	10	15	20	25	10	15	20	25	10	15	20	25	10	15	20	25
Rect 1:4	2.6%	3.1%	2.4%	1.3%	5.4%	5.2%	3.7%	2.0%	18.4%	14.0%	9.3%	4.6%	20.8%	15.7%	10.3%	5.1%
L-shape	11.5%	9.9%	6.8%	3.5%	16.4%	13.0%	8.8%	4.3%	27.4%	20.3%	13.3%	6.5%	33.8%	24.5%	15.8%	7.5%
U-shape	10.7%	9.6%	6.8%	3.4%	20.4%	15.4%	10.1%	4.9%	26.0%	19.1%	12.4%	6.0%	31.2%	22.7%	14.6%	7.0%
T-shape	2.7%	3.9%	3.2%	1.8%	17.6%	13.6%	9.0%	4.5%	20.9%	15.8%	10.4%	5.1%	31.3%	22.8%	14.7%	7.0%
Triangle	7.3%	7.5%	5.6%	2.9%	25.0%	19.0%	12.6%	6.3%	32.9%	24.1%	15.5%	7.5%	🟩	The efficient cases		

By including the combined effect of WWR ratios and solar shading devices, the energy-efficiency saving percentage had differed. By controlling window size and supplying suitable shading devices could enhance buildings’ energy-saving, especially those forms with intensive energy consumption as triangle and T-shaped. At the same time, the rectangular shape had a limited effect with these parameters which could not exceed 1.5%.

It noticed that the efficiency of advanced shading systems as “0.5 louvers, overhangs with side fins” had the most efficient energy-saving for all cases, followed by 0.5m overhangs with high WWR (table 4).

For north one view façade, no shading to 10% WWR could count on as optimal design, due to the slight difference in energy-saving percentage that not exceeded 1% to the best-performed shading device. In the case of the best energy performed to design, “0.5 Louver, overhangs with side fins” was the efficient shading device to 20% WWR for rectangle, U, and T-shaped forms, as well as 15% WWR to L-shaped. The exceptional was the triangle form, as the most efficient shading device was the 1 m overhang for 15% WWR.

In the same way, the shading device worked efficiently with 15% WWR to rectangle, L-shaped forms when the view was for two facades (north and east). While the best WWR to U and T-shaped was 10%. Once more, the triangle form had an odd behavior, as the most efficient shading device was the overhang with side fins for 10% WWR.

With the increase, facades expose to the view more than two, the ideal fixed ratio to Window to the wall not to exceed 10% with shading. As beyond this ratio, the internal spaces would expose to over-heating energy during the long heating-period. Table 4 shows the change in energy-saving percentages for all cases by illustrating the preferable shading design of the opening. For further clarification, a simulation for one façade of the advanced forms is examined in the four main orientations to position the suitable WWR ratio. From all the forms, the rectangular layout affected efficiently toward orienting effected its consumption. The suitable direction was toward north or east, to help the building to decrease its total consumption. The presence of 1m louver at the north negatively influenced the performance of all forms except the T-shaped, even it consumed more energy rather than the absence of shading. Furthermore, using 0.5m louver, overhang, with side fins had the best performance among all other shading types, as it allows the maximum lighting without direct sun rays.

Presence of shading devices allowed enlarging the WWR for some form as the U-shaped from 10% to 25% to achieve energy reduction from 13.8% to 21.5% while using at one façade to all the building's facades. Table 3 shows the preferable design alternatives for each form. These alternatives were the acceptable efficiency range, while the highest energy-efficient alternative was always the 0.5 louver, overhang, with side fins for all cases.

Table 3: Preferable WWR and shading design for one viewed façade

Orientation	WWR range	Shading type
	Rectangle 1:4	
North	10% ~30%	No shading
East	20%	0.5m louver
South	25%	1m overhang
West	20%	0.5m louver
	L-shape	
North	15%	0.5m louver
East	10%~20%	1m overhang
South	10% ~15%	0.5m louver
West	10% ~15%	0.5m louver
	U-shape	
North	15%	0.5m louver
	10% ~15%	0.5 overhang
East	10% ~15%	0.5m louver
South	10%~20%	1m overhang
West	10%~15%	1m overhang
	T-shape	
North	10%	0.5m louver
East	10% ~15%	0.5m louver
South	10%	0.5m louver
West	10%	0.5m louver

CONCLUSION

The study revealed the optimized building form and wall design to enhance the energy performance of office building in the hot desert climate. The longitudinal forms were suitable to lower the heating and cooling loads, as a rectangular layout with a ratio of 1: 4 facing north achieved from 14% to 18% energy-saving in the Egyptian cities. While advanced forms as T, U, and L-shapes were intense-energy consumers. Furthermore, the triangle form was the lowest in dealing with energy-efficiency, as its consumption exceeded by 20% compared to the circular shape.

There are additional aspects that can affect building energy performance. Consequently, the result highlighted the role of optimizing the window size, shading devices types, and facades number to introduce better building forms performance. The results showed that by using a complex shading device as "louver, overhang with side fins" even with small WWR there is a need to supply the balance between the lighting and cooling energy. Also, the one-meter overhang had a competitive performance as it came in second place in energy efficiency.

From the energy-efficiency standpoint, the façade needed to decrease the fenestration ratio and increase lighting loads in comparison to cooling loads. And from the same side, the results suggested using one façade with 15% to 20% WWR without shading instead of multiple facades with 10% WWR openings for all forms. This design could reduce the energy-saving from 10% to 16% of energy consumption. On the other hand, the most energy-efficient design of the form in the term of WWRs with the allowed openable façade numbers varied depends on the form, as the difference in energy-saving between the best and worst design was as the following:

- Rectangle 1:4: one opened façade to north saved energy by 27.4%.
- L-shape: three opened-facades saved energy by 46.3%.
- U-shape: two opened-facades saved energy by 43.5%.
- T-shape: one opened-facades saved energy by 43.9%.
- Triangle: two opened facades saved energy by 42.9%.

As the form orientation has a giant impact on energy consumption, also the fenestration design can play a key role. By analyzing building forms in different cases, a significant result showed up. Layout orientation has a great impact on longitudinal forms more than the effect of WWR and shading devices. While advanced forms had a

Table 4: Change in energy-saving percentages for parametric cases of WWR and shading types for different building forms in Cairo

Rectangle 1:4
Window Shading System

	WWR	No Shade	Louver 0.5m	Louver 1m	OV 0.5m	OV 1m	L, OV, Fins 0.5m	OV with Fins 0.5m
N Façade	10	BC	0.1%	-14.9%	0.2%	0.2%	-0.3%	-0.2%
	15	0.5%	1.0%	-14.3%	0.9%	1.1%	1.5%	1.3%
	20	-0.2%	0.7%	-13.2%	0.5%	0.8%	1.5%	0.9%
	25	-1.4%	-0.1%	-6.3%	-0.4%	0.0%	1.0%	0.1%
	30	-2.7%	-1.0%	-6.1%	-1.6%	-0.9%	0.2%	-1.0%
N,E Facades	10	BC	0.4%	-13.3%	0.5%	0.6%	0.3%	0.3%
	15	-0.2%	0.8%	-12.2%	0.7%	1.2%	1.8%	1.2%
	20	-1.7%	0.0%	-10.7%	-0.3%	0.4%	1.5%	0.3%
	25	-3.6%	-1.1%	-5.5%	-1.7%	-0.6%	0.7%	-1.0%
	30	-5.7%	-2.5%	-5.5%	-3.2%	-1.9%	-0.4%	-2.5%
N,E,S Facades	10	BC	2.7%	-4.2%	2.8%	3.8%	4.7%	3.9%
	15	-5.4%	0.0%	-4.2%	-0.5%	1.7%	4.2%	1.4%
	20	-11.1%	-3.2%	-4.9%	-4.2%	-0.9%	2.4%	-2.1%
	25	-16.9%	-6.4%	-5.3%	-8.0%	-3.5%	0.4%	-5.8%
	30	-22.5%	-9.6%	-7.3%	-11.7%	-6.1%	-1.7%	-9.5%
4 Facades	10	BC	3.5%	-1.9%	3.3%	4.6%	6.0%	4.8%
	15	-6.5%	0.1%	-2.5%	-0.9%	1.8%	4.9%	1.3%
	20	-13.2%	-3.7%	-3.8%	-5.4%	-1.3%	2.7%	-3.0%
	25	-19.9%	-7.5%	-4.9%	-9.8%	-4.5%	0.2%	-7.4%
	30	-26.3%	-11.1%	-7.2%	-14.1%	-7.5%	-2.3%	-11.7%

L-shaped
Window Shading System

	WWR	No Shade	Louver 0.5m	Louver 1m	OV 0.5m	OV 1m	L, OV, Fins 0.5m	OV with Fins 0.5m
N Façade	10	BC	0.8%	-10.5%	1.3%	1.4%	0.2%	0.5%
	15	-1.9%	0.9%	-9.5%	0.7%	1.8%	2.5%	1.0%
	20	-5.3%	-0.7%	-8.5%	-1.4%	0.6%	1.9%	-0.9%
	25	-9.1%	-3.0%	-8.0%	-4.1%	-1.3%	0.4%	-3.5%
	30	-13.0%	-5.4%	-8.5%	-6.9%	-3.5%	-1.4%	-6.4%
N,E Facades	10	BC	2.2%	-7.4%	2.3%	3.1%	2.8%	2.1%
	15	-4.1%	0.6%	-6.8%	0.0%	2.0%	3.4%	0.7%
	20	-9.1%	-2.1%	-6.8%	-3.4%	-0.3%	1.8%	-2.6%
	25	-14.4%	-5.4%	-7.5%	-7.2%	-3.1%	-0.4%	-6.4%
	30	-19.6%	-8.8%	-9.0%	-11.0%	-6.0%	-2.9%	-10.2%
N,E,S Facades	10	BC	5.7%	3.2%	5.3%	7.6%	10.4%	7.4%
	15	-9.7%	0.0%	-0.5%	-1.0%	3.1%	7.1%	1.4%
	20	-19.5%	-5.8%	-4.3%	-7.4%	-1.5%	3.3%	-4.9%
	25	-28.8%	-11.3%	-7.8%	-13.5%	-5.8%	-0.4%	-10.9%
	30	-37.7%	-16.4%	-11.5%	-19.2%	-9.8%	-3.9%	-16.7%
4 Facades	10	BC	8.9%	10.2%	7.3%	10.9%	15.8%	10.5%
	15	-14.0%	0.8%	4.9%	-2.2%	4.0%	10.5%	1.2%
	20	-27.2%	-6.8%	0.1%	-11.2%	-2.5%	5.1%	-7.7%
	25	-39.6%	-13.9%	-4.4%	-19.6%	-8.4%	0.1%	-16.1%
	30	-51.0%	-20.4%	-8.6%	-27.2%	-13.7%	-4.4%	-23.8%

T-shaped

	WWR	No Shade	Louver 0.5m	Louver 1m	OV 0.5m	OV 1m	L, OV, Fins 0.5m	OV with Fins 0.5m
N Façade	10	BC	0.1%	-20.2%	0.3%	0.3%	-0.2%	0.0%
	15	1.3%	2.0%	-19.6%	1.9%	2.2%	2.9%	2.6%
	20	0.5%	1.9%	-18.0%	1.6%	2.1%	3.4%	2.4%
	25	-1.0%	1.1%	-15.4%	0.5%	1.2%	2.9%	1.4%
	30	-2.8%	-0.1%	-14.6%	-0.9%	0.1%	2.0%	0.1%
N,E Facades	10	BC	2.2%	-7.9%	2.6%	3.5%	4.2%	3.4%
	15	-4.8%	-0.3%	-8.3%	-0.3%	1.6%	3.8%	1.1%
	20	-10.4%	-3.6%	-8.8%	-4.1%	-1.2%	1.7%	-2.4%
	25	-16.0%	-7.1%	-10.1%	-7.9%	-4.1%	-0.7%	-6.3%
	30	-21.4%	-10.7%	-11.9%	-11.7%	-7.0%	-3.3%	-10.1%
N,E,S Facades	10	BC	3.0%	-5.1%	3.6%	4.7%	6.0%	4.9%
	15	-6.4%	-0.5%	-6.5%	-0.3%	2.1%	4.8%	1.7%
	20	-13.2%	-4.6%	-7.9%	-4.7%	-1.2%	2.4%	-2.7%
	25	-19.9%	-8.9%	-9.9%	-9.1%	-4.5%	-0.4%	-7.1%
	30	-26.4%	-12.9%	-12.3%	-13.4%	-7.6%	-3.3%	-11.4%
4 Facades	10	BC	8.0%	6.8%	7.0%	10.2%	14.1%	9.6%
	15	-12.4%	0.9%	2.8%	-1.2%	4.4%	10.1%	1.8%
	20	-24.2%	-6.0%	-0.8%	-9.1%	-1.3%	5.5%	-6.0%
	25	-35.4%	-12.4%	-4.5%	-16.4%	-6.5%	1.1%	-13.4%
	30	-45.6%	-18.2%	-8.0%	-23.1%	-11.1%	-2.9%	-20.2%

U-shaped

	WWR	No Shade	Louver 0.5m	Louver 1m	OV 0.5m	OV 1m	L, OV, Fins 0.5m	OV with Fins 0.5m
N Façade	10	BC	0.3%	-14.5%	1.1%	0.8%	-0.9%	0.0%
	15	-1.3%	1.6%	-13.6%	1.6%	2.7%	3.3%	2.0%
	20	-4.5%	0.8%	-11.6%	0.1%	2.2%	3.8%	0.7%
	25	-8.2%	-0.8%	-9.8%	-2.2%	1.1%	3.4%	-1.4%
	30	-12.1%	-2.8%	-9.7%	-4.7%	-0.4%	2.2%	-4.0%
N,E Facades	10	BC	4.0%	-8.4%	3.4%	5.2%	6.8%	4.3%
	15	-6.4%	0.4%	-9.3%	-0.8%	2.3%	4.9%	0.5%
	20	-13.0%	-3.5%	-9.9%	-5.4%	-1.1%	2.2%	-4.1%
	25	-19.5%	-7.4%	-10.5%	-9.9%	-4.4%	-0.6%	-8.6%
	30	-25.7%	-11.3%	-12.3%	-14.3%	-7.6%	-3.3%	-13.0%
N,E,S Facades	10	BC	5.7%	-1.9%	5.6%	8.0%	10.6%	7.5%
	15	-9.3%	0.4%	-4.4%	-0.3%	3.9%	7.7%	2.0%
	20	-18.3%	-5.0%	-6.8%	-6.1%	-0.3%	4.3%	-3.8%
	25	-26.9%	-10.1%	-9.2%	-11.5%	-4.2%	1.0%	-9.3%
	30	-35.0%	-14.9%	-12.2%	-16.7%	-7.7%	-2.2%	-14.5%
4 Facades	10	BC	8.4%	4.9%	7.2%	10.7%	14.9%	9.9%
	15	-12.4%	1.3%	1.3%	-1.0%	4.9%	10.6%	2.0%
	20	-24.2%	-5.5%	-2.0%	-8.8%	-0.6%	6.1%	-5.8%
	25	-35.2%	-11.7%	-5.2%	-15.9%	-5.7%	1.8%	-13.0%
	30	-45.4%	-17.5%	-8.7%	-22.5%	-10.2%	-2.1%	-19.7%

	WWR	No Shade	Louver 0.5m	Louver 1m	OV 0.5m	OV 1m	L, OV, Fins 0.5m	OV with Fins 0.5m
N Façade	10	BC	-7.6%	-16.6%	1.0%	0.9%	-9.7%	0.9%
	15	0.2%	-3.6%	-15.3%	2.4%	3.1%	-3.6%	2.4%
	20	-1.9%	-2.4%	-12.7%	1.5%	2.8%	-0.4%	2.3%
	25	-4.7%	-2.9%	-11.0%	-0.4%	1.6%	0.2%	0.7%
	30	-7.9%	-4.0%	-10.1%	-2.6%	0.0%	0.1%	-1.4%
N,E Facades	10	BC	1.3%	-5.1%	4.9%	6.2%	4.4%	7.3%
	15	-8.0%	-2.3%	-7.1%	0.4%	3.3%	4.5%	3.2%
	20	-16.5%	-6.6%	-8.8%	-4.6%	-0.2%	2.9%	-1.3%
	25	-25.0%	-11.1%	-11.3%	-9.6%	-3.7%	0.6%	-6.3%
	30	-33.4%	-15.7%	-13.9%	-14.5%	-7.1%	-2.0%	-11.1%
N,E,S Facades	10	BC	6.2%	5.4%	7.0%	9.6%	13.6%	11.8%
	15	-13.3%	-1.2%	0.9%	-1.6%	3.3%	10.0%	3.6%
	20	-26.1%	-8.3%	-2.9%	-9.9%	-2.6%	5.7%	-4.6%
	25	-38.1%	-15.0%	-6.9%	-17.6%	-8.1%	1.3%	-12.3%
	30	-49.2%	-21.3%	-10.5%	-24.7%	-13.1%	-2.8%	-19.5%

▨ Base Case
🟩 Saving percentage < 4%
🟩 4%<Saving percentage<10%
🟩 Saving percentage >10%

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Optimizing building forms would be a guideline for architects to design an energy-efficient building. The form would have a significant role in reducing heating and cooling loads; also the fenestration design besides many other factors can improve energy performance for the tested shapes that have high values of energy consumption because of their complex form. This study did not offer the main guideline to architects but a deep understanding of how the form, orientation, and shading device type can control building energy performance passively, to decrease the energy needed to get rid of mechanically.

FURTHER STUDIES

Further studies are recommended for studying the relation between Compactness ratio and energy consumption rates in the building, to set the formula that controls the influence of building envelope surface area and its volume on the energy consumption value.

In addition, studying the economic aspect of energy-efficient forms of office buildings helps to find the optimal relationship. This could be discussed by calculating the life cycle cost for energy-efficient forms, in order to achieve a comprehensive evaluation for energy performance.

NOMENCLATURE

A/V	Surface Area to Volume Ration
BC	Base Case
HVAC	Heat, Ventilation, and Air Cooling
WWR	Window to Wall ratio

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