IEREK PRESS
Academic Research Community
http://www.press.ierek.com
ARChive
CrossMark
ISSN (Print: 2537-0154, online: 2537-0162)
International Journal on:
The Academic Research Community Publication
DOI: 10.21625/archive.v2i3.344

Buildings Orientation and its Impact on the Energy Consumption

Rania E. Ashmawy[1], Neveen Y. Azmy[1]
[1] *Faculty of Engineering, Tanta University, Tanta ,Egypt*

Abstract

Nowadays, many countries suffer from severe shortage of energy resources and the inability of saving it. It is necessary to develop an integrated strategy, to make buildings consume less energy and to integrate active and passive design techniques.

Since the building orientation is one of the most important factors affecting energy consumption, this paper addresses the effect of building orientation on the amount of energy consumption within buildings. We employ the simulator "Energy-plus" to estimate energy consumption annually and during critical months in summer and winter. To obtain the best orientation for maximum energy saving, different orientations are tested. It is found that an air-conditioned building that has a southern facade consumes less energy. However, a western facade causes higher annual energy consumption by 26% over the southern facade. In the case of a two-facade building, the lowest energy consumption is obtained between the northern and southern orientations in Cairo, Egypt.

Keywords

Buildings orientation; Active techniques; Energy consumption; Cairo; Passive techniques

1. Introduction

Energy represents a major component in any country's economy and hence it affects the world's economy. Saving energy consumption, especially in buildings, directly affects national economy. The shortage in the traditional energy sources and the early stages in using the renewable energy sources motivated the design of energy saving buildings. Many design treatments are developed to achieve energy saving. These treatments are targeted to enhance the thermal performance of the building shell e.g. walls, ceilings, floors, and openings (Marszal, Heiselberg, Bourrelle, Musall, Voss, Sartori, & Napolitano, 2011). Many studies have tried to reveal the effect of the building shell components and its orientation on energy usage efficiency (Pai, 2015). Many passive and active strategies for energy saving are employed to enhance the efficiency of cooling, warming, ventilation and lighting (Sadineni, Madala, & Boehm, 2011).

The effect of building shell improvement on the of energy consumption efficiency is extensively studied. This includes the techniques for thermal insulation for walls and ceilings and the techniques for openings shading, the type of glazing, and the window-wall ratio (WWR). In addition, the building orientation was subject to many experiments, especially in cold regions.

This paper focuses the effect of building orientation on the amount of consumed energy. This is important as the orientation is a basic factor that affects the exposure to sun radiations and hence the thermal acquisition, ventilation and lighting. The amount of consumed energy in a hot dry climate is calculated for the different orientations annually and during critical months in winter and summer. The building is modeled and its orientation is changed by 15 degrees to calculate energy consumption every 15 degree including the basic orientations (north – south – east –west). The study area adopted is Cairo, which is the capital of Egypt.

1.1. Objectives

This research objective is to obtain the building orientation that provides the maximum reduction of energy consumption, while achieving the thermal comfort, and attaining the window wall ratio 20%, according to the Egyptian code of energy, to find the optimum orientation that achieves lower thermal loads and less energy consumption for months.

1.2. Research Methodology

The methodology is based on the study of energy problem, its causes and their impacts on the buildings sector. In addition, we discuss different strategies and architectural solutions to reduce energy consumption in buildings. The study of the effect of buildings' orientations on reduction of energy consumption is achieved by using the simulation program "Energy plus". The impact of different orientations on the study model is calculated every 15 degrees. The selected study area is the city of Cairo, Egypt. The consumed energy in summer and winter is monitored to get the optimum orientation for achieving lower energy consumptions inside the building. The energy consumed in summer and winter is measured during the critical months and is annually measured.

2. The Energy Problem

At the beginning of the new century and the fall of the global economy and with lower global energy indicators, it was necessary to pay attention to the energy problem because it would represent a radical part of our daily lives. Moreover, our dependence on traditional energy increases every day, especially with the massive technological progress, which increases our energy needs. It is known that buildings constitute nearly half of global energy and local consumption. The high-energy consumption in buildings is due to the use of separate glass facades in our environment besides the increased dependence on mechanical methods instead of dependence on the most suitable designs. Due to separation from our environment, it was necessary to establish new rules for the formation of our lives and to rationalize the consumption of non-renewable energy. It should be a trend to find a strategy to take advantage of the natural energies that is abundant in the Arab world, such as solar energy and wind energy. Solar energy stands as the best choice for consumption in comparison to other forms of energy. However, the challenges facing this system are seen in the difficulty of covering the needs of big cities and supplying energy for longer periods of time. These challenges push us to seek energy-saving architectural designs that depend on its structure to improve the building design performance in manner that makes it an energy-saver. If integrating it with renewable energy structure, it will become a low energy consumption building (Pérez-Lombard, Ortiz, & Pout, 2008). Research has focused on studying the strategies that work to reduce energy consumption by controlling the building envelope as shown by the following.

3. Energy Reduction Strategies for the Building Envelope (Algohary, 2002).

Reducing energy consumption inside a building depends on the passive and active techniques as in Figures (1), (2) (Ashmawy, 2015).

The figures show solar passive and active technologies that through their integration, low energy building can be achieved (Givoni, 1991). However, because of the high cost of the active techniques, which rely on energy generation inside the building, this research deals with passive solar technologies that can be employed for the building design and operation. Passive strategies for building design and processing help to avoid heat gain and to reduce cooling loads. This leads to reducing energy consumption in summer and winter periods and along the entire year, and provides a range of thermal comfort for users in addition to reducing dependence on mechanical means.

4. Passive Solar Strategies for Energy Consumption Reduction ”Building Design”

Passive solar strategies and techniques depend on building design, orientation, efficiency of its outer envelope, and treating roofs, openings and outer walls. This helps controlling the consumed energy and achieving thermal comfort. The following discussion will explain this (Paul, 2001).

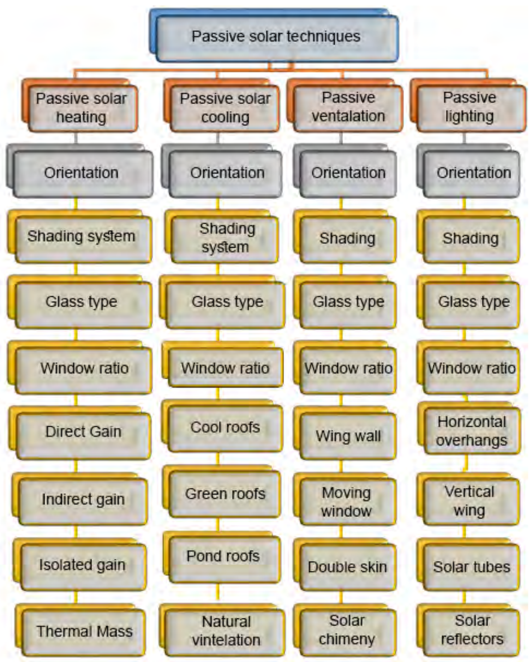


Figure 1. Passive solar strategies to reduce energy consumption inside buildings (Ashmawy, 2015).

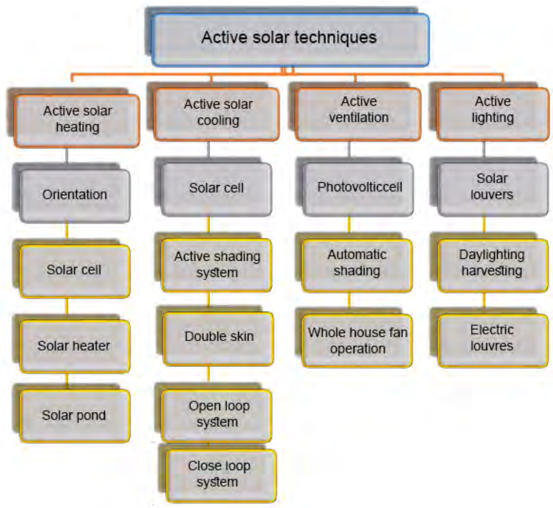


Figure 2. activesolar strategies to reduce energy consumption inside buildings (Ashmawy, 2015).

4.1. Orientation of the Building

Building orientation represents the relation between its elevations and the original geographical direction. In design process, it is important to consider the actual quantity of solar radiation on the facades of a building as a whole, as it affects the thermal load of the building and controls the thermal behavior and the amount of thermal comfort of the space (Morrissey, Moore & Horne, 2011). In addition, it affects the quantity of ventilation crossing inside the building, which in turn affects the quantity of energy consumed in it to achieve the thermal and life requirements.

4.2. The Window Wall Ratio

Windows are openings, which represent the weak areas in the outer envelope of the building, where the building is susceptible to the highest intensity of radiation through the opening, which means that it allows the entry of solar radiation to insider spaces. Therefore, handling the windows has an effective role in reducing the thermal loads inside the building. Ratio of windows in the facades varies according to its orientation. The thermal load on the facades of the building varies from one direction to another direction according to the movement of the sun in summer and winter, which requires the reduction of windows in a specific area of facades and increase them in certain facades (Goia, 2016).

4.3. The Glass Thickness

Glass is one of the important determinants of openings; it is the means of transmission of light rays into the inner spaces. When the solar radiation is incident on the surface of the glass, a portion of it enters the space and absorbed, and the glass material absorbs another portion and the rest is reflected outside the space. The reflected part depends on the angle of the incidence of the solar radiation; either absorbed part will transfer via convection and conduction properties of the materials (Vanhoutteghem, Skarning, Hviid & Svendsen, 2015).

4.4. Shading System

A shading system is the means used for treating the different openings for significantly reducing the acquisition of heat into the building through them. In addition, it improves the quality of natural lighting in the spaces, depending on the number and location of windows. Also, it contributes to improving the convenience of users visually and thermally by reducing glare and the thermal acquisition, in addition to controlling the natural ventilation (David, Donn, Garde, & Lenoir, 2011).

4.5. Thermal Insulation

Thermal insulation is used to reduce heat transfer from outside to inside and vice versa. Studies indicate that the heat transmitted through walls and ceilings in the summer is approximately 60-70% of the heat removed by air conditioning. The rest comes from the windows and air vents, and requires that electrical energy consumption of up to 66% of total energy consumption. Therefore, we must use heat-insulating materials that reduce the influx and the flow of heat through the various structural elements and thus help in the rationalization of electricity consumed in the summer cooling and winter heating (Eben Saleh, 1990).

5. Different Orientation Patterns and Their Impact on Reducing Energy and Achieve Thermal Comfort (Shick, 2009)

Building orientation and openings play an important role in achieving thermal comfort and reduction of energy consumed in cooling, heating, lighting, or any other purposes. It is found that many studies prefer to take the building longitudinal direction axis along the East-West direction, so that the southern facade takes the largest amount of the heat in the cold period as the north façade takes less amount in extremely hot period, depending on the azimuth and elevation angles of the sun in summer and winter.

Therefore, this research paper studies the different orientations and their impact on reducing energy consumption to reach the best orientation that achieves greater thermal comfort and makes full use of lighting and natural ventilation. This is reflected in reduction of energy consumption in buildings. The energy consumption is studied and modeled for every 15 degrees from the north to the south over a year as shown below.

6. The Applied Study

The EnergyPlus™ simulation program is used to study the effect of orientation on energy consumption of the model every 15 degrees. The amount of energy consumed per year is monitored to report the change during the critical months in the summer and winter and to find the loads affecting the consumption rates.

6.1. Simulation Tool Description

The EnergyPlus™ simulator is an energy simulation program for building to model both energy consumption for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings. A full list of its capabilities can be found in (EnergyPlus).

The developers of EnergyPlus test it using industry standard methods. The goal is to assure reliable and accurate results as possible. It is subject to analytical tests such as HVAC tests, based on ASHRAE Research Project 865 and building fabric tests, and is based on ASHRAE Research Project 1052. It is also subject to comparative tests such as ANSI/ASHRAE Standard 140-2011, EnergyPlus HVAC Component Comparative tests and EnergyPlus Global Heat Balance tests (EnergyPlus). Overall, the results of EnergyPlus compared very closely with the analytical results obtained from the ASHRAE 1052-RP Toolkit. In a study by Anđelković, Mujan, & Dakić (2016) an experimental validation test for EnergyPlus shows that simulation results are very close to the measurements in the experiment proposed throughout it. Hence, the EnergyPlus can be considered a reliable simulation tool.

6.2. The Study Model

Buildings consume approximately 45% of the total energy consumption in any country. Therefore, when developing a strategy to reduce energy, buildings sector should be taken into account to reduce energy consumption in it. Therefore, many countries today seek how to realize the principle of energy-saving and low-energy buildings by the year 2020. This target motivated the choice of the research study model that is selected for the study, which is a room with a bathroom as an extension. Such a unit is the core for most of the buildings used by individuals of residential buildings and hotels buildings.

The room-area is (7.2 x 3.6) square meters (m2). A bathroom of area (2.4 x 2.4) squared meters is appended to that room. The room is painted using white color. The height of them is 3.3 meters. It includes one window as shown in Figure (3). The window is square shaped with size of (1.9x1.9) squared meters i.e. 3.6 square meters. The glazing is a one layer transparent glass of thickness 3 mm. Its lattice has total solar permeability of 0.64 and 0.9 photovoltaic permeability. This glazing specification represents the quality and type of the commonly used glass in Egypt.

The details of the structural components of the selected room and the determinants of key elements used, which are installed within the environmental simulation program, are found in table (1). Note that the layers of structural elements are arranged from the inside outside. It is assumed that the building is fully air-conditioned throughout the day and it is not allowed to open windows and there is full dependence on the air supply in accordance with the air-conditioning system.

This assumption is important for rooms, especially for hotels in Egypt, as the climate is very hot in summer and cold in winter. This necessitates the existence of air conditioners to achieve the thermal comfort for residents.

Table 1: Research sample characteristics

Room Dimensions				Bed room (3.6*7.2) m^2 Height (3.3 m)
Window area				3.6 m^2
Heating and cooling systems			Cooling critical point	23
			Heating critical point	21
			The type	Heating and ventilation ducted supply + extract
Lighting			Intensity of illumination	300 lux
			The type	Bulbs Vrusnt (closed)
			Lighting control	Linear
Layersof the building envelope	U-value (w\m 2-k)	0.704	Exterior wall	Whites perlite plaster board 2 cm + Cement \plaster\mortar-cement 2 cm + brick wall thickness of 25 cm + Cement \plaster\mortar-cement 2 cm + Plastic paint white color 2 cm.
		0.662	Interior wall	Whites perlite plaster board 2 cm + Cement \plaster\mortar-cement 2 cm + brick wall thickness of 12 cm + Cement \plaster\mortar-cement 2 cm + Plastic paint white color 2 cm.
		0.662	Bathroom wall	Ceramic 2 cm+ Cement \mortar-cement 2 cm + brick wall thickness of 12 cm + plastic paint thickness of 2 cm
		0.658	Ground	Carpets 1 cm + Ceramics Port Celine 2 cm + mortar thickness of 2 cm + Sand settlement 4 cm + reinforced concrete 12 cm + 3 cm thickness of the epithelium layer + Plastic paint white color 2 cm
		0.658	celling	Slanting slab 2 cm + mortar 2 cm + Sand settlement 4 cm + Concrete 7 cm + isolate moisture 2 cm + heat isolating 2 cm + reinforced concrete 12 cm + Plastic paint white color 2 cm.
Room - Painting color				Wight
Window ratio				%30
Glass Type				Transparent glass Single (thickness = 3 mm)

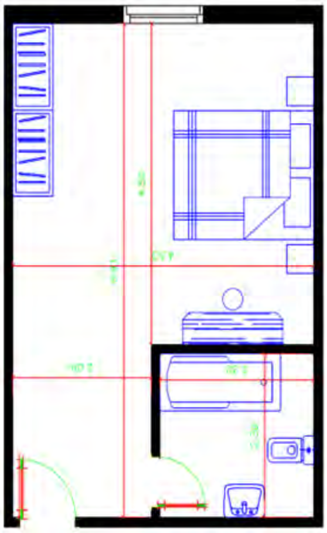


Figure 3. model under

Thermal characteristics of the study area (Hasanin, 2000).

The city of Cairo lies on the sides of Nile River Islands in the north of Egypt directly southeast of the point where the river leaves its limits in the desert and becomes two branches in low-Delta region. It represents the highest populated city in Egypt and it is characterized by climatic characteristics of this region. Cairo climate is characterized by high temperature during the summer months and cold during the winter months. The average daily range of temperature in the month of July (summer) is between 37 °C and 21 ° C, while the average daily range during the month of January (winter) is between 17 ° C and 6 °C. Solar glare rates in Cairo reach a maximum of 95% in summer, while in December the glare rates in winter are about 60% as shown in table (2).

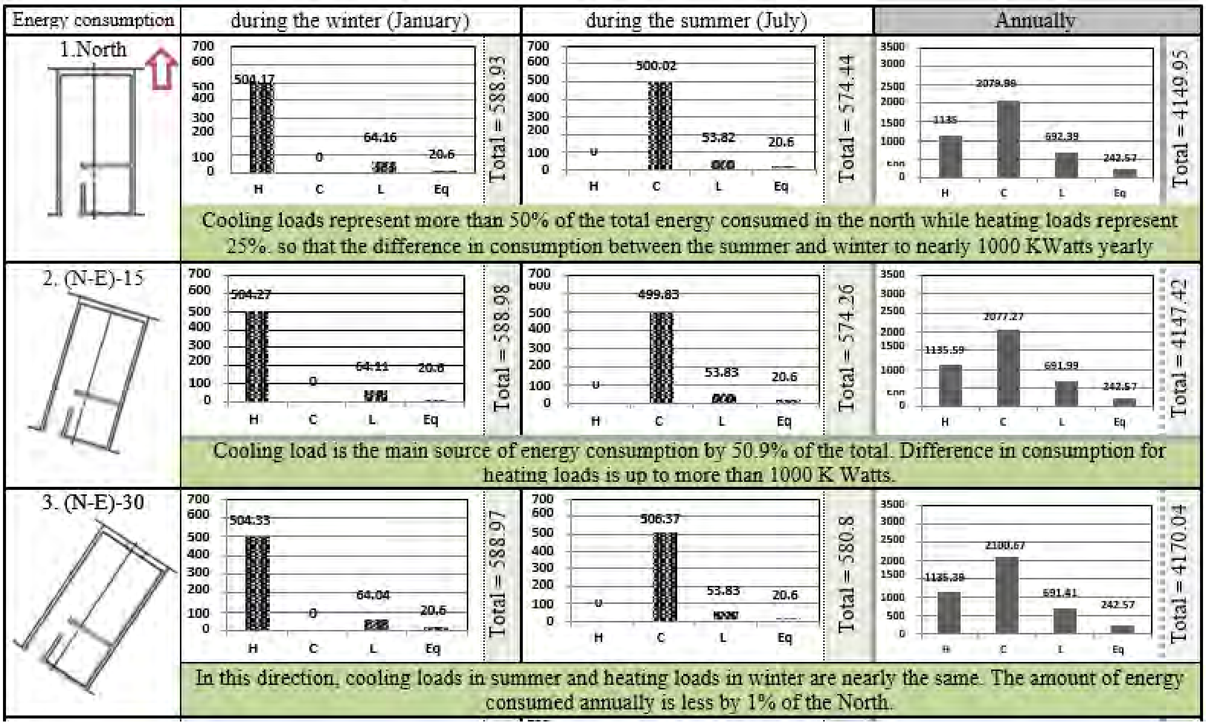
Table 2: Climate Zone characteristics

	Longitude:			***31.40***
	Latitude:			*30.13*
	Elevation above sea level			*47m*
Sky Cover Range	*Clear sky, cloudy during the winter*			
Solar Radiation	*Exposure to direct solar radiation is strong and the proportion of high surfaces in the summer*			
Temperature	**Average high**		**average low**	
	Summer	**winter**	**summer**	***Winter***
	37	27	21	*8*
Relative Humidity	*Relative humidity is relatively high and swinging between 50-70%*			
Rain Range	*rainfall Fall limited amounts during the winter months as a result of coming under blowing air decreases coming from the west to the east*			
Wind Wheel	*Cairo sometimes exposed to the Khamaseen winds during the period between March and June*			

6.3. Analysis of the Energy Consumed in Different Directions

Using the simulation program ”EnergyPlus”, the energy consumption has been studied and analyzed for the model every 15 degrees for Cairo Region throughout a year and during the summer and winter months as shown in table (3,4,5,6) (H: Heating , C:Cooling , L:Lighting , Eq :Equipment) .

Table 3: Analysis of energy consumption in the directions (north + northeast) annually and during the summer and winter



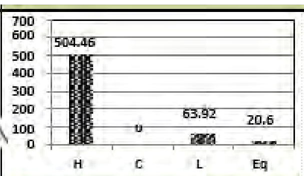
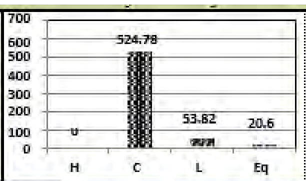
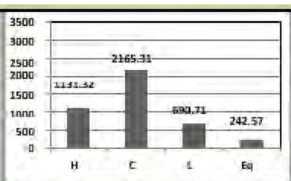
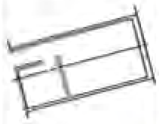
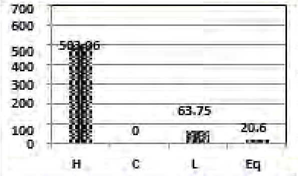
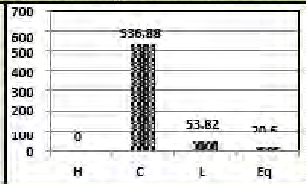
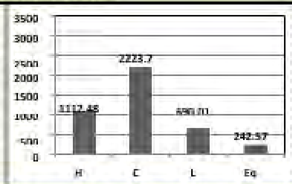
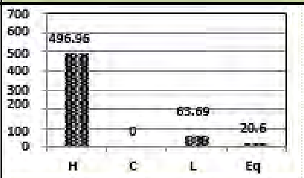
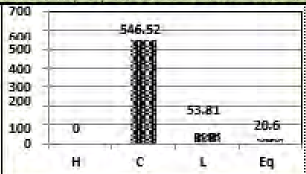
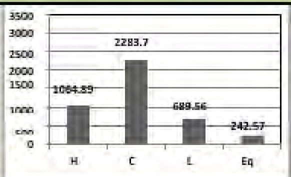
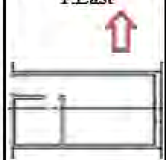
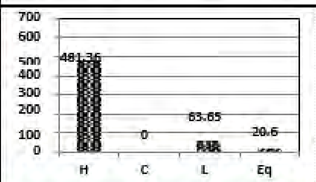
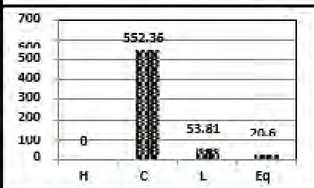
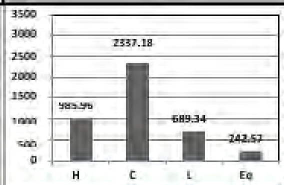
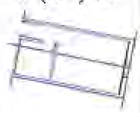
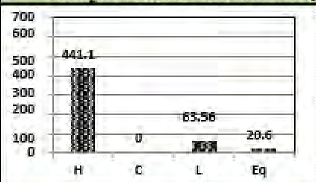
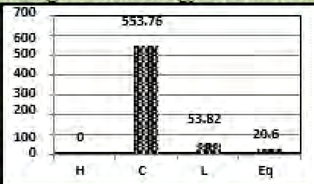
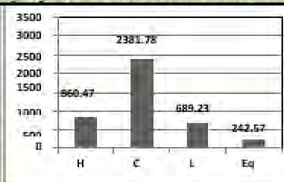
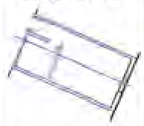
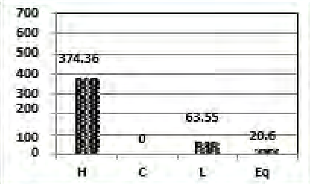
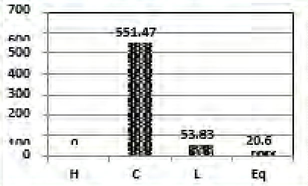
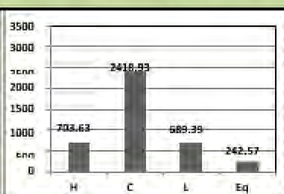
4. (N-E)- 45 		Total = 588.98		Total = 599.2		Total = 4229.91
	Heating loads in this direction nearly equal heating loads in the north. Cooling loads increased by 5% over the north. the total annual energy consumed is 2% more than the North.					
5. (N-E)-60 		Total = 587.41		Total = 611.3		Total = 4268.76
	An increased cooling load by 7.4% compared to the north is noticed, which increases the total energy consumed annually by about 3% from the north.					
6. (N-E)-75 		Total = 581.25		Total = 620.93		Total = 4280.72
	Heating loads slightly decreases from the north, while cooling load increases in summer by 9% from the north. total annual energy consumed increases by 3.1% over North.					

Table 4: Analysis of energy consumption in the directions (east + southeast) annually and during the summer and winter months

Energy consumption	during the winter (January)		during the summer (July)		Annually	
1.East 		Total = 565.61		Total = 626.77		**Total= 4255.05**
	Heating loads for the East decreases by 4% below the north , while cooling loads increases in summer by 10.5% compared to the north. Hence, increasing the total energy consumed annually by about 2.5% of the North.					
2. (S-E)-75 		**Total = 525.26**		Total = 628.18		**Total= 4174.05**
	Annual energy consumption is reduced in the direction of 75 degrees with the South East by 1.9% compared to the eastern direction.					
3. (S-E)-60 		Total = 458.51		Total = 625.9		**Total= 4054.52**
	In this direction heating loads decreases by 22% below the east direction, while cooling load converge to that of the East. The annual energy consumption decrease of 4.7% compared to the east.					

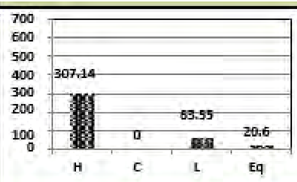
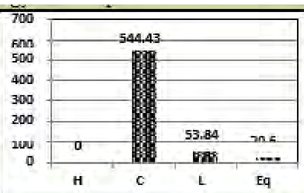
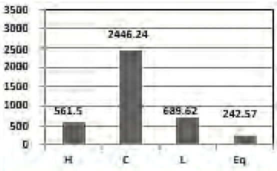
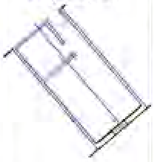
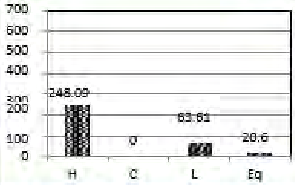
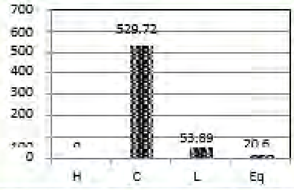
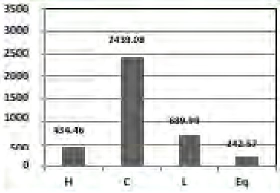
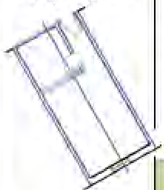
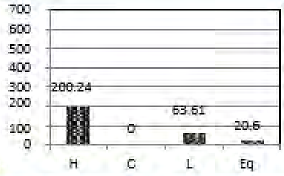
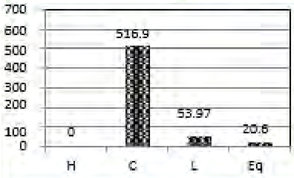
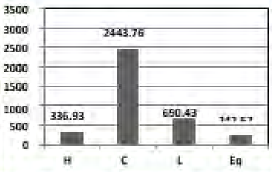
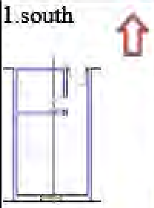
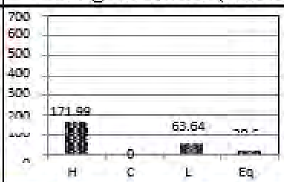
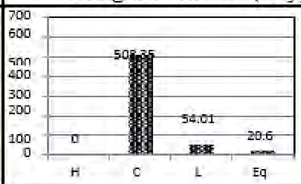
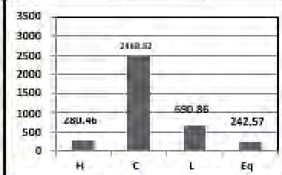
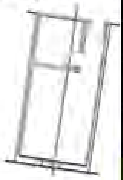
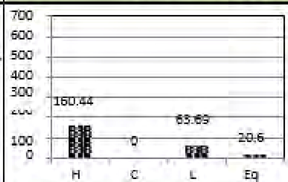
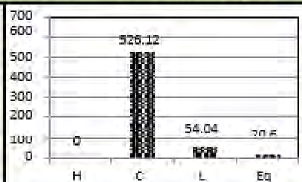
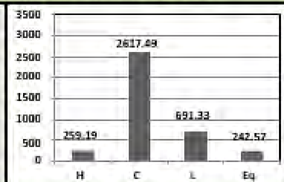
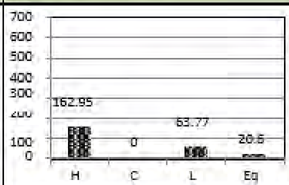
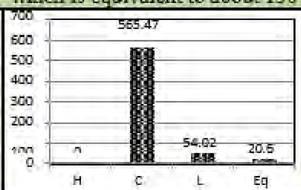
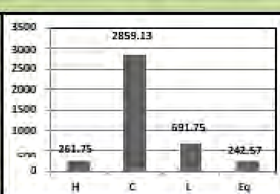
4. (S-E)- 45 		Total = 391.29		Total = 618.87		Total= 3939.93
	the direction 45 with the south-east introduces a decreases in heating loads by 36% as compared to the East, and annual energy consumption is reduced 7.5% from the East.					
5. (S-E)-30 		Total = 332.3		Total = 604.21		Total= 3806.1
	A decrease of heating loads in the direction 30 with the south-east by 48% as compared to East, and annual energy consumption is reduced 10.5% from the East.					
6. (S-E)-15 		Total = 284.45		Total = 591.47		Total= 3713.69
	The direction 15 with the south-east causes a Decreases in heating loads by 58% from the East, and the annual energy consumption is reduced by 12.7% from the East.					

Table 5: Analysis of energy consumption in the directions (east + southeast) annually and during the summer and winter months

Energy consumption	during the winter (January)		during the summer (July)		Annually	
1.south 		Total = 256.23		Total =582.96		Total=3682.71
	This orientation represents more reduction in energy consumption, as it decreases the heating loads by 75% of the north, and by 71.5% of heating loads of the east. cooling loads increase by 18.7% of the North and 5.6% of the east.					
2. (S-w)-15 		Total = 244.73		Total = 600.76		Total= 3810.58
	Heating loads go down in this direction from the South by 7.5%, while cooling loads increase by 6% of the south which is equivalent to about 130 kW.					
3. (S-w)-30 		Total =247.32		Total = 640.09		Total= 4055.2
	The energy consumed in cooling represents 70.6% annually in this direction from the south which represents an increase by 16%. heating loads are still low as for the south.					

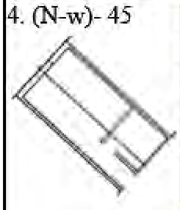
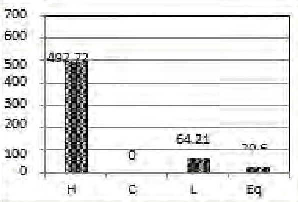
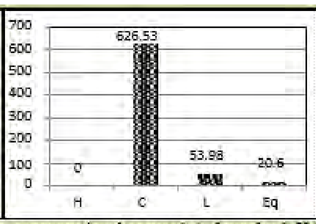
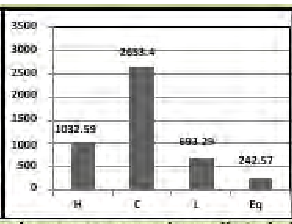
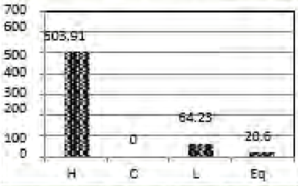
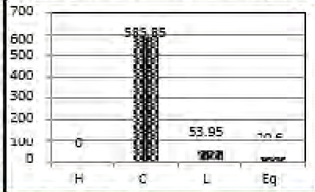
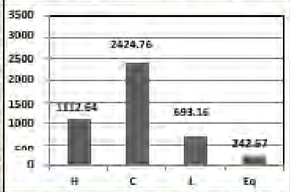
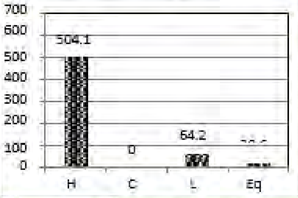
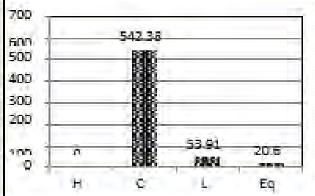
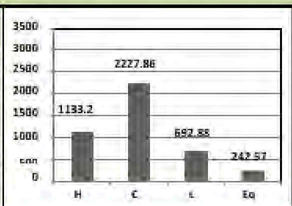
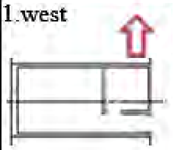
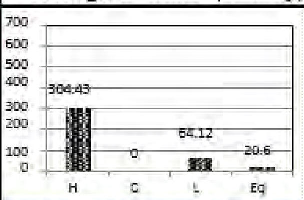
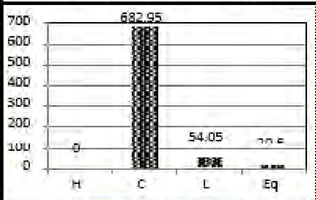
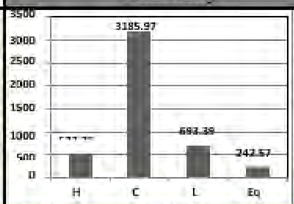
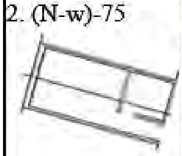
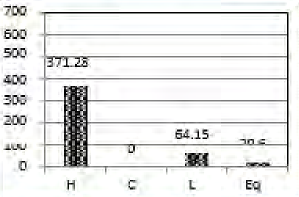
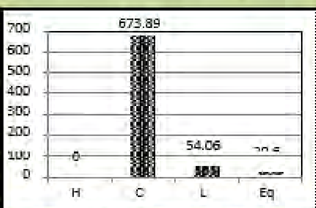
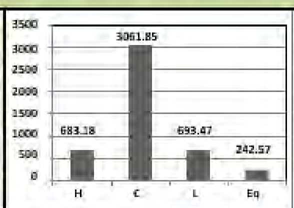
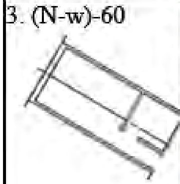
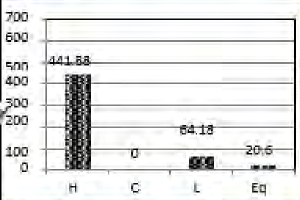
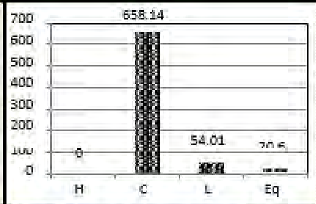
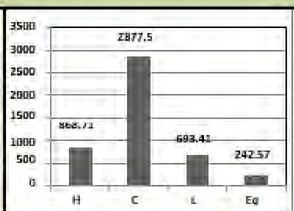
4. (N-w)- 45 		Total = 577.53		Total = 701.11		Total= 4621.85
	The direction 45 northwest is the top in energy consumption, because it is down by 0.5% from the energy consumed annually in the West.					
5. (N-w)-30 		Total = 588.74		Total = 660.4		Total= 4473.13
	Cooling load reduced by 24% from the West. Cooling load is more than twice the heating loads consumed annually in this direction, while heating loads increase from the West as we head north.					
6. (N-w)-15 		Total = 588.9		Total = 616.89		Total= 4296.51
	the amount of energy consumed annually decreases in this direction by 8% from the West. Reduced cooling loads is noticed which represents twice the heating loads consuming 30% annually for the cooling load in the direction of the west.					

Table 6: Analysis of energy consumption in the directions (west + northwest) annually and during the summer and winter months

Energy consumption	during the winter (January)		during the summer (July)		Annually	
1.west 		Total = 389.15		Total = 757.6		Total=4649.69
	the value of the energy consumed increases in this orientation over other directions. Cooling loads in the West increase by 53% from the north, and by 28% from the south, as heating loads increase by 88% from the south, and energy consumption increases more than 1,000 kilowatts for the south.					
2. (N-w)-75 		Total = 456.03		Total= 752.14		Total= 4681.07
	Increasing the annual energy consumed value. Heating loads from the West increase by 29%, cooling load is less than 4% for the West.					
3. (N-w)-60 		Total = 526.66		Total = 732.75		Total= 4682.19
	Energy consumed annually reaches the highest level in this direction. Heating loads increase by 64% from the West, cooling load goes down less than 10% from the West.					

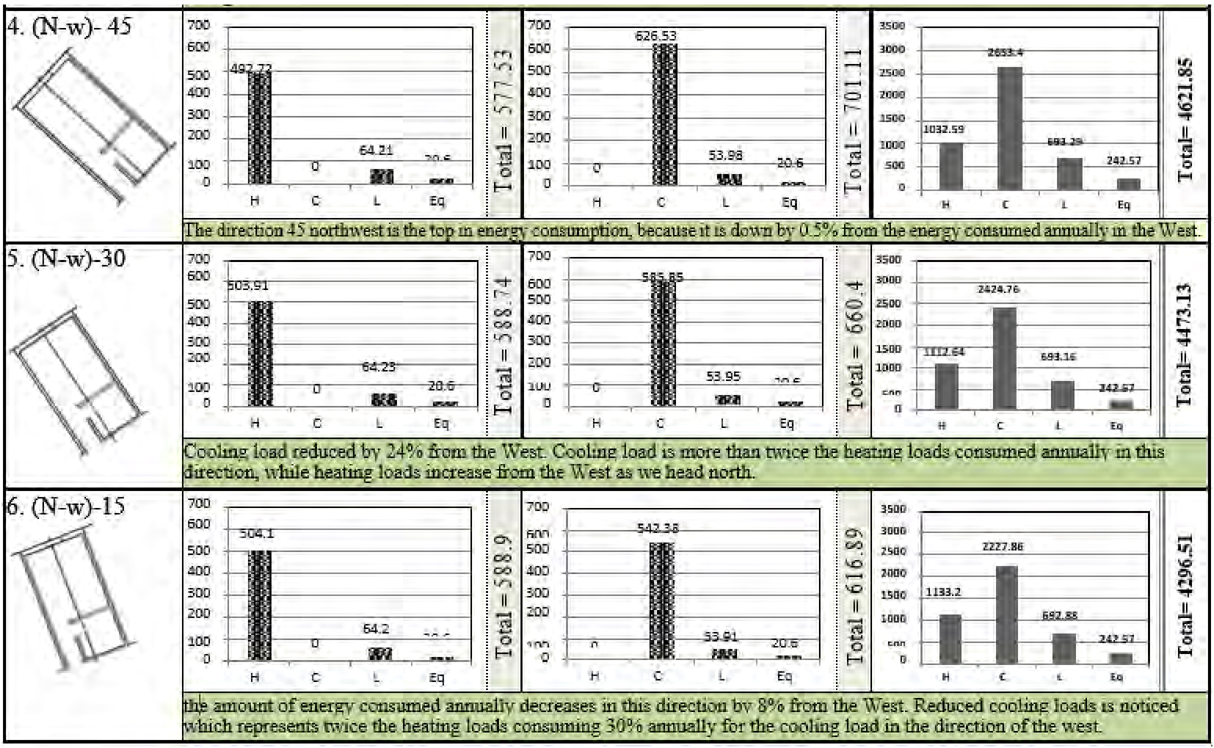


Figure (4) summarizes the results of estimation for the interior energy consumed in heating, cooling and lighting loads in summer, winter and all over the year for different directions that spaced by 15 degrees.

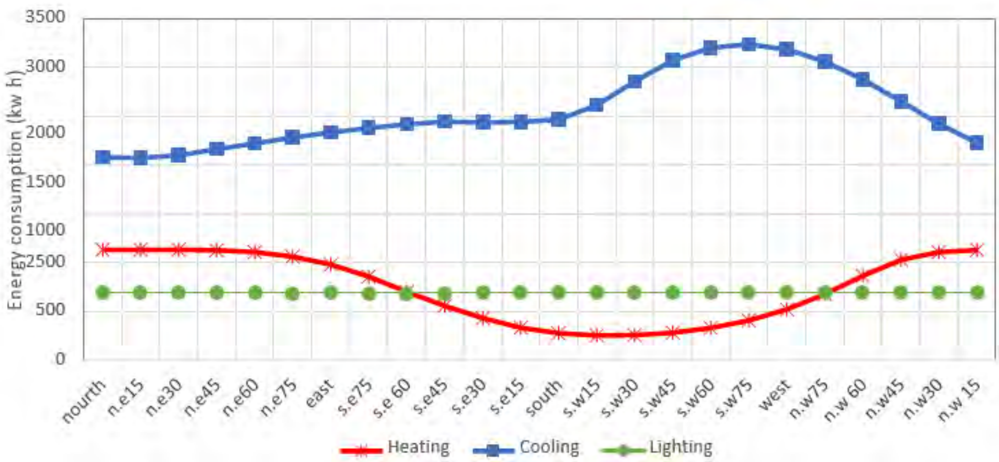


Figure 4. Total energy consumed annually in the cooling, heating and lighting in different directions

It shows that lighting loads are almost constant in most of the orientations. Heating and cooling loads are fully responsible for the energy consumed at different orientations. Moreover, most of the energy consumed is for cooling, which is the main source of energy consumption in Egypt and the study area. It represents folds of heating loads around the southern and western orientations. Up to half of the energy consumed in cooling is consumed for heating annually in the northern direction and orientation slanted especially toward east.

The figure shows also that north orientation and (North + East) at angles of 15 and 30 degrees with the north represent the orientation for the least energy consumed in the cooling load per year, while the heating loads per year increase. The orientations of south especially the (South + West) at an angle of 15 and 30 degrees with the south introduce the least heating loads.

The western direction and (South + West) at angles of 75.60 with South, the orientation for highest energy consumption in cooling affects the total energy consumed annually in these directions.

Figure (5) shows how much energy that annually consumed in different directions every 15 degrees, which is measured using the Energy plus program.

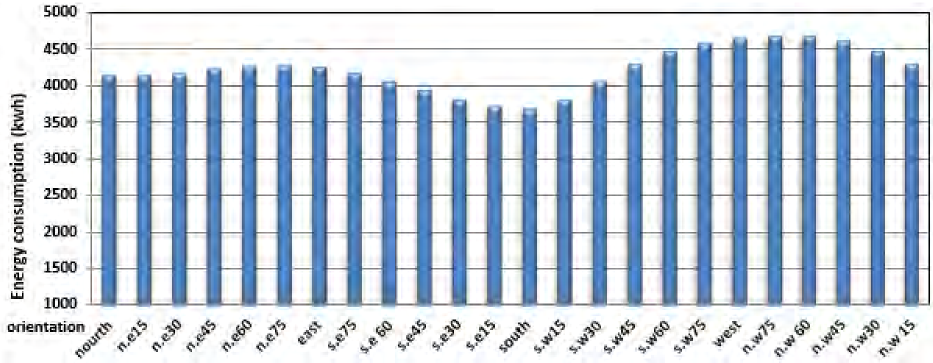


Figure 5. Total energy consumption per year in different directions

It was found that the total energy consumed annually in the simulated room (study model), reaches a lower level when the room is in the direction of the south (3636.35 kW / h per year), followed by the direction South-East oblique angle 15 with the South (3661.41 kW / Q). When the room is directed towards the north - west at an angle 60 with the North the energy consumption becomes (4590.2 kw / h), which represents the highest level of annual consumption. This means that the southern façade, without any processors, gives less annual consumption of energy, so as to their role in achieving warm during the winter months, in addition to the fact that the east-south direction makes the energy consumed in the summer significantly less than that in the south-west orientation.

It was observed that the maximum percentage reduction in the energy of the room consumption in different directions up to about 26% from the maximum value which is about (1000 kW). To reach the best direction for the rooms of the building and openings in terms of energy consumption, the following is measured

– The energy consumed in every two opposite facades.
– Total energy consumption for a group of adjacent rooms that consists of the basic simulated room as a building unit.

This allows finding how the impact of opposite facades on the amount of energy consumed, as well as to know the amount of energy that is reduced in the case of repetitive room construction.

6.4. Analysis of the Energy Consumed in Every Two Opposite Facades

Because in urban planning, resort buildings face to achieve parallel road networks, we collect the energy consumed in all every two opposite interfaces to reach the best two opposite interfaces for reducing energy consumption, as shown in Figure (6).

It was found that the buildings with opposite facades that are oriented at (north - south) represent the maximum reduction in energy consumption. The facades at (northeast - southwest) at an angle of 15 degrees and (northwest - southeast) at an angle of 15, caused an increase by 1.6% over the (north - south) orientation. Moreover, the energy consumption increases by nearly 5% over the north-south orientation, for the facades at (northeast + south-west) at an angle 30 and (northwest - southeast) at an angle 30. Interfaces with oblique angle of 45 represent the worst facades, as the energy consumption is over 8.8% of the energy consumption by (North + South) direction.

When the facades (East + West) are monitored, it is found that the energy consumption significantly increased. Energy consumption increases up to 13.7% over that for the facades (North - South). This confirms that the facades in the direction (East - West) suffer from an increase in the annual consumption to achieve the requirements of cooling, heating and lighting.

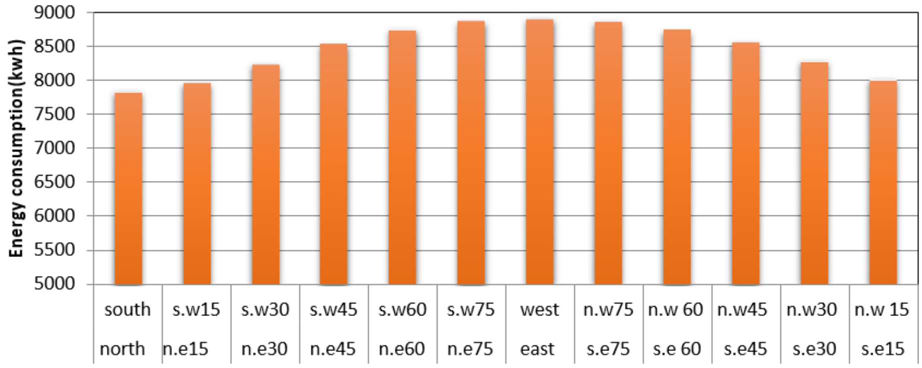


Figure 6. Total energy consumption in all two interfaces opposite annually

6.5. The Study of Consumed Energy for Adjacent Chain of Rooms that Built Using the Core Room Model

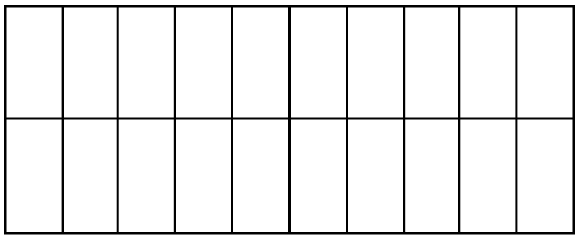


Figure 7. The compound model for the study model

To evaluate the impact of orientation on energy consumed within a whole building, the annual energy consumption for a model combines 20 units (modeled rooms); each 10 units constitute a façade as shown in Figure (7). The direction of the combination is then changed by 15 degrees to calculate the annual energy consumption for all directions. The results of this experiment are shown in Figure (8), which depicts the compound model by examining these figures, interesting results can be found. For the rooms chain model, the orientation (North-South) causes a decrease of the annual energy consumed to about 8577 KW as compared to orientation (East-West), which is equivalent to about 9% of the total energy consumed annually.

Economically, and in terms of electric power prices according to Egyptian tariff, the reduction in annual energy consumption price in the direction (North-South) compared to the direction (East-West) is about 13%, which is equivalent to more than (3000 EGP) per floor of this model.

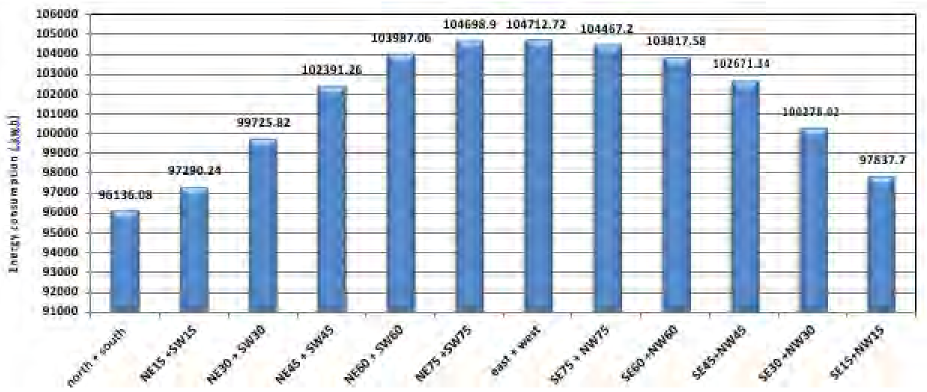


Figure 8. Total energy consumption of the model compound annually in different directions

In case of the 15 degrees obliqueness with the (North-South) toward east, the increase of annual energy consumption does not exceed the (North-South) direction by more than 1.2%. When this 15-degree obliqueness is with west, the consumption increases by 1.7% as compared to the basic (North-South) direction. This represents slight difference compared to the basic (North-South) direction.

Similarly, if the obliqueness is 30 degrees instead of 15 degrees and toward east, there is an increase of 3.7%. If the obliqueness is toward west, the increase is 4.3% as compared to the basic (North-South) direction. This increase is less than 5%, which makes it ineffective in terms of annual energy consumption at that basic direction. Hence, it is clear that the building orientation has an impact on annual, summer and winter energy consumption.

7. Conclusions

In the hot arid zone climate like the city of Cairo that is the capital of Egypt, it is found that the building orientation has a major effect on the amount of the energy consumed to achieve comfort for its users. As the building is adapted to the local climate, it can benefit from the surrounding environment and achieve users comfort. This will directly reflect on reducing the energy consumption. It is found that a southern facade results in the least energy consumption because of lower heating loads in winter. However, the western facade causes the highest annual energy consumption by 26% over the southern façade.

In case of two facades for the building, the optimum orientation for least energy consumption is the North-South. The orientation that is leaning with an angle ranges from 15 to 30 degrees with East causes slight higher consumption than the North-South. The orientation that leans from 15 to 30 degrees with the West leads to slight higher consumption than the former. These two leaning directions introduce low rates in annual energy consumption, which is no more than 5% as compared to the North-South direction.

In the simulated compound model (the chain of adjacent modeled rooms), it is found that the energy consumption for the facades North-South is lower than the energy consumption for the facades East-West by nearly 10%, which is reflected on reducing the annual energy consumption rates by about 13%.

8. References

1. Algohary, S., (2002) “The Importance Of Energy and Environmental Aspects In The Design Of Solar Passive Building”, Doctor Degree, Ain Shams University.

2. Anđelković, A. S., Mujan, I., & Dakić, S. (2016). Experimental validation of a EnergyPlus model: Application of a multi-storey naturally ventilated double skin façade. Energy and Buildings, 118, 27-36.

3. Ashmawy, R.E., (2015), Establish a sustainable strategies for low energy building. Master thesis, faculty engineering. Tanta University

4. David, M., Donn, M., Garde, F., & Lenoir, A. (2011). Assessment of the thermal and visual efficiency of solar shades. *Building and Environment*,*46*(7), 1489-1496.

5. Eben Saleh, M. A. (1990). Thermal insulation of buildings in a newly built environment of a hot dry climate: the Saudi Arabian experience. *International Journal of Ambient Energy*, *11*(3), 157-168

6. Energy Design Tools. (n.d.). Retrieved from http://www.energy-design-tools.aud.ucla.edu/

7. EnergyPlus. (n.d.). Retrieved from https://energyplus.net/

8. Givoni, B. (1991). Performance and applicability of passive and low-energy cooling systems. *Energy and buildings*, *17*(3), 177-199

9. Goia, F. (2016). Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential. Solar Energy, 132, 467-492.

10. Hasanin, T. G. H. (2000). Trains of urban development in Egypt, update evaluation for the experience of new urban communities.

11. Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I., & Napolitano, A. (2011). Zero Energy Building–A review of definitions and calculation methodologies. *Energy and buildings*, *43*(4), 971-979

12. Morrissey, J., Moore, T., & Horne, R. E. (2011). Affordable passive solar design in a temperate climate: An experiment in residential building orientation. *Renewable Energy*, *36*(2), 568-577.

13. Pai, M. Y. (2015). Effect of Building Orientation and Window Glazing on the Energy Consumption of HVAC System of an Office Building for Different Climate Zones. *International Journal of Engineering Research & Technology (IJERT)*, *4*(9), 838-843.

14. Paul, T. (2001). Passive Solar Design for the Home

15. Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and buildings*, *40*(3), 394-398.

16. Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews*, *15*(8), 3617-3631.

17. Shick, W.L.,(2009). Effects of building orientation on energy savings", Small homes council– Building Research Council, University of Illinois, Champaign.

18. Vanhoutteghem, L., Skarning, G. C. J., Hviid, C. A., & Svendsen, S. (2015). Impact of façade window design on energy, daylighting and thermal comfort in nearly zero-energy houses. *Energy and Buildings*, *102*, 149-156.