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Research Article

Energy Efficiency in residential buildings in Egypt with special reference to windows

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Abstract

Global warming and climate change are definitely bringing disasters to the mankind according to all the recent studies. Building sector is a great contributor to energy consumption and greenhouse gas emissions which make it a crucial matter to consider energy efficiency related to building sector. Considering energy efficiency in buildings and sustainability factors will result in significant energy reduction, environmental saving and greenhouse gas emissions reduction. The building envelope influence the building energy demand greatly, windows are important components of any building envelope contributing in daylight mainly and thermal transfer partially. This paper focuses on the main three climatic regions in Egypt covering almost all of the country in order to maintain the energy efficiency concepts in the entire residential sector allover Egypt. The paper studies Cairo and delta climatic zone, northern coast and southern Egypt climatic zone. The paper highlights the best orientation in each climatic zone. The paper studies the optimum window to wall ratio in all the orientations from energy efficiency perspective as well. The studied orientations are divided into steps of 30°. The paper holds an applied study using designbuilder energy simulation software.

Keywords: *Energy Efficiency, Windows, Openings, window to wall ratio, designbuilder, energy simulation, Environmental Engineering*

1. Introduction

Prior to the international energy crisis and climate change, all countries around the world started pursuing energy efficiency in all fields to overcome the current and coming problems of the limited energy resources, climate change and global warming. One aspect of solving and overcoming these problems is building green buildings including energy efficiency and renewable technologies. Over 60% of the total electricity consumption in Egypt is attributed to residential, commercial and Governmental buildings. (B. George,2013) Using energy efficiency and renewable technologies has a lot of benefits such as creating less environmental damage than existing technologies, treating and preventing environmental damage, creating less pollution with fewer emissions and less waste, managing resources more efficiently with reduced energy and resource consumption and providing economical advantages. Climate change and energy crisis are becoming essential topics that need to be put in consideration in all aspects of our lives, especially in a country like Egypt with low financial resources and a huge amount of pollution and population. All governmental associations and private companies should hold together to help climate change mitigation and achieve energy efficiency in different fields through reducing pollutants, balancing the greenhouse gases and optimizing energy consumption. Building sector accounts for 40% of total energy consumption and similar proportion of greenhouse gases emissions in the world. (Dirlich, S., 2011) Reducing the energy consumption from buildings sector will help enormously in the whole strategy of climate change mitigation and reducing energy consumption.

The big international economical development was followed by a serious energy crisis and environmental problem, over the past years crude oil prices jumped to new records(Financial Times 2007) And of course there's no doubt that the whole environment, buildings sector and energy are all critical issues because of the huge energy consumption of buildings in its operation phase. (M. Zimmermann, *et al*). If we achieved energy efficiency in buildings that will help mitigate carbon emissions by 60% in the same context building bioclimatic designed buildings will reduce fossil fuel use and energy consumption (Tzikopoulos, F., *et al*, 2005)

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2. Energy Consumption in Buildings

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Buildings are a key towards sustainability as they represent between 30% and 40% of the energy demand in most developed countries.(Kapasalaki, M., 2012). In buildings, energy is used for several purposes such as heating, cooling and lighting.(Langston, C., *et al*, 2001) Building envelopes have major problems of heat escaping in winter through it, and heat penetrating it in summer (Jarmul, S., 1980).

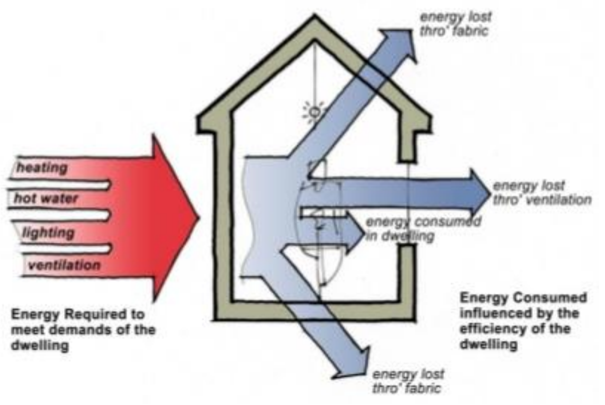

Fig.1 Energy in Buildings

Factors influencing energy use in buildings are:

- Building Envelope

Location, size, orientation, form, layout, construction materials, openings

- Building services

Type of systems, size of systems, energy, operation system

- Human Factor

Comfort requirements, occupancy, activity, management, maintenance, control system

3. Energy Consumption in Egypt

Egypt is the biggest oil and natural gas consumer in Africa, representing around 20% of petroleum consumption and 40% of dry natural gas consumption in Africa in 2013. The main challenge in Egypt is to meet the oil demand. The oil consumption in Egypt recorded an increase of 3% annually over the last 10 years. Oil consumption in Egypt currently exceeds its oil production (U.S. Energy Information Administration).

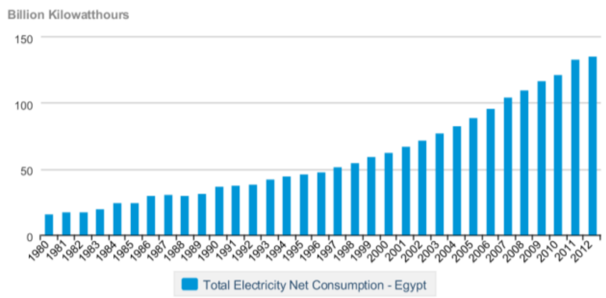

Fig. 2 Total electricity net consumption in Egypt

4. Energy Efficiency in Buildings

Energy efficiency is the design of buildings, products or systems to use less energy and produce the same or higher performance. In buildings, energy efficiency means that the building uses less energy for its cooling, heating, ventilation and lighting. The idea behind energy efficient buildings is about saving the environment by using less fossil fuel and mitigating climate change, as well as improving the quality of buildings themselves. Reduction of fossil fuel is a strategic approach for environmental sustainability.
The urgency of having energy efficient buildings has grown recently due to the depleting energy resources and the increase of pollution. That's why all different sectors should work altogether to find innovative ways to decrease the energy consumption not to ignore the great energy consumption of buildings. Energy efficient buildings should provide not only less energy consumption than traditional buildings but also a comfortable environment for its users.

The first step for building an energy efficient building starts at the design stage, orientation, materials, form, size, shading devices, openings, ventilations and lighting are all factors that should be put in consideration to ensure having an energy efficient building.

Building envelopes are the skin that separates the interior of the building from the outdoor environment; doors, windows, roofs, walls and balconies are all components of building envelopes which should work together to keep the comfortable environment inside the building warm in winter and cool in summer. Various approaches can help improve the performance of building envelope such as, shading devices, windows with specific sizes, materials and glazing and insulation.

Energy efficiency in new buildings can be achieved through:

- Bioclimatic design
- Passive solar architecture
- Energy efficient lighting and HVAC systems
- Utilizing renewable energy resources
- Using energy efficient construction methods and low energy materials

5. Energy Efficiency's Effect on Buildings

Energy efficiency in buildings can result in 50-75 % energy consumption reduction which in return will mitigate climate change and improve indoor environment.(Clark, A., 2001). Energy efficient building reduces not only resource depletion but also the environmental impacts of pollution caused by energy production which is considered as a cornerstone for sustainable design. The first premise in energy efficiency is to reduce the energy need which can be realized through passive heating and cooling techniques that reduce the load on mechanical systems. The amount of energy conservation that occurs depends on the building's type, location, climate and the used systems.

6. Climatic Classification of Egypt

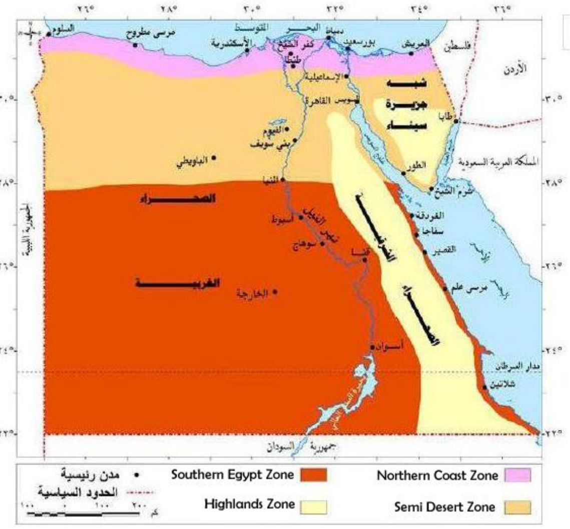

Fig. 3 Climate Classification of Egypt

This climatic classification of Egypt divides Egypt into four main climatic zones, northern coast zone, Cairo and delta semi desert zone, southern Egypt zone and highland zone. This research will study the three zones of northern coast zone, Cairo and delta semi desert zone, southern Egypt zone as they represent the maximum spread of residential and housing projects with maximum population growth.

7. Passive Solar Design

Passive solar design is a design that increases human comfort and decreases the demand of energy. In this design the building utilizes natural energy characteristics and utilizes the effect of solar radiation and natural cooling and heating sources to minimize heating, cooling and lighting energy requirements for the comfort of the building's occupants (Prasad, D.,*et al* 2005).

Passive solar design depends in considering the sun and its daily and seasonal cycle to use it in ventilation, heating and cooling instead of using mechanical systems. A passive solar design includes the storage, collection and distribution of the solar energy. The design principles are concerned with storing sun's energy when needed and the removal of it when it's not needed. Using passive solar design and depending mainly on natural daylight will decrease the dependency on fossil fuel generated electricity and decreases carbon dioxide emissions, saving energy will in turn make significant energy cost reductions.

Passive solar design follows these principles:

- Thermal mass- used to store heat from the sun and provide a heat sink when required
- Ventilation- provide fresh air and cools spaces
- Building materials- insulation in walls, roof and floors to optimize heat loss or heat gain
- Building orientation- the optimum orientation of the most frequently used spaces to utilize maximum sunshine and control heat transfer
- Windows- adequate glazing to trap sun heat when needed and provide protection when unwanted. Providing the best window wall ratio for optimizing heat transfer and daylight penetration

8. Daylight

Thinking about the sun and how to achieve the occupants' thermal and visual comfort inside the spaces, the first thing that should be considered is the sunlight that reduces the use of artificial lighting and the energy consumption. Building layout should be in a position that enhances the penetrating a sufficient amount of natural daylight. Passive design should accurately position windows in order to achieve maximum energy efficiency.(Dr. Guido Wimmers, *et al*, 2009).

9. Solar Radiation

Sun should be fully considered in architectural design, sun's energy in one minute is enough to supply the world's energy need for one year if properly captured. Sun is a clean energy resource that doesn't have any bad impact on the environment. Langston, C., *et al*, 2001)

10. Building Envelope and Openings

10.1 Window Performance Requirements

Glazing type and amount, and the location and shape of windows are effective controllers of heat gain and heat loss to buildings along with their enormous effect in ventilation and daylight. (Energy efficiency in Buildings CIBSE Guide F., 2004), some countries have acknowledged some requirements including window area in order to avoid problems of overheating. This kind of regulations hasn't been conducted in Egypt yet.

10.2 Sunlight and Daylight Penetration

Outdoor light is natural light which has two components, sunlight that arrives directly from the sun and the light that is diffused by the atmosphere.(Szokolay, S., 2008). Window's main purpose is to admit daylight, and maintain visual contact between the inside and outside. As well as providing ventilation for the spaces. Rooms that are frequently used by people should have direct daylight access.(BBR, 1999). Windows have four benefits, the access of environmental information, the feeling of connection to the outside world, restoration and recovery and feeling sensory change.

10.3 Thermal Insulation

Thermal performance is described by the U-value. U-value (total heat transfer coefficient) is a simple sum of the thermal resistances of each layer of all building components; it is the measure of the rate of heat loss through a material. (Anderson, B., 2006). U-values describe the thermal performance of building elements and are used to assess the thermal performance of building elements. (Conservation group, 2011), It is measured in W/(m^2•K)

U-value of a window (Uw) is the sum of:

Ug (g = glazing) U-value of the glazing
Uf (F = frame) U-value of the frame
The total heat transfer coefficient of the window U-Value (Uw) is affected greatly by the size of the window.

Walls are not to be with certain materials to achieve the maximum energy efficiency but they should have a U-value that improves the thermal resistance of the building, according to the Egyptian code for energy efficient residential buildings, these are the U-value of walls in different orientations in the studied climatic regions, Cairo and delta, Northern coast and Southern Egypt.

Table 1 Required U- value of opaque parts in different climatic zones

Climatic Zone	U-Value for the opaque part (m^2.C°/W)	
Cairo & Delta	North	0.55 – 0.67
	East/ West	0.92 – 1.35
	South	0.67 – 0.89
Northern Coast	North	0.35 – 0.47
	East/ West	0.72 – 1.15
	South	0.47 – 0.69
Southern Egypt	North	0.8 – 0.9
	East/ West	1 – 1.3
	South	0.7 – 0.8

10.3 Basic Window Physics

The basic heat transfer in buildings is from the inside to the outside in case of a warmer indoor atmosphere.

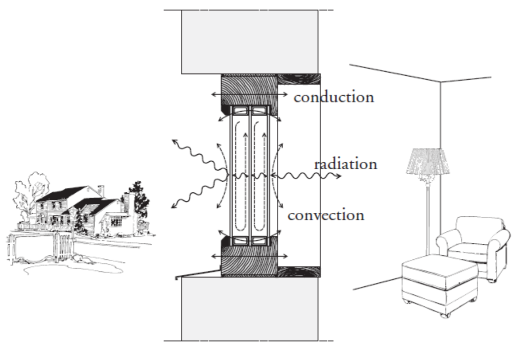

Fig. 4 Heat transfer through a window, radiation, convection and conduction

Some of the short wave solar radiation is transported to the inside of the buildings in daytime. Direct solar radiation is the main contributor but the diffused parts from sky and ground are not to be neglected because of their significant contributions (Roos, A., 1994). The bigger the window area is, the more solar direct and diffused radiation will be permitted into the building.

10.3.1 Ultraviolet Transmittance

Ultraviolet radiation is weakly transmitted through the window glass; however, the energy content of the short wave lengths is high and can cause heating of the indoor spaces .(IESNA, 1993).

10.3.2 Light Transmittance

Light transmittance is the transmittance of solar energy within the visible region of the eye. For ordinary clear glass, almost 90% of the light that hits it is transmitted.

10.3.3 Solar Energy Transmittance

There's a difference between the directly transmitted energy and the energy that is gained from the heat transfer processes (absorption) which depends on the absorbed energy in the glazing which is transported to the room.(Bulow, H.,2001).

10.4 Windows and Daylight

Windows are the objects that provide the building with a view for the outdoor, as well as lighting. The main factors that affect the daylight in the rooms are the window size, shape and position of the window. The strategic placing of windows can contribute in the optimization of energy as well as the view (Miller, N., 2013).

11. DesignBuilder Software

Designbuilder software provides modeling using EnergyPlus interface for envelope, ventilation, sunlight, daylight capabilities and heating and cooling the model and gives a lot of simulation options whether to make calculations for the whole model or only concentrate on a single zone.

DesignBuilder is user friendly software that enables a wide range of users to get advantage from its features. Consulting engineers, researchers, students and architects are the main users for the software due to its great contribution to fulfilling their needs. This software enables the modeling of very complex buildings easily and rapidly not to mention the use of EnergyPlus simulation that adds more reliability in the results. DesignBuilder software undertakes the following applications:

The calculation of Energy consumption in buildings
The evaluation of façade options
The visualization of solar shading and site layout
The thermal simulation of naturally ventilated buildings
The integration between day lighting and artificial electric lighting

The calculation of heating and cooling equipment size
The simulation of any building in DesignBuilder software depends on the climatic data of a specific climatic zone, this data is inserted to the software in a climate file that includes data generated on hourly and sub-hourly basis over 10 years or more. This climate file ensures the accuracy of the simulation.

DesignBuilder software provides the output data on annual, monthly, daily, hourly and sub-hourly intervals which increases the benefit of the data. The output data of DesignBuilder software are:

Weather data
Energy consumption and fuel consumption
Internal temperature
Carbon dioxide generation
Heating and cooling loads
Heat transmission through building elements (walls, roofs, etc)

The use of designBuilder software varies from early in design stage, building assessment and building retrofit. It provides energy simulation for buildings at different stages according to the purpose of each user.

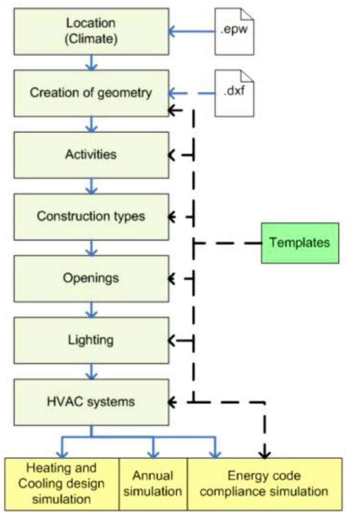

Fig. 5 DesignBuilder workflow

12. Case study Selection

The choice of the case study was determined by the survey of 140 residential projects and surveying the living spaces (reception) and sleeping spaces (Bedrooms) dimensions in meters for medium class housing units from governmental and nongovernmental projects to give an indication of the standard unit to apply the experimental study on. Some examples of the surveyed residential units are Mubarak housing project, youth housing, social housing project, in addition to some private residential buildings in Egypt in different governorates and various climatic zones.

From the previous survey, the standard unit of the living space is 5 meters width, 6.7 meters length and 2.8 meters height. The standard unit of the sleeping space is 3.6 meters width, 4.4 meters length and 2.8 meters height.

The surveyed units fulfill the executive list of the construction code, law number 119 for year 2009 which is authorized to the regulation of construction in Egypt.

As reported in subject 93, the minimum clear height of one storey in each storey of the building is 2.70 meters. As reported in subject 94, the minimum floor area of any living or sleeping space is 7.5 square meters and the minimum side length is 2.5 meters.

As reported in subject 96, each room should have at least one opening or more were the total area of the opening should be at least 8% of the total area of the space where the opening is located. If the space has more than one opening, the total area of the openings should not be less than 8% of the total area of the space where the openings are located. This percentage will be considered in the window wall ratio of each space where the living space window area should not be less than 2.60 meters; this percentage will also be considered in the window wall ratio of each space where the sleeping space window area should not be less than 1.26 meters.

12.1 Base Case Model Parameters

The base case model as mentioned before is a standard unit of the dimensions of 6.7 meters length and 5 meters width, the activity on the space is set to living space in a residential building, the negligible difference between the activities of living and sleeping lead to the decision of working on a living space as the use of this space is in a more critical time than the time of using the sleeping spaces The building envelope was defined by the materials that are mostly and repetitively used in residential buildings in Egypt.

12.2 Location, Orientation and climate

The Base Case models are located in Cairo, Alexandria and Aswan. Cairo represents Cairo and delta zone and it represents the capital of Egypt as well as the location of the major population across Egypt which makes the study very effective in applying these guidelines to residential buildings to be built in the future. Aswan represents southern Egypt zone and Alexandria represents northern coast zone. The orientation is to be tested in all orientations. A climate file with hourly data provided by ASHRAE for Cairo, Aswan and Alexandria regions are used in the simulation.

12.3 Construction

The building construction materials and envelope is set up by defining the properties of the elements of walls, floors and glass properties. The external wall is composed of a 25 cm red brick wall, a plaster layer on the outer side and a plaster layer and plastic paint as the interior cladding material.

Table 2 Characteristics of opaque materials of the envelope

Elements	Material	Conductivity (W/m.K)	Specific heat (J/kg.K)	Density (Kg/m³)
Walls	Masonry brick	0.72	835	1920
	Reinforced concrete (columns)	2.30	1000	2300
Surface Finishing	Plaster (Dense)	0.50	100	1300
Roofs & Floors	Reinforced concrete	2.50	1000	2600
	Mortar	0.88	896	2800
	ceramic	1.3	840	2300
	Sand	0.15-0.25	830	1600

12.4 Orientation

The standard unit was energy simulated in twelve orientations on steps of 30° to investigate the influence of the change of orientation on the energy performance and to determine the optimum orientation of the spaces in each climatic zone of Cairo and delta, northern coast and southern Egypt zone.

Window to Wall Ratio

The effect of the increase of the window to wall ration thus the increase in the glazed area is investigated in 10 steps starting from 10% WWR till 100% WWR to see its influence on the energy consumption in 12 orientations on steps of 30°.

Results and Conclusions

Effect of the Change of Building Envelope Parameters on the Energy Consumption in Cairo and Delta Climatic Zone

The effect of the change of the parameters concerning the external envelope of the standard unit is investigated through the energy simulation program to show the influence on energy consumption and how to achieve the ultimate energy efficiency. The simulation is firstly conducted on Cairo and delta zone.

Orientation

The simulation used the weather file of Cairo as the climatic data input. The tested orientations were twelve orientations in steps of 30°.

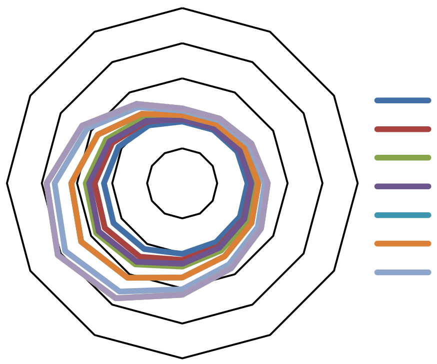

Fig. 6 Energy consumption of the case study unit in twelve orientations

As shown in the previous figure, the energy consumption varies a lot according to the orientation, the orientation with the highest energy consumption in all windows to wall ratios is the 240° south west orientation, and the best orientation with the lowest energy consumption in all the window wall ratios is the 30° north east orientation. The difference in energy consumption between the best and worst orientations achieves almost 22% energy reduction in the 10% window to wall ratio, and about 48% in the 100% window to wall ratio which highlights that the orientation has a significant effect on the energy consumption.

Window Size (Window to Wall Ratio WWR)

The effect of the window size (window wall ratio) on the energy consumption was tested in a range of 10% WWR to 100% WWR on 10% steps. The shown figure summarizes the effect of changing WWR in different orientations on energy consumption. The results of this simulation showed the extent to which the energy consumption can be affected by the window size that controls the heat transfer along with the external wall area. The previous figure shows the energy consumption and its relation to window to wall ratio in different orientations. The figure shows the direct relation between window area and energy consumption, the more the window area is, the bigger the energy consumption.

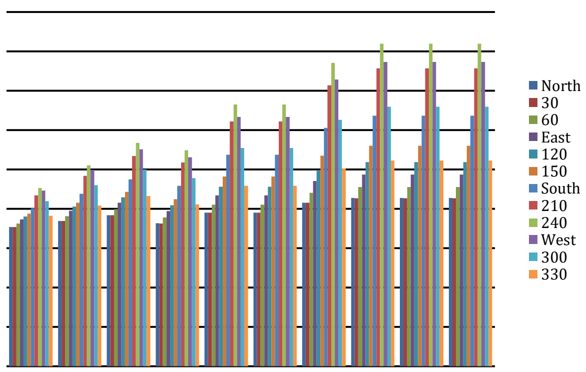

Fig. 7 Effect of different window to wall ratios on energy consumption tested in different orientations

For north orientation, the window to wall ratio records a slight difference in energy consumption due to the difference between the 10 % and the 100% WWR, for North, the difference between the 10% WWR and 100% WWR is 17% in the energy consumption. In the south orientation, the difference between the 10% WWR and 100 % WWR is 37%, in the 330° orientation, the difference between the 10% WWR and the 100% WWR is 26%. From the figure, it is obvious that the following orientations are very sensitive to the WWR, south, 220°, 240° and west orientations. The chart as well clears up that using 50% and 60% WWR are almost the same in energy consumption.

Effect of the Change of Building Envelope Parameters on the Energy Consumption in Southern Egypt zone

The effect of the change of the variables concerning the external envelope of the standard unit is investigated through the energy simulation program to show the influence on energy consumption and how to achieve the ultimate energy efficiency. The simulation is secondly conducted on Aswan city representing southern Egypt zone.

Orientation

The simulation used the weather file of Aswan as the climatic data input. The tested orientations were twelve orientations.

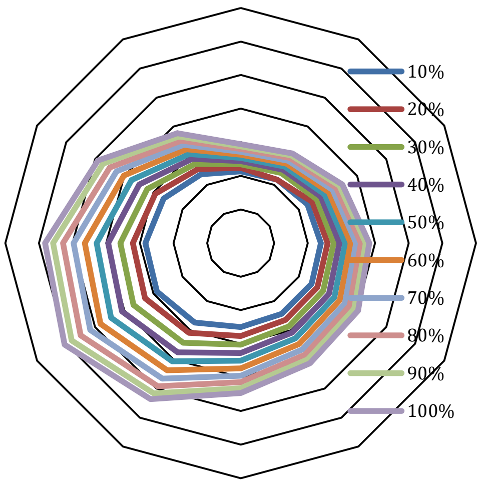

Fig. 8 Effect of different orientations on annual energy consumption in southern Egypt zone

As shown in the previous figure, the energy consumption varies a lot according to the orientation, the orientation with the highest energy consumption in all windows to wall ratios is the 240° south west orientation, and the best orientation with the lowest energy consumption in all the window wall ratios is the north orientation. The difference in energy consumption between the best and worst orientations achieves almost 26% energy reduction in the 10% window to wall ratio, and about 51% in the 100% window to wall ratio which highlights that the orientation has a significant effect on the energy consumption and the window to wall ration should be accurately chosen for buildings as to control the energy consumption.

Window Size (Window to Wall Ratio WWR)

The effect of the window size (window wall ratio) on the energy consumption was tested in a range of 10% WWR to 100% WWR on 10% steps. The shown figure summarizes the effect of changing WWR in different orientations on energy consumption. the results of this simulation showed the extent to which the energy consumption can be affected by the window size that controls the heat transfer along with the external wall area. The previous figure shows the energy consumption and its relation to window to wall ratio in different orientations. The figure shows the direct relation between window area and energy consumption, the more the window area is, the bigger the energy consumption.

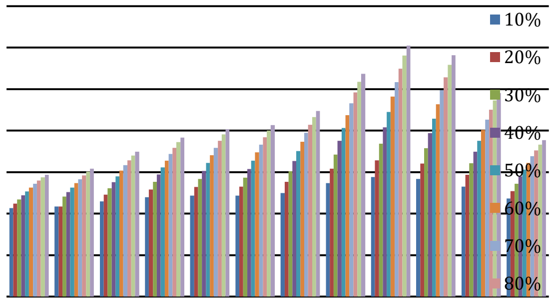

Fig.9 Energy consumption relation with window to wall ratio in different orientations in Southern Egypt zone

For north orientation in southern Egypt zone, the window to wall ratio records a slight difference in energy consumption due to the difference between the 10 % and the 100% WWR, for North, the difference between the 10% WWR and 100% WWR is 27.4% in the energy consumption. In the south orientation, the difference between the 10% WWR and 100 % WWR is 44%, in the 330° orientation, the difference between the 10% WWR and the 100% WWR is 37.3%. From the figure shown, it is obvious that the following orientations are very sensitive to the WWR, south, 220°, 240° and west orientations. The chart as well clears up that using 50% and 60% WWR are almost the same in energy consumption. it is also obvious that the southern Egypt zone is affected greatly more that Cairo and delta zone by the difference in WWR which makes it a critical issue in the design process.

Effect of the Change of Variables on the Energy Consumption in Northern Coast Climatic Zone

The effect of the change of the variables concerning the external envelope of the standard unit is investigated through the energy simulation program to show the influence on energy consumption and how to achieve the ultimate energy efficiency. The simulation is firstly conducted on Northern Coast climatic zone.

Orientation

The simulation used the weather file of Alexandria as the climatic data input. The tested orientations were twelve orientations.

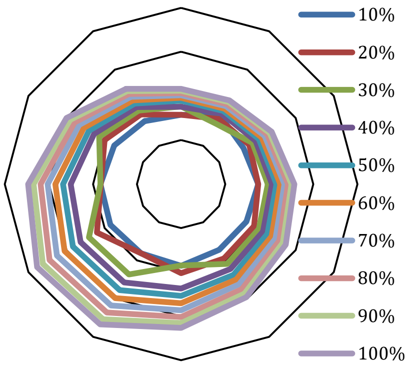

Fig.10 Effect of different orientations on annual energy consumption in Northern Coast climatic zone

As shown in the previous figure, the energy consumption varies a lot according to the orientation, the orientation with the highest energy consumption in all windows to wall ratios is the 240° south west orientation, and the best orientation with the lowest energy consumption in all the window wall ratios is the 30° north east orientation. The difference in energy consumption between the best and worst orientations achieves almost 22% energy reduction in the 10% window to wall ratio, and about 48% in the 100% window to wall ratio which highlights that the orientation has a significant effect on the energy consumption.

Window Size (Window to Wall Ratio WWR)

The effect of the window size (window wall ratio) on the energy consumption was tested in a range of 10% WWR to 100% WWR on 10% steps. The shown figure summarizes the effect of changing WWR in different orientations on energy consumption. The results of this simulation showed the extent to which the energy consumption can be affected by the window size that controls the heat transfer along with the external wall area. The shown figure shows the energy consumption and its relation to window to wall ratio in different orientations. The figure shows the direct relation between window area and energy consumption, the more the window area is, the bigger the energy consumption.

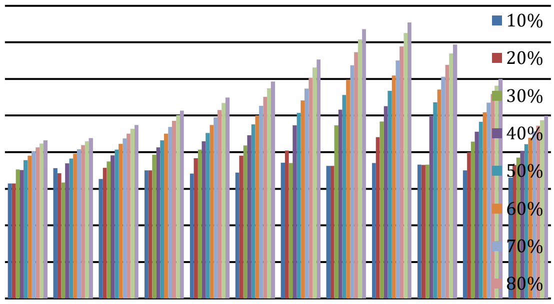

Fig.11 Effect of different window to wall ratios on energy consumption tested in different orientations in Northern Coast zone

For north orientation, the window to wall ratio records a great difference in energy consumption due to the difference between the 10 % and the 100% WWR, for North, the difference between the 10% WWR and 100% WWR is 27% in the energy consumption. In the south orientation, the difference between the 10% WWR and 100 % WWR is greater recording 34%, in the 330° orientation, the difference between the 10% WWR and the 100% WWR is 26%. From the shown figure, it is obvious that the following orientations are very sensitive to the WWR, south, 220°, 240° and west orientations. The chart as well clears up that using 50% and 60% WWR are almost the same in energy consumption.

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