



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 7, July 2023

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

ijirset@gmail.com

www.ijirset.com

# The Effect of Building Orientation on Energy Efficiency of Residential Buildings

Karim Saad Ezzeldin<sup>1</sup>, Mamdouh Ahmed Farag<sup>2</sup>, Sherif Mohamed Sabry Elattar<sup>3</sup>

Assistant lecturer, Department of Architecture, Faculty of Engineering, Fayoum University, Egypt<sup>1</sup>

Assistant Professor of Architecture, Department of Architecture, Faculty of Engineering, Fayoum University, Egypt<sup>2</sup>

Professor of Architecture, Department of Architecture, Faculty of Engineering, Fayoum University, Egypt<sup>3</sup>

**ABSTRACT:** There are many variables that effect buildings energy efficiency, which can be classified into urban design, architectural design, and structural variables. One of the most effective architectural design variables is mass orientation.

The orientation of a building is influenced by various external factors such as solar radiation, wind, and noise. The most important of these influences is the solar radiation as it is responsible for the use of cooling and heating systems. This research paper aims to determine the best orientation for different climate zones using energy simulation tools.

**KEYWORDS:** Energy efficiency; Rationalizing Energy Consumption; Residential Building; Orientation.

## I. INTRODUCTION

Energy is one of the basic necessities of life and an essential component in all aspects of life. Energy relies on renewable sources such as wind, sun, and water, as well as non-renewable sources such as oil, coal, and natural gas. Currently, 80% of global energy consumption is dependent on non-renewable sources, which will run out in the future. In addition, these sources are major contributors to carbon dioxide emissions [1], which is directly linked to climate change, the most prominent issue facing humanity. The accumulation of carbon dioxide reserves solar radiation near the Earth's surface, leading to a gradual increase in the surface temperature of the earth and the phenomenon of global warming.

One of the main reasons for this crisis is the massive consumption of energy for treatment design problems for buildings, such as ventilation, lighting, and others. Buildings consume more than 40% of the total energy consumption [2]. Countries need to invest in improving energy efficiency to mitigate greenhouse gas emissions that trap heat in the atmosphere, resulting in a rise in Earth's temperature and leading to climate change, biodiversity loss and threatening human life. While energy-efficient buildings may incur higher construction costs, they prove to be more cost-effective in terms of operation.

## II. RELATED WORK

### 1. Energy Efficiency

#### 1.1. Energy Efficiency Definition

Energy efficiency is defined as the ability to provide the same (or higher) level of energy services, such as thermal comfort, lighting quality, etc. with lower energy consumption and cost. It is also defined as the amount of energy required to perform a particular job, and this is done by reducing energy inputs while achieving the same level of services, or the same energy inputs with an increase in the level of services [3].

#### 1.2. Energy Efficiency Benefits

Optimising energy efficiency refers to a set of means, techniques, and technologies associated with energy-consuming devices and building components to reduce their energy consumption [4]. In this section, we present the benefits of rationalising and optimising energy efficiency for the environment, economy, and people:

a) **Environmental benefits**

- Reduction of greenhouse gas emissions.
- Decreased air pollution and waste production.

b) **Economic benefits**

- Lower energy consumption.
- Reduced operating costs of buildings.
- Decreased resource waste.

c) **Humanitarian benefits**

- Achievement of thermal and visual comfort.
- Enhanced luxury for building occupants.

### 1.3. Energy Efficiency Systems

There are three systems that contribute to achieving energy efficiency.

- **Passive Systems:** are one of the energy efficiency systems that surpass traditional buildings in terms of energy efficiency while maintaining a comfortable indoor climate. The goal of these systems is to minimise the need for energy consumption by adopting methods that support design decisions at the building level such as: shape, orientation, building materials, windows, etc.
- **Active Systems:** Renewable energy sources are utilised in place of depleted energy sources within active systems.
- **Hybrid Systems:** are comprehensive approaches that combine passive and active systems. They achieve the lowest energy consumption through passive systems and then supplement energy requirements with active systems that utilise renewable energy in order to achieve either rationalisation, conservation, or production energy.

### 1.4. Energy Efficiency Indicators

Two indicators are commonly used to evaluate and compare the energy efficiency of buildings. The first indicator is related to per capita energy consumption, while the other indicator is related to building energy consumption by area and is called Energy Use Intensity rate (EUI) [5].

#### 1.4.1. Per Capita Energy Consumption Index

The indicator relies on aggregate data from various agencies, such as the Ministry of Electricity and Renewable Energy, the Ministry of Petroleum and Mineral Revolution, and the Central Agency for Public Mobilisation and Statistics. Based on this data, the indicator was built.

#### 1.4.2. Energy Use Intensity rate (EUI)

It is the most common metric for evaluating the energy performance of buildings and helps identify variables that affect buildings' energy performance. It is considered a reference for estimating the amount of energy that must be saved. The lower the value of the metric, the more efficient the energy performance of the building.

$$\text{EUI} = \frac{\text{The amount of energy consumption annually (Kwh/y)}}{\text{The total area of the building (m}^2\text{)}}$$

☒ In this research, Authors depend on the energy use intensity rate as an indicator of energy efficiency in buildings.

## 2. Rationalizing Energy Consumption

Rationalization of energy consumption takes place through two methods. One of them depends on the rationalization of the current energy by reducing energy losses, and the other method depends on future energy, by replacing the current energy with sustainable or more efficient ones [6].

### 2.1. Methods of Rationalizing Energy Consumption

- **Direct methods:** by reorganising what is available to reduce losses and improve performance efficiency.
- **Indirect methods:** using alternative energy sources or energy consumption components [7].

☒ Direct methods are the most reliable solution at the present time, while efforts are made to overcome current obstacles and address indirect methods.

### 2.2. Axes of Rationalizing Energy Consumption in Buildings

Energy consumption in a building can be rationalized and can improved efficiency according to three axes as follows:

- 1) **The building itself**, which is related to the building's design and envelope.
- 2) **Devices and operating systems**, which are related to the equipment, tools, and systems that consume energy and are used in the building.
- 3) **Users**, which is related to the behavior of the person who uses the building.

#### 2.2.1. Axis of Building Itself

As a result of users' pursuit of development and their search for advanced technologies without realising what is appropriate for the environment, this contributed to the reproduction of design ideas and models of buildings that are not appropriate in terms of building materials, climate, and social environment. Consequently, this has led to an increase in energy consumption.

The external envelope is the link between the interior and exterior of the building. It includes elements such as windows, which allow for visual connection, as well as lighting, noise, heat, ventilation, and other external factors that impact the internal space.

The external envelope of a building is defined as the sum of the walls, windows, ceilings and floors that are exposed to the surrounding external climatic conditions [8]. It is considered one of the main factors affecting the energy efficiency of buildings, as it accounts for a significant portion of heat gain and loss [9].

**2.2.2. Axis of Devices and Operating Systems**

It is important to study energy-consuming devices and the loads related to heating, cooling, water heating, lighting, and other loads, as most of which operate during the building's operational phase. Home devices have become a significant point of interest for users, as they facilitate household chores, which contributes to an increase in electrical energy consumption [10].

Therefore, it is necessary to find some scientific solutions and use advanced operational systems to reduce this consumption. Accordingly, the Egyptian General Organisation for Standardisation and Quality (EOS) established an energy efficiency and rationalisation unit with the aim of activating the decision of the Engineer / Minister of Industry and Foreign Trade No. 171 of 2011 (regarding obligating producers and importers to place energy consumption labels on electrical appliances and lamps for domestic use and obliging them to refer to the Egyptian Authority General specifications and quality to match its data and verify the level of energy consumption before putting it on market [11].

**2.2.3. Axis of Building's Occupants (Users)**

Understanding the relationship between user behaviours and energy consumption in a building is the most effective way to bridge the gap between expected and actual energy consumption [12]. It has been widely acknowledged in previous studies that there is a large gap between projected and actual building energy consumption (sometimes the difference in values reach up to 300%) [13], because most studies rely on many variables to study energy consumption and overlook the influence of human factors.

Most energy simulation tools rely on climatic data and the physical/thermal properties of building elements in their calculations, and the impact of building occupants is considered only through static behaviour.

For example, some studies regarding the impact of users on building ventilation have proven that the behaviour of users - in using windows and doors - contributes to more than 50% of the total air change per hour (ACH), which affects energy consumption and thermal comfort [14].

**III. METHODOLOGY**

In this study, the author depends on applied studies to determine the best orientation for different climate zones using applied studies.

**IV. EXPERIMENTAL RESULTS**

**3. Applied studies on the impact of building orientation on energy efficiency**

The research presents two studies to determine the best orientation and the affecting factors, using simulation programs. In this research, the author uses Ladybug & Honeybee plugin.

**3.1. First Study**

The authors propose a simple rectangular building block consisting of two floors with dimensions of 20m length x 12m width x 6m height. A simulation was made to determine the amount of radiation falling on the block, with the building orientation angle changing (independent variable) 360:0°, as well as the location (independent variable), where a group of sites were chosen, each site follows a different climate zones and all of them are located in the northern hemisphere so that the direction of the sun's movement is from the east through the south and ends at the west. The specific sites (Table 1) were determined based on the climate zones map (Figure 1).

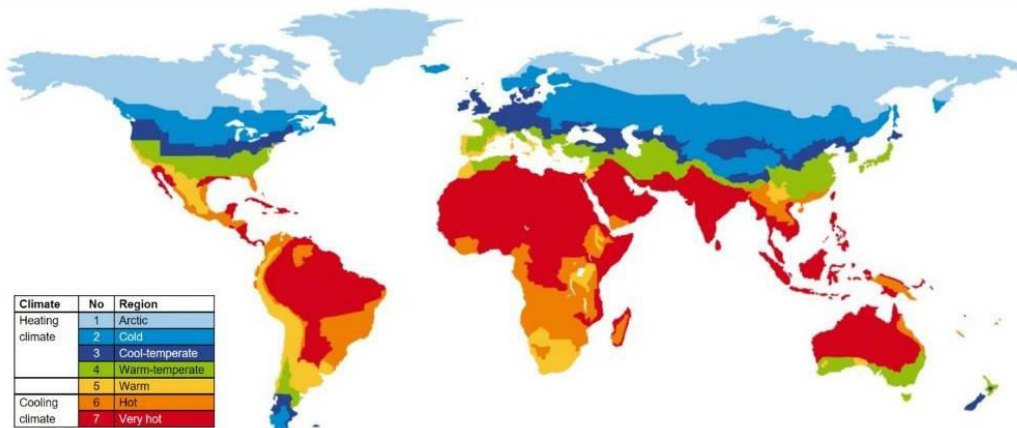


Figure 1: An illustrative map of climatic regions.

Source: Passive House Institute.

**Table 1:** The first applied study sites. **Source:** Author.

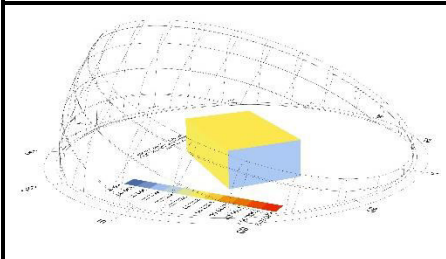
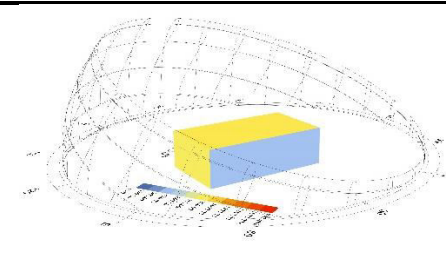
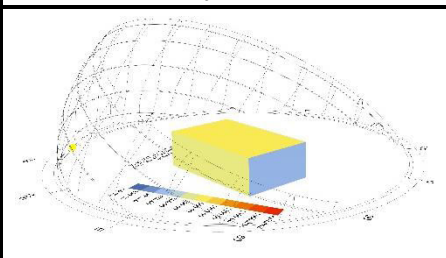
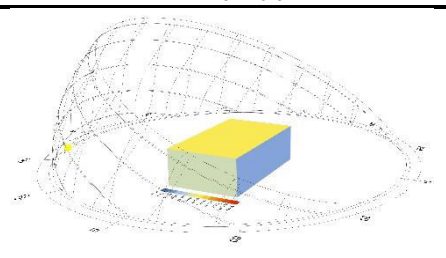
Climate Zones	Arctic	Very Cold	Cold	Cool	Warm	Hot	Very hot
Selected Country	Greenland	Iceland	Germany	USA	Jordan	Hong kong	Egypt
Selected City	Nuuk	Reykjavik	Berlin	San Francisco	Amman	Victoria	Aswan
Average temperature of the year (°C)	3.5-	5	9.8	14.9	17.6	23	26.2

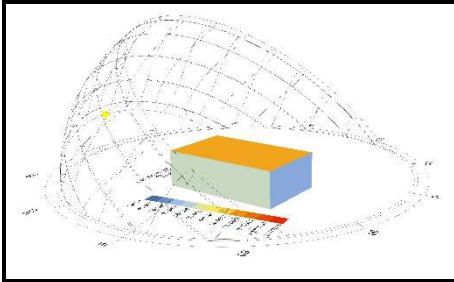
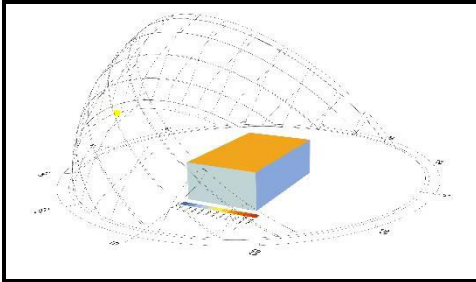
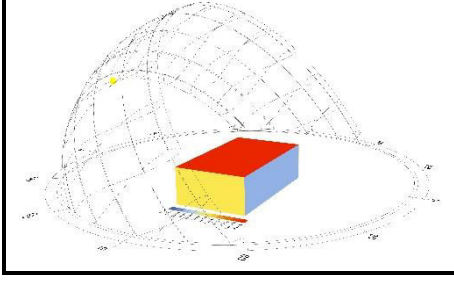
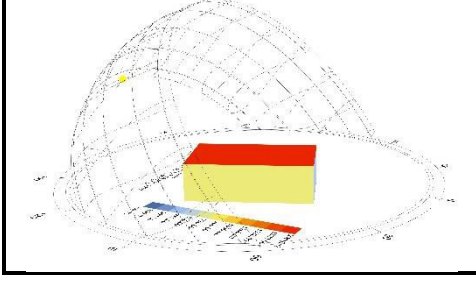
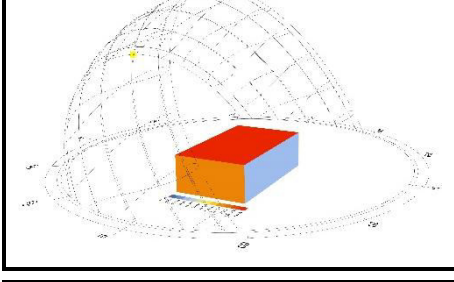
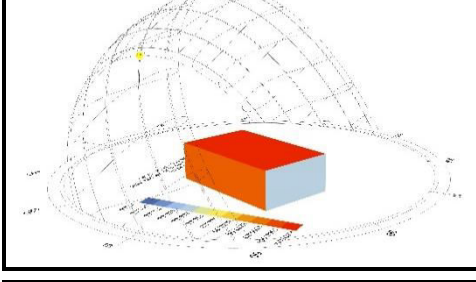
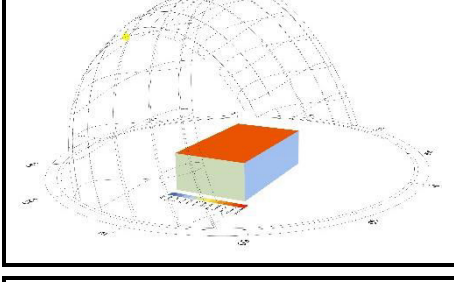
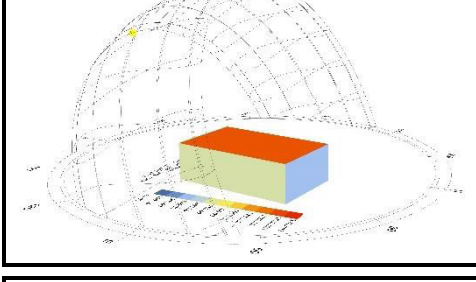
**The Analysis of the First Study**

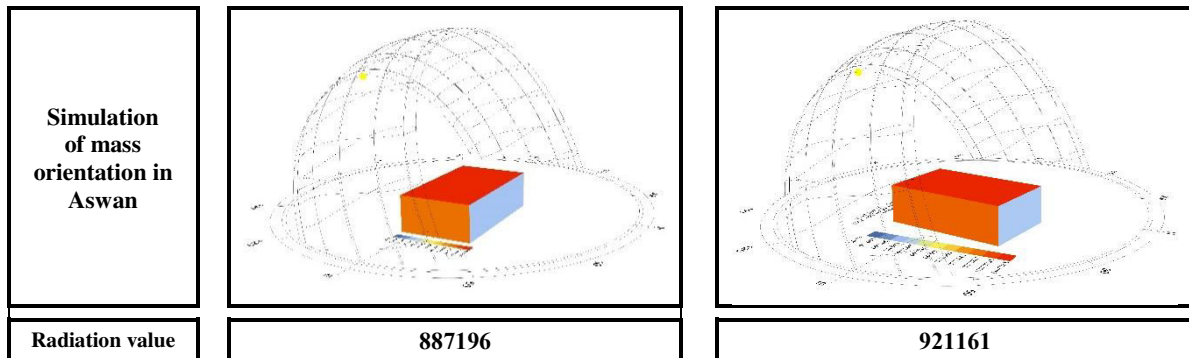
A total of 360 simulations were conducted, representing the number of angle degrees of mass rotation around its centre across seven locations, resulting in a total of 2520 simulations. The findings are presented in (Table 2):

- 1) The results indicate the absence of an absolute best orientation for the rectangular mass. However, for **hot regions**, the best orientation is to direct the largest side perpendicular to the north axis, and this is consistent with the study (Al-Fadil 2019) [15]. Conversely, the worst orientation for these regions is to direct the largest side parallel to the north axis or slightly inclined towards the east or west at an angle of 22°, contradicting the recommendations in the study (Zagreb 2014) [16] suggesting an orientation angle of 22.5 from the south. Additionally, a separate study (Kandeel 2010) [17] recommends that the largest side is directed perpendicular to the east axis (or parallel to the north axis), but this is true for **cold regions**. In these regions, the orientation that minimises solar radiation corresponds to the worst orientation, where the largest side is perpendicular to the north axis. On the other hand, the best orientation is the one that maximises solar radiation, which is the orientation of the largest side perpendicular to the east direction, or the inclination slightly towards the southeast axis.
- 2) The solar radiation value increases as the location approaches the equator because the closer the location is to the equator, the longer the sunshine duration. This is evident in Table 2, where the highest daylight hours are observed. However, despite this general trend, the study proved that the solar radiation value at the Victoria site (Hong Kong) is lower than that of Amman, despite Victoria being closer to the equator and having longer sunshine duration. This can be attributed to the impact of sky conditions, particularly in winter, as clouds can diminish solar radiation [18]. It is important to note that Victoria has a subtropical climate.

**Table 2:** Best and worst orientation of the rectangular mass in different climate zone. **Source:** Author.

Orientation	Best Orientation	Worst Orientation
Angle	°214 - °34	°300 - °120
Simulation of mass orientation in Nuuk		
Radiation value	397349 Kwh/m <sup>2</sup>	395263 Kwh/m <sup>2</sup>
Angle	°202 - °22	°270 - °90
Simulation of mass orientation in Reykjavik		
Radiation value	359441	356704
Angle	°189 - °9	°270 - °90

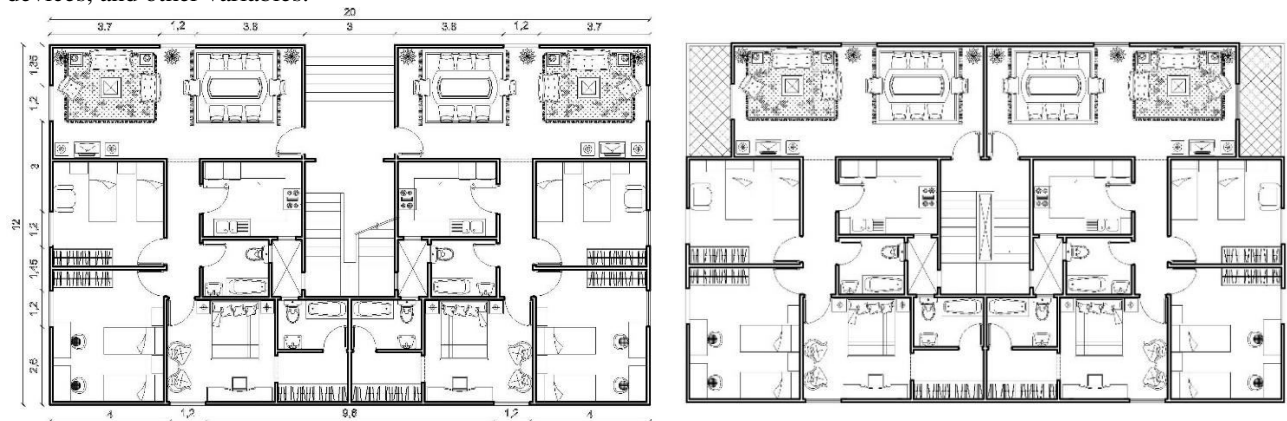
Simulation of mass orientation in Berlin		
Radiation value	418051	415616
Angle	°270 - °90	°339 - °159
Simulation of mass orientation in San Francisco		
Radiation value	729686	747096
Angle	°270 - °90	°202 - °22
Simulation of mass orientation in Amman		
Radiation value	804465	826212
Angle	°270 - °90	°188 - °8
Simulation of mass orientation in Victoria		
Radiation value	508416	516840
Angle	°270 - °90	°188 - °8



**3.1. Second Study**

The authors proposed a design for the mass in the first study, which consists of 2 apartments per floor, with a total of 4 units. Each apartment consists of a hall, a kitchen, a bathroom, and 3 bedrooms, including a master bedroom with a private bathroom and a dressing room (Figure 2).

In this study, a simulation is run to determine the value of the Energy Use Intensity (EUI) and the value of the solar radiation falling on the building in the 7 locations. The simulation focuses on orienting the building entrance (the largest side) in the main directions after inputting the data, including mass, materials, windows, number of occupants, devices, and other variables.



**Figure 2:** Plan of ground and first Floor. **Source:** Author.

➤ **The Analysis of the Second Study**

8 simulations were run in seven locations, with a total of 56 simulations. The results indicated:

**Table 3** Energy use intensity rate for different climatic zones depending on the mass orientation towards the cardinal directions.

**Source:** Author.

Location		Orientation (for Entrance)							
Climate Zone	City	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Arctic	Nuuk	334.3	332.7	332.5	330.6	331.5	331.3	333.3	334.1
Very Cold	Reykjavik	228.7	227	227	225.4	226.6	226.3	228.1	228.6
Cold	Berlin	181.27	180.5	180.6	179.4	179.8	179.6	180.8	181.26
Cool	S.Francisco	113.7	113.8	112.8	112.1	111.1	111.9	112.8	114.1
Warm	Amman	126.9	128	126.4	126.3	124.6	127.1	127.3	128.5
Hot	Victoria	172.8	175.1	174	174.8	172.2	174.9	174.1	174.5
Very hot	Aswan	210.1	215.7	213.5	214.2	207.1	214.6	214.2	216.8

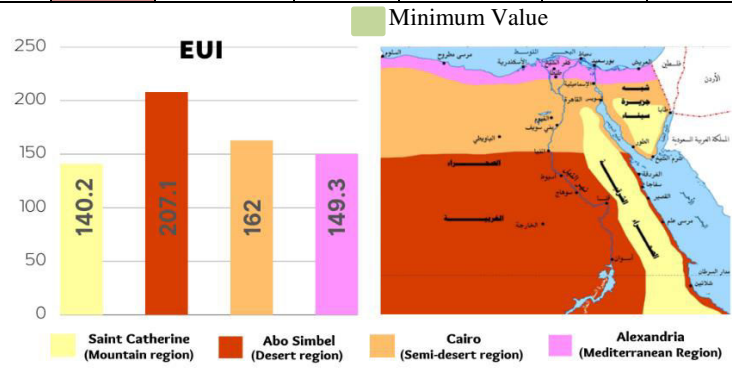
Maximum value

Minimum Value

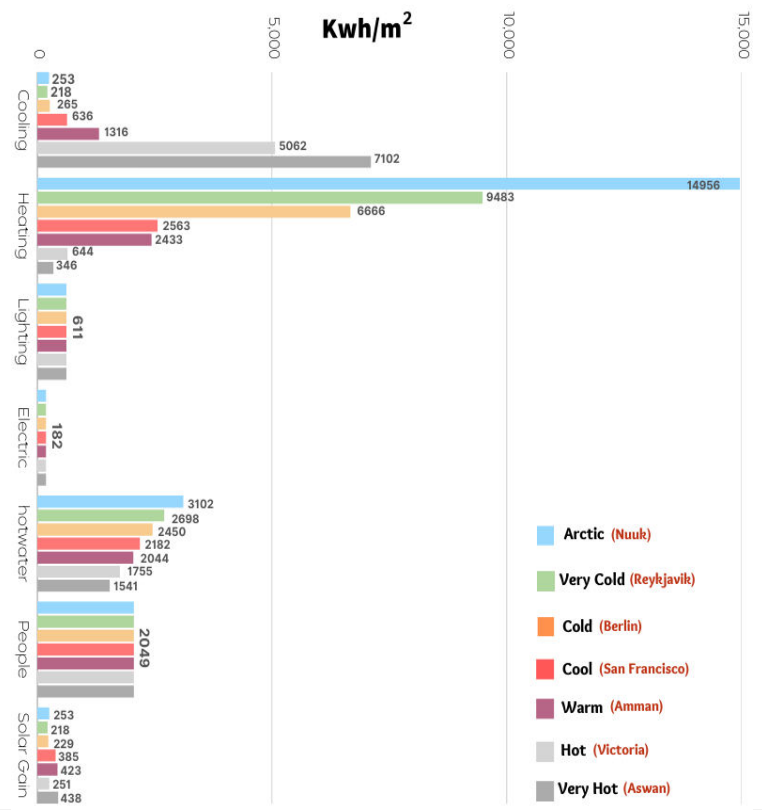
**Table 4:** The solar radiation values according to the building orientation towards the cardinal directions. **Source:** Author.

Location		Orientation (for Entrance)							
Climate Zone	City	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Arctic	Nuuk	394831	394864	395832	397777	396855	396052	395645	396110
Very Cold	Reykjavik	354899	356228	357048	358643	356668	357146	356726	357062
Cold	Berlin	412466	414517	414726	416063	414439	415735	414748	414591
Cool	S.Francisco	722962	736688	740796	738891	726788	739692	741354	736051
Warm	Amman	797121	813298	819637	818275	801275	815655	818735	814540
Hot	Victoria	504214	510336	512667	510605	506029	511444	512959	509545
Very hot	Aswan	878681	901406	914949	906189	882820	903741	914293	902956

- The results of the second study supported the results of the first study in determining the best orientation (Table 3,4).
- The location has a huge impact on energy consumption, as there is a discrepancy in the intensity of use of energy between different climate zones for the same building. For example, energy consumption in the Nuuk region (Arctic climate) increased by more than 195% compared to S. Francisco (Cool climate). Also in the Abu Simbel (very hot climate) more than S. Francisco by 85% (Table 3).
- Also, when a simulation was run in many sites in Egypt, where each site represents one of the climate regions (Figure 3). For example, the results showed variation in energy use intensity, and this variation reached 32.3% in the same country.
- The building orientation that achieved the highest solar radiation values -in cold climate regions- (southeast) is the one that achieved the lowest energy consumption Vice versa, the building orientation that achieved the lowest solar radiation values -in hot climate regions- is the one that achieved the lowest energy consumption. But consumption value may vary according to WWR and the Mass Form, as the results show that the direction of the building entrance towards the north achieved a less solar radiation value than its orientation towards the south, because the mass form in the north direction casting its shadows, thus reducing the solar radiation (Figure 5).
- The results (Figure 4) showed that the cold regions have the highest consumption of heating loads, and its percentage increases as the region



**Figure 3:** energy use intensity rate of the proposed building in the most important climatic regions in Egypt. **Source:** Author.



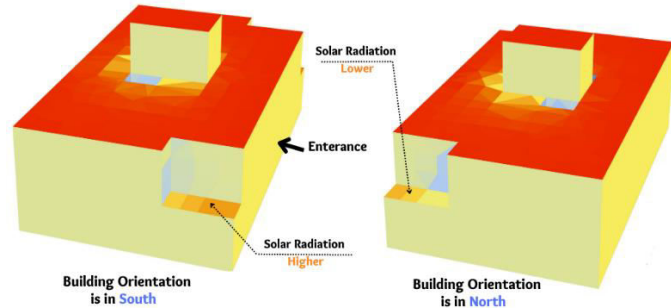
**Figure 4:** Values of energy loads for seven sites. **Source:** Author.



becomes colder. so the percentage of

heating loads consumption out of the total energy consumption in the regions Nuuk, Reykjavik, and Berlin is 70%, 66%, and 54%, respectively. As for the hot regions, cooling loads are the highest in consumption, so the percentage of cooling loads consumed out of the total energy consumption in the Abu Simbel and Victoria regions is 58% and 48%, respectively.

6) Different regions cause a change in the loads of cooling, heating, water heating and solar gain. As for lighting, electricity consumption and heat gain from building occupants aren't affected by different regions.



**Figure 5:** The difference in the solar radiation values where the building entrance is directed towards the north and south. **Source:** Author.

#### IV. CONCLUSION

Studies recommend using energy simulation tools to determine the best orientation for buildings. It is important to note that the best orientation is not fixed, as it varies depending on the nature of the site and the form of the mass in each location. However, the study recommends directing the largest side of the rectangular mass perpendicular to the north axis for hot regions, and directing it parallel to the axis North or slightly inclined towards the northeast axis for cold regions. Determining the best orientation for buildings can reduce energy consumption 4.5% in Egypt (very hot regions).

#### REFERENCES

- [1] Elnazer, Heba. (2019). Developing the standard of energy consumption for residential apartments in Oman. Jordan green Building Council. p. 20, 2019.
- [2] Hamed, Asmaa. (2020). "The impact of solar energy on interior design, down to solar energy buildings. Journal of Architecture. Arts and Humanities. Egypt. V. 5. N. 23.
- [3] Kamouna, Ghada. (2018). Effect of veneer facades on energy efficiency in buildings "Application of the double-veneer stoic façade model on a hypothetical administrative building in Baghdad". Journal of the Federation of Arab Universities for Engineering Studies and Research. Iraq. Volume 25. Issue 3.
- [4] Ferwan, Walid. Shawakh, Riyadh. (2020). The integration of solar cell systems with the external envelope of residential buildings and its impact on rationalizing energy consumption and protecting the building from sunlight, the city of Sebha as a model. The Fourth International Scientific Conference of the Faculty of Economics and Commerce. Libya.
- [5] Economic and Social Commission for Western Asia (ESCWA). (2018). Energy sustainability in the building sector in the Arab region. Beirut.
- [6] Saad Ezzldin, Karim. (2022). An Applied Study for the Impact of the Initial Design Stages on Improving the Energy Efficiency of Residential Projects in Egypt. IJRSET. Volume 11. Issue 11.
- [7] Kamal, Amal. (2003). Rationalizing energy consumption during the building construction phase. Master Thesis. Engineering Faculty, Ain Shams university. Egypt.
- [8] The National Center for Housing and Building Research. (2006). The Egyptian Code for Energy Efficiency Improvement in Buildings, Part One, Residential Buildings. Code No. (306/1). The National Center for Housing and Building Research. Egypt.
- [9] Bano, F., & Kamal, M. A. (2016). Examining the role of building envelope for energy efficiency in office buildings in India. Architecture Research, 6(5), 107-115.
- [10] Ammar, Aisha. (2003). Rationalization of energy consumption for residential buildings. International Conference on Energy and Environment. Libya.
- [11] The Egyptian General Authority for Standardization and Quality (EOS) website, <https://www.eos.org.eg/>. accessed, May 2023.
- [12] D'Oca, S., & Hong, T. (2014). A data-mining approach to discover patterns of window opening and closing behavior in offices. Building and Environment, 82, 726-739.
- [13] Delzendeh, E., Wu, S., Lee, A., & Zhou, Y. (2017). The impact of occupants' behaviors on building energy analysis: A research review. Renewable and sustainable energy reviews, 80, 1061-1071.



- [14] Pereira, P. F., Ramos, N. M., & Delgado, J. M. (2018). Intelligent Residential Buildings and the Behavior of the Occupants: State of the Art.
- [15] Al-Fadil, Doaa. (2019). "Passive Design Strategies for Cooling Residential Buildings in Hot Climates (Global and Local Case Studies)". Master Thesis. College of Graduate Studies - Sudan University of Science and Technology, Sudan.
- [16] Zagreb, Samar Mahmoud. (2014). An evaluation study of thermal comfort in residential buildings in the Gaza. Master Thesis. College of Engineering - Islamic University. Gaza. Palestine.
- [17] Kandeel, E. A. M. (2010). Energy-Efficient Building Design Strategies in Gaza Strip (With Reference to Thermal Insulation). Master Thesis. Faculty of Engineering-The Islamic University of Gaza. Palestine.
- [18] Mubarak, Hessa. Hajji, Zakia. (2019). Analysis of the effect of high temperature on horizontal urban expansions in Al-Ahsa Governorate, an applied study using remote sensing technology and geographic information systems. Arab Journal of Geographical Studies. Issue 2, pp. 73 - 110.



**INNO SPACE**  
SJIF Scientific Journal Impact Factor  
**Impact Factor: 8.423**



**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

**9940 572 462** **6381 907 438** **ijirset@gmail.com**



[www.ijirset.com](http://www.ijirset.com)

Scan to save the contact details