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The Influence of Buildings Proportions and Orientations on Energy Demand for Cooling in Hot Arid Climate

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Abstract: Considering the growing number of people around the world, and even limited resources, the global demand for energy will be massive. In Egypt, energy consumption in buildings is rising relative to every other sector because of the cooling and lighting needs. Thus, reducing energy demand will be a major issue in buildings. In this context, the objective of this study was to examine the impact of different building proportions with different building width to length W/L and surface-to-volume ratios S/V considering various building orientations on the energy demand for cooling in Aswan city that located in the hot arid regions. Design-Builder (V.4.0.0.105) tool was used to evaluate the amount of energy needed for cooling in the residential buildings located in Aswan city. Building proportions and orientations have been found to have a significant impact on energy consumption for cooling in hot climates. Furthermore, the study discovered that building surface-to-volume ratios S/V less than 0.38 could save more than 36% of the energy needed for cooling. Furthermore, a significant correlation was discovered between building surface-to-volume ratios S/V and energy demand for cooling.

Keywords: Surface-to-volume ratio, building orientations, Building proportions, Design Builder, Energy demand for cooling.

1 Introduction

In Egypt, the New Urban Communities Authority (NUCA) offers various housing program models to meet the growing demand for construction and to mitigate the negative effects of unplanned urban growth in order to provide adequate housing for every citizen in proportion to his or her income level. As a result, the New Urban Communities Authority built approximately 470 thousand housing units in 25 new cities[1]. Nowadays as the natural consequence of these new buildings and cities, there is a massive demand for energy to meet the ever-increasing number of these structures. Similarly, the neighborhood councils are implementing several land subdivisions projects in current cities allover the country. Furthermore, the neighborhood councils provide the necessary infrastructure, such as electricity[2].

As a necessary consequence, Egypt's Sustainable Development Vision 2030 was released in February 2016 to develop local strategies that contribute to energy savings in the building sector and other sectors. It also reflected the country's goals of developing a sustainable energy market. The Egyptian energy sector is the primary driver of socio-economic progress in Egypt, accounting for around 13% of Egypt's current GDP, rendering economic growth contingent on the country's stability. According to Egypt's most recent annual energy survey, Egyptian buildings use around 63% of overall electricity usage. One of the main causes of the demand for energy in the Egyptian buildings sector is cooling. More than 80% of the rising energy usage values in Egyptian buildings were attributed to the growing need for cooling [3].

Building physics, internal conditions, building geometry [4], building envelop, and glazing types are all widely acknowledged to have a considerable influence on improving thermal performance and energy efficiency [5-16]. Also, geometric configurations, specifically building proportions, can have an impact on the building's energy performance[17]. The surface-to-volume ratio and the width to length ratio are the most variables that affect building proportions.

The aforementioned factors that influence building energy performance are more in line with the vision of

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the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), which highlighted six issues related to building energy use [18]. Such points are the building characteristic, building configurations, outdoor design conditions[19-21], indoor design conditions, date and time, and operating schedules. Furthermore, solar energy has a considerable impact on the built indoor environment and energy consumption [22, 23].

This study looks at how different building proportions affect potential energy savings across four different building orientations in Aswan, Egypt, which has a hot, arid climate. Previous reports indicate that the residential sector accounts for 60% of all Egyptian buildings, with the number of residential buildings expected to triple to 23 million by 2030. As an outcome, residential building energy consumption was approximately 18.8% in 2010, increased to approximately 22% in 2018, and is expected to increase further by 2030. As a result, the study focuses on residential buildings, which are among the most energy-intensive building sectors when compared to other building sectors[2, 24].

Several factors affect the amount of solar radiation received to the external building envelope. One of the major factors that control the thermal performance of the building and its relationship with the surrounding environment is the building form. As a result, the amount of solar energy received, the rate of air infiltration, and the indoor environmental conditions can all be affected. The H- and L-forms, for instance, could provide self-shading of surfaces, lowering direct solar radiation [25]. Furthermore, wind movements and airflow patterns, as well as possible to maximize the use of natural light, are all influenced by the building form [26]. The building area and volume are mainly controlled by geometry parameters such as length, height, and width [12]. Generally, the total net façade area determines how much heat passes through the building envelope [27].

Various studies have highlighted the significant role of building form and its effects on energy consumption in buildings. Previously, the effect of the size of non-airconditioned areas surrounding air-conditioned spaces on building energy consumption was investigated in Seoul using the IES VE simulation software. The results demonstrate that temperature, direct solar radiation, and precipitation all have an impact on building energy consumption. Furthermore, the findings reveal that heating requirements in Korean residential buildings are roughly 8 times those for cooling. Even so, cooling loads in spaces with the identical width-to-depth ratio as spaces with a 4:1 width-to-depth ratio tended to be higher. However, when it came to heating load, the opposite was true [28].

Khalil et al[29], investigate the best design for an open office building form in three distinct cities with different climates using a genetic algorithm. Cairo, London, and Chicago are the three cities that have been investigated. They discovered that energy consumption has decreased by 22.76 %, 29.7 %, and 19.2 % in Cairo, London, and Chicago, respectively.

The surface-to-volume ratio (S/V ratio) and the width-to-length ratio are the two most important building proportions that influence the geometric form. The surface-to-volume ratio is an obvious criterion of urban size, depicting the total amount of exposed surfaces on buildings and thus their ability to interchange with the climate via natural ventilation, daylighting, and other means [30]. On the other hand, Increased heat loss in the winter and heat gain due to solar radiation exposure in the summer are both counteract indicators of a high surface-to-volume ratio (S/V ratio) [31].

AlAnzi et al [32], devised a new model for interpreting the influence of building form on the electrical energy demand in office buildings in Kuwait. The focus of this research is on the building's relative compactness and how it relates to the electrical energy demand. A constructed form's relative compactness is determined by the ratio of its volume to the surface area of its enclosure when compared to the most compact form of the same volume. According to the findings of this study, the effect of building form on the entire building energy consumption is dependent on relative compactness, window-to-wall ratio, and glazed windows type. Furthermore, it is discovered that the overall energy consumption is significantly and negatively relational to the relative compactness of the building, regardless of its form.

Kocagil et al [33], noticed that building form and settlement texture have an impact on the heating and cooling loads and the required energy for these purposes in Turkey's hot dry climate zone. Their study was applied in the traditional Diyarbakr houses. According to their study outcomes, even though the area/volume ratio A/V rises, so do the heating and cooling loads. Furthermore, the inner courtyard plan type requires the least heating and cooling loads of any of the building form alternatives, whereas the L-type plan requires the most.

According to Ling et al [34], the width-to-length W/L ratio affects the exposed surface-to-volume ratio S/V of the building form. S/V was found to be smaller in building forms with a higher W/L ratio. They claimed that the width-to-length ratio W/L and building orientation are the most fundamental factors that influence the relationship between solar insolation and building forms. However, their findings were linked to a hot and humid climate without any other climatic regions being studied.

Lee et al [35], look into the impact of urban and building form, as well as microclimate, on building energy consumption in Seoul. They discovered that microclimate elements like wind speed and humidity are important in determining how extremely energy the building uses.

Catalina et al [36], assessed the effect of the building form on energy demand for heating. Their research counts on the building form aspect (also known as building characteristic length), which has been identified as the ratio of the heated volume of the building (V) to the sum of all heat loss surfaces in contact with the outer environment, ground, or adjacent non-heated spaces. They investigated the heating demand of numerous forms with various building form factors and in several climates.

1.1 Problematic of the study

Based on previous studies, it was noticed that the width-to-length ratio and surface-to-volume ratio are the primarily responsible factors for thermal performance in various geometric forms. Unfortunately, the influences of urban form and building form on thermal performance in the buildings are not taken into account in newly planned urban districts in Aswan. Typical lands in districts are planned with different areas without considering the location's latitude, sun path during the day, and the effects of the building width-to-length ratio on internal thermal conditions.

As a result, the majority of building facades are highly exposed to direct solar radiation throughout the day, resulting in stressful heat conditions. Although there has been an increase in heat stress on the external facades in the study area, the effect of building proportions and building orientations has not previously been investigated in the same location. Additionally, the significance of the correlation between building surface-to-volume ratios S/V and energy demand for cooling purposes has not been previously investigated in past studies.

1.2 The Study objective

The main objective of this study is to improve the energy efficiency of buildings in hot arid regions, particularly in the early stages of urban planning for land subdivision projects, by choosing the appropriate building proportion and building orientation during the early stages of land subdivision projects and architectural design process.

2 Research Methodology

To determine the optimal width-to-length ratio (W/L) and surface-to-volume ratio (S/V) for residential buildings located in hot arid regions in terms of energy required for cooling, the study went through several steps, considering various building orientations. Simulations are conducted throughout the year. As a result, the studied area has obtained hourly weather data meant for the entire year via the Aswan University weather station. The obtained weather data was converted from the Comma Separated Value file (CSV) into epw file using the Energyplus weather statistics and conversions tool. The generated epw weather file was imported as input data for the simulation software (Design Builder).

Other input data, such as activity, construction, openings, and HVAC, were provided to the simulation software (Design Builder). The internal spaces were supposed to be fully air-conditioned, with 18.00°C and 25.00°C setpoints for heating and cooling, respectively. Building usage (hours of occupancy) was assumed to be constant according to the traditional Egyptian lifestyle [37]. Internal heat gain from occupancy and appliances, as well as energy demand for heating, and lighting were not considered in the study scope due to their minor contribution to total energy consumption in buildings located in hot arid regions [7, 13].

Additionally, this study has other limitations such as the window-wall ratio WWR, which has been assumed to be 10% because it is the most used ratio in residential buildings. Another limitation is the area of the building model, which is equal to 200m^2 as the most common building model in Aswan city land subdivision projects. **Fig 1**. depicts the study framework, which includes the study steps.

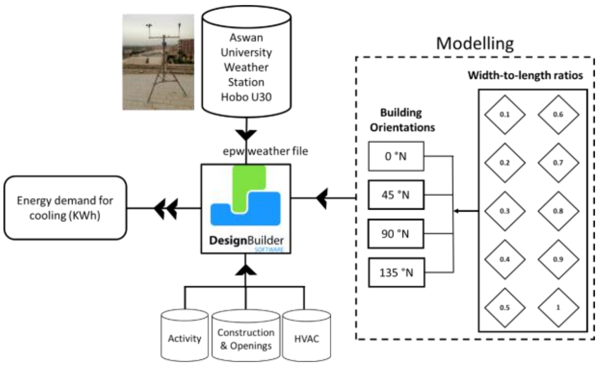


Figure 1. The study framework

2.1 The Simulation software

Evaluation of energy consumption in buildings is a critical step to get an energy-efficient building. Numerous techniques were adopted in the previous studies to analyze the building's energy consumption[38]. For instance, EnergyPlus[39], DOE-2[40], TRNSYS[41], IDA ICE (IDA Indoor Climate and Energy)[42], BLAST (Building Load Analysis and System Thermodynamics) [39], and other simulation software are used previously in the past studies.

In this study, the Design-Builder (V.4.0.0.105) software tool was used for modeling and simulation. Design-Builder is a software tool based on EnergyPlus that measures and controls energy, carbon, light, and comfort. Design-Builder enables all users to create complex models for buildings with minimal time and effort, and it provides users with potential energy for various purposes such as cooling, heating, and lighting. It assists all users to produce a diversity of outputs and reports to help users compare the performance of design options Furthermore, it aids designers in optimizing their building at any phase of design based on the priorities of the customer.

2.2 Weather data description

This study was conducted in Aswan City, which is in Egypt's hot dry arid zone. Hourly weather data from a fixed weather station at Aswan University was obtained for the year 2020. The collected data refer to the increase in air temperature during the summer months for more than 40ºC, particularly during the daytime hours. While it reaches minimum values during the winter season at the night hours. Maximum and minimum mentored air temperatures are 48.23ºC and 6.5ºC. While the maximum and minimum values of relative humidity reach 75.2% and 4.2%. The average dry air temperature during the year has been highlighted in **fig 2**. In the same context, the epw file was generated by using Energyplus weather statistics and conversions tool to provide Design Builder software with the actual weather data.

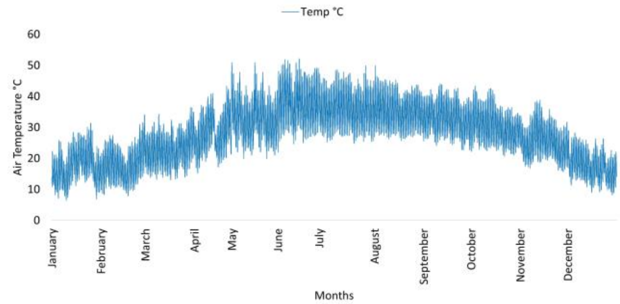


Figure 2. Dry air temperature for Aswan city.

2.3 Model Validation

The most common building model was validated using monthly simulated results in terms of energy consumption and collected monthly electricity bills in an Aswan family building. As shown in **fig 3**, the average error was about 9.76%. The validated building is 200m^2 in the area and has the following dimensions: 20m length, 10m width, and 15m height. As a result, the building has a (W/L) ratio of 0.5 and a (S/V) ratio of 0.367.

In order to simulate the current reality of the building model, several data were provided to the simulation software. For example, the external wall layers are 20mm cement plaster, 250mm brick, and 20mm for the innermost layer. Within that particular instance, the window-to-wall ratio is around 10%. The windows, meanwhile, are made of metal and have a single layer of 3mm thick glazing and with the following characteristics: Solar Heat Gain Coefficient (SHGC) is 0.861 and U-value is 5.894 W/m^{2}K).

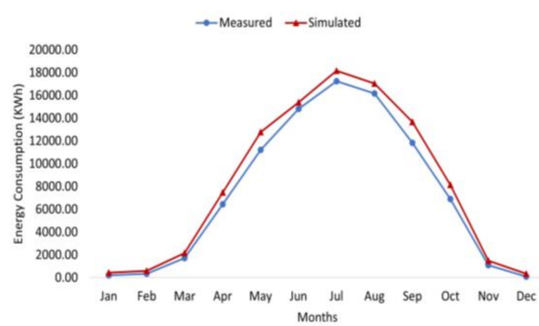


Figure 3. The indirect validation used in the common building model resulted in an average percentage error of 9.76%.

2.4 Investigated building options

As previously stated, the surfaces exposed to incident solar radiation have an impact on energy efficiency. As a result, this study investigates the effect of different building width-to-length ratios W/L associated with different surface-to-volume ratios S/V in four building orientations on cooling energy demand and potential energy savings. For the rectangular building shape, ten options representing ten width-to-length ratios were investigated associated with ten surface-to-volume ratios S/V. These width-to-length ratios were ranged from O1, which represented (W/L= 0.1), to O10, which represented (W/L= 1).

The building area was determined to be 200 m^2, which is one of the most common options in multi-story residential buildings in Aswan. The building height was assumed to be 15m (5 stories), which is the common height for residential buildings in Aswan city and the volume is assumed to be 3000 m^3. Furthermore, the study investigates all examined options in four building orientations: 0°N, 45°N, 90°N, and 135°N. In the 0°N, the building width faces the North direction. Where in the 90°N the building length faces the North direction. All the examined options are listed in **Table 1**. As well as the examined building orientations have been presented in **fig 4**.

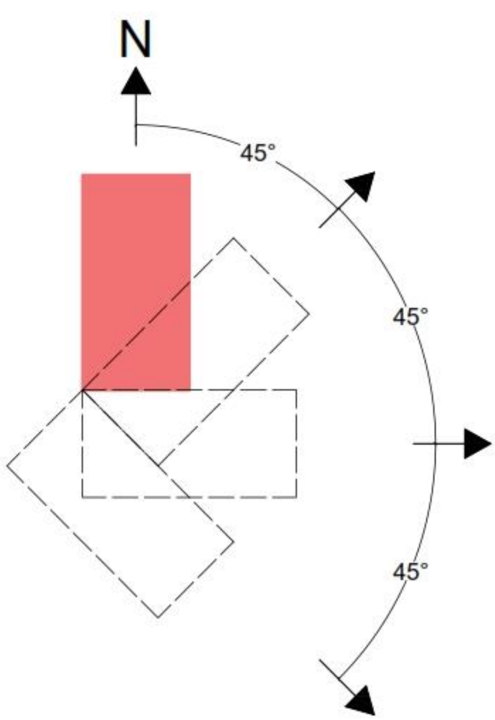
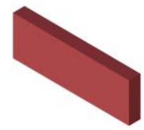
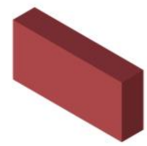
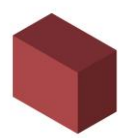


Figure 4. The investigated building's orientations.

Table1. Characteristics of the Studied Building Options.

Options	Building shapes	W/L ratio	S/V ratio
O1		0.1	0.559
O2		0.2	0.446
O3		0.3	0.402
O4		0.4	0.38
O5		0.5	0.367
O6		0.6	0.359
O7		0.7	0.354
O8		0.8	0.351
O9		0.9	0.35
O10		1.0	0.349

2.5 The simulation hypothesis

During and after the modeling step, simulation hypotheses were provided as input data to the simulation software. These hypotheses can be classified into two groups. The first one is about the location, and the second is about the building features. As previously stated, the location is Aswan, which has a different latitude than the other previously studied locations.

The building's envelop, which either includes exterior walls and openings, is one of the most important hypotheses. The exterior walls consist of three layers. The outermost layer is a cement plaster with a 20 mm thickness. Then layers of brickwork with 250 mm thickness. Finally, the innermost layer is cement plaster with 20 mm thickness.

The overall resistance and the thermal transmittance for this cross-section were obtained from the Design-Builder software. The total resistance for this external wall is 2.029 m^2K/W, and the thermal transmittance is 0.492 W/m^2K. This value then was checked by the following equation.

$$U = 1/\sum R \qquad (1)$$

where:

U is the thermal transmittance for the cross-section wall (w/m^2K)

∑R is the overall resistance of the cross-section wall (m^2k/K).

The assumed glazing types in this study were provided to the simulation software in accordance with the Egyptian Residential Energy Code (EREC), which identified four categories of glass that are commonly used in Egypt's four climatic zones. These categories are single glass, single reflective glass, double glass, and double reflective glass.

This study intends on a single glass in the simulation process due to the spread of using this glass category in different climatic regions in Egypt as well as its cheapest cost value. This glass has different thicknesses in Egypt. The most used glass is with 3mm thickness. **Table 2**. shows the simulation hypothesis for the study buildings.

Table 2. The simulation hypothesis for the building's options.

Item	Specification
Type	Multi-story residential building
Location	Aswan city
Latitude	23.97 N
Elevation above sea level	194.0 m
Floor area	200 m^2
No. of floors	5
Occupancy (Persons)	10 persons per floor
Windows	Single-glazed (SG) (3 mm)
Window-to-wall ratio	10%
U-value for glazing	5.894 W/m^2K
Solar Heat Gain Coefficient (SHGC) for glazing	0.861
Orientations	0°N, 45°N, 90°N, 135°N.
Lighting	400 Lux
Cooling setpoint	25.00 °C
Heating setpoint	18.00 °C

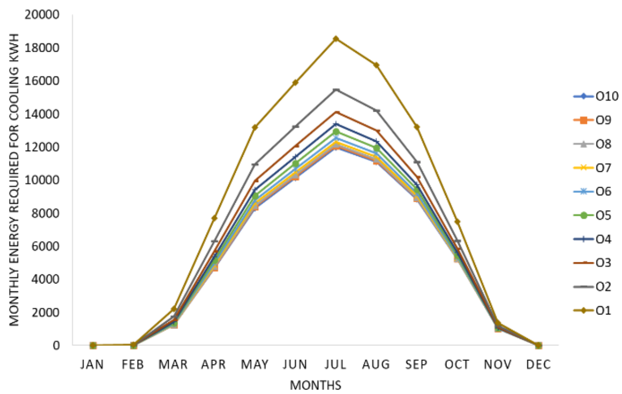
3. Results

The effect of different building proportions represented by width-to-length ratios (W/L) and surface-to-volume ratios (S/V) on cooling energy demand has been examined in four different orientations: 0°N, 45°N, 90°N, and 135°N. This study was conducted in Aswan city which is located in the hot desert of Egypt using Design Builder simulation software.

The findings show that there was a significant difference in the amount of energy required for cooling from April to October in all the studied building orientations. During the other months, all studied options almost had the same performance. Among all the studied building options, O1 which denotes the width-to-length ratio= (0.1) is the worst case. As a result, the effectiveness of all other studied building options was compared to O1 to determine the efficiency of each building option in the same orientation.

3.1 Effects of building proportions on the energy demand for cooling in the 0°N orientation.

The amount of energy needed to cool a building with a 0°N orientation ranged from 62565.02 kWh to 96594.76 kWh. According to the findings, the most energy-efficient building option in terms of cooling energy required is O10, which denotes the width-to-length ratios= (1), with an improvement of about 35.23 %. O2 is the less efficient building option when compared to the reference building option O1. It has reduced the amount of energy needed for cooling by 16.61 %. Other investigated building options reduced the amount of energy required for cooling by an average of 23.82 % to 34.75 %. **Fig 5** depicts the monthly energy required for cooling as well as the potential annual energy savings for the investigated building options in the 0°N orientation.



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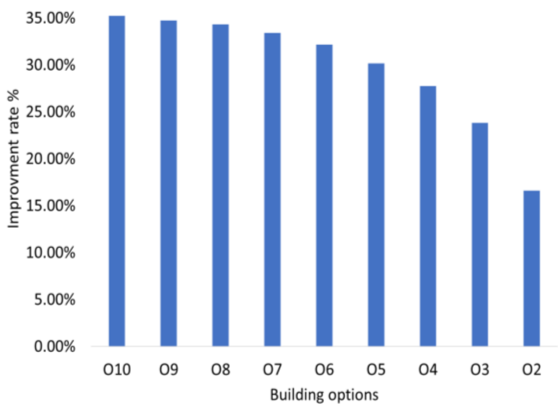


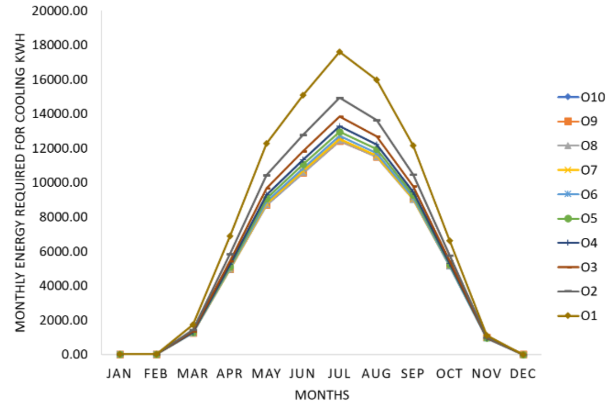
(b)

Figure 5. Simulation results for building orientation 0°N: a) Monthly energy required for cooling. b) Annual energy saving.

3.2 Effects of building proportions on the energy demand for cooling in the 45°N orientation.

The 45°N simulation results are practically similar to the results of the previously mentioned orientation 0°N. The cooling energy required ranged between 64636.54 kWh and 89448.88 kWh. In comparison to the results of O1, the energy efficiency ranged from 14.65 % to 27.74 %. The most efficient building option, as shown in **Fig 6**, is O10. However, O10 in this orientation is inefficient compared to the same building option in 0°N.

Furthermore, the findings of the study show that other investigated building options have a reasonable efficiency. For example, the annual energy savings obtained for the following building options O9, O8, O7, O6, O5, O4, O3, and O2 are 27.7 %, 27.55 %, 27.39 %, 26.64 %, 25.23 %, 23.6 %, and 20.61 % respectively.



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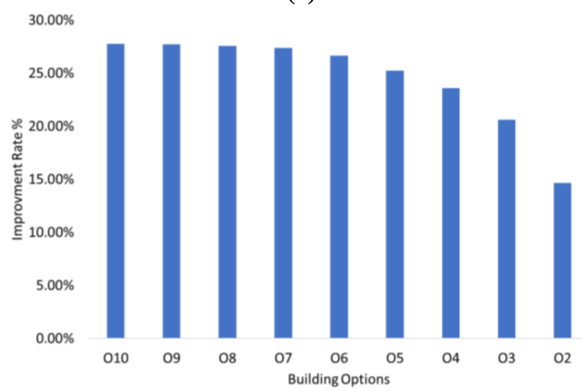


(b)

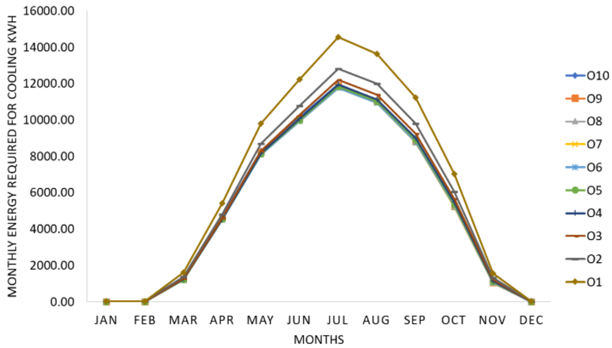
Figure 6. Simulation results for building orientation 45°N: a) Monthly energy required for cooling. b) Annual energy saving.

3.3 Effects of building proportions on the energy demand for cooling in the 90°N orientation.

The simulation results of 90°N orientation differ slightly from the previously tested orientations. Due to the significant reduction in cooling energy, this orientation generally produces the most efficient results in terms of energy required for cooling.

The results for the O10 are similar to those obtained with the same building option at 0°N orientation. However, since the amount of energy required for cooling in the reference case O1 has been decreased, O1 does not achieve the same improvement rate in this building orientation.

O6 has proven to be the most successful building option. According to the findings, the O6 has a cooling energy demand of 61550.59 kWh, followed by the O7 and O8, which have cooling energy demands of 61576.43 kWh and 61775.98 kWh, respectively. In terms of energy required for cooling, the building option with the lowest efficient performance among the studied options for the 90°N orientation is O2. However, it reduces cooling energy demand by approximately 9490.29 kWh, with a 12.31 % improvement rate. **Fig 7** depicts the energy demand for cooling in the 90°N orientation when various building options are considered, as well as the energy savings for each option.



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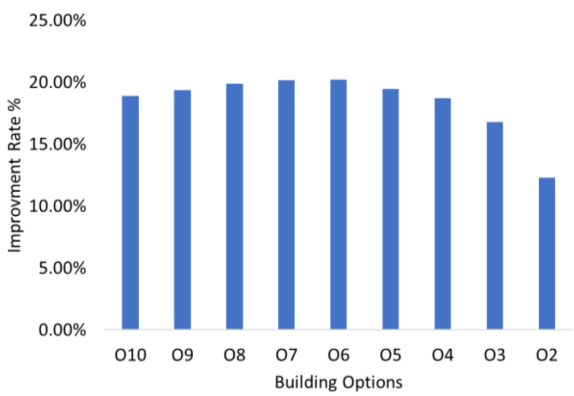


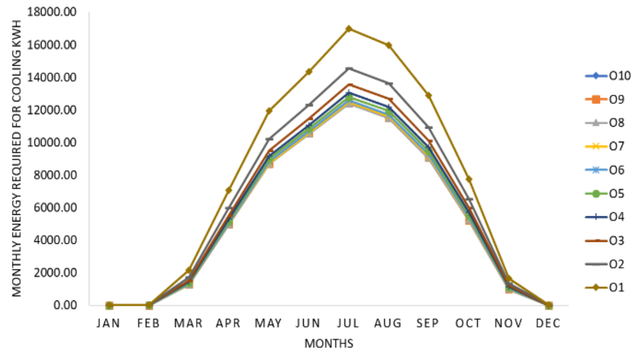
(b)

Figure 7. Simulation results for building orientation 90°N: a) Monthly energy required for cooling. b) Annual energy saving.

3.4 Effects of building proportions on the energy demand for cooling in the 135°N orientation.

According to the study findings, the energy demand for cooling in the 135°N orientation is strikingly similar to that in the 45°N orientation, with a slight increase across all studied building options. The cooling energy demand increased gradually from 64636.53 kWh to 90927.46 kWh. The cooling energy efficiency rate was also gradually increased from O2 to O10. As shown in **Fig 8**, the annual energy saving has been increased from 15.01 % to 28.91 %.

Furthermore, O10, O9, O8, and O7 performed nearly identically, with O10 exhibiting slightly higher efficiency. O10 saves about 26290.92 kWh while O9, O8, O7 save about 26203.18 kWh, 26188.68 kWh, and 25705.76 kWh respectively.



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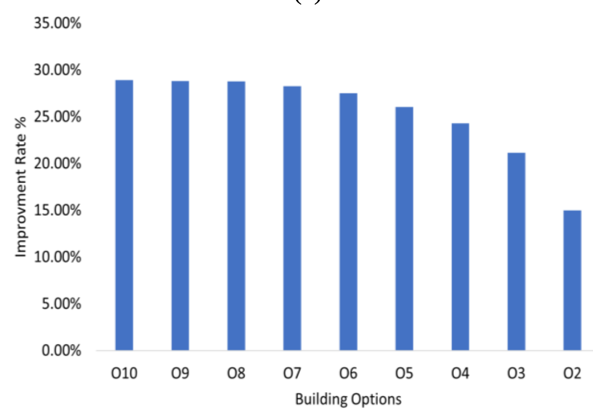


(b)

Figure 8. Simulation results for building orientation 135°N: a) Monthly energy required for cooling. b) Annual energy saving.

4. Discussion

It was discovered that buildings oriented in the 90°N orientation are the most energy-efficient in terms of cooling energy demand, using the building option O1 in the 0°N orientation as a benchmark for which all other options were compared. Building options O10, O9, and O8 that are oriented in the 0°N orientation is an efficient solution after buildings oriented in the 90°N orientation. Other building orientations are unsuitable for Aswan's buildings as shown in **Fig 9**.

Furthermore, increasing the width-to-length ratios lowers the cooling energy demand by a significant amount. Building width-to-length ratios of 0.6 in the 90 N orientation exhibited the best building characteristic among the studied buildings in Aswan city.

Considering a building height of 15m and a volume of 3000m^3, it was clear that a building with a short side on the western façade and a lower value of surface-to-volume ratios S/V could improve thermal performance and reduce cooling energy demand in hot arid climates. This could be due to the air conditioner's long hours of operation from 8 a.m. to 8 p.m., as well as the fact that outside dry bulb temperatures are lower in the early morning, reducing the cooling load in this period compared to the afternoon.

The cooling load increases gradually in the afternoon due to the effects of direct solar radiation on the western facades. As a result, reducing the area of the west facades reduces the amount of cooling energy required for the building, increasing its energy efficiency.

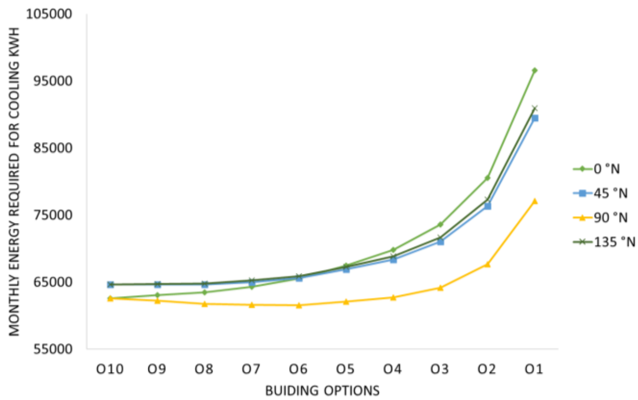
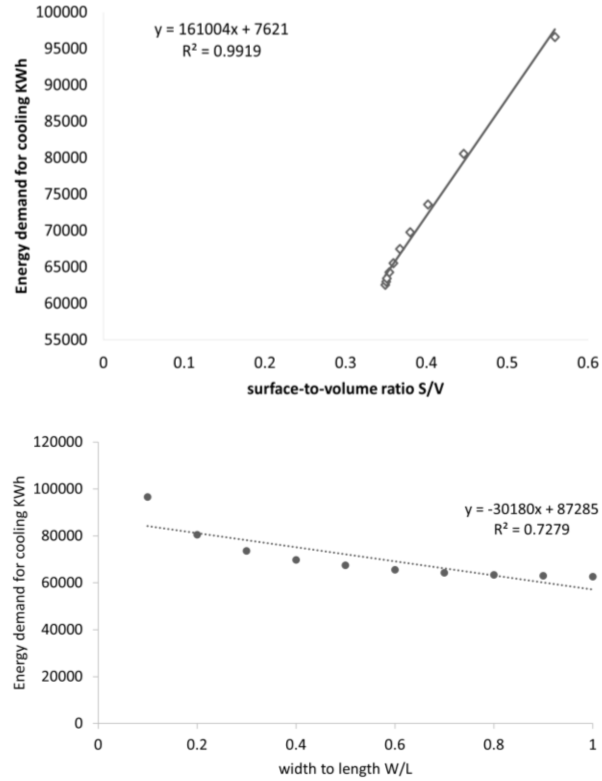


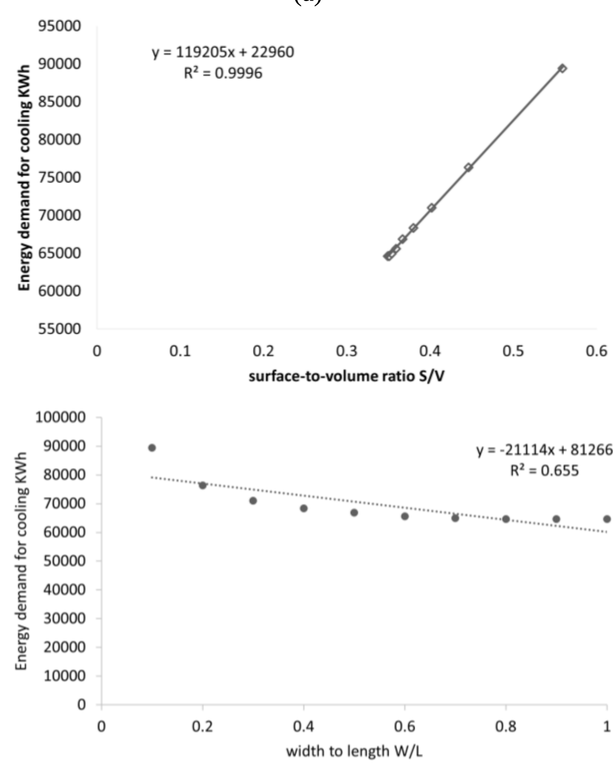
Figure 9. Effects of building orientations on the annual energy required for cooling in the studied building options.

As a result, when all of the above simulation hypotheses are considered, the results show a correlation between building surface-to-volume ratios S/V and cooling energy demand. The relationship between building surface-to-volume ratios S/V and cooling energy demand is shown in **Fig 10**.

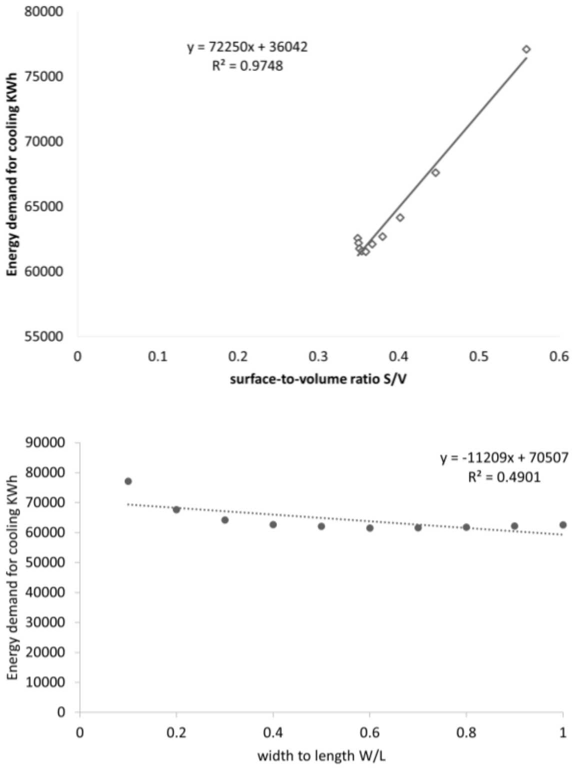
The cooling energy required for cooling is correlated with the surface-to-volume ratios S/V, with R2= 0.9919, 0.9996, 0.9748, 0.992 for the following orientations: 0°N, 45°N, 90°N, and 135°N, respectively. In other words, the surface-to-volume ratios (S/V) of buildings account for more than 97% of the cooling energy required for each orientation. In other words, building surface-to-volume ratios S/V are responsible for more than 97% of the required cooling energy for each orientation. This is a significant finding because the linear regression equation allows for the evaluation of energy needed for cooling using only building surface-to-volume ratios S/V data. This significance is linked to the high costs of cooling energy, which could be reduced with passive solutions



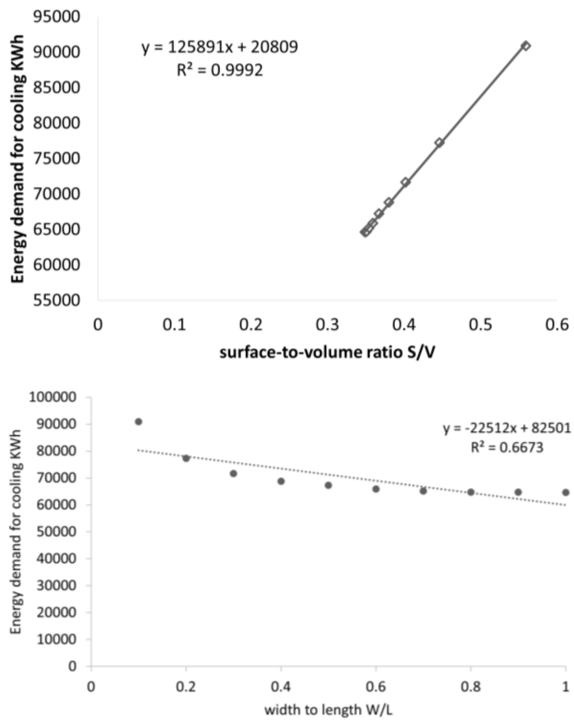
(a)



(b)



(c)



(d)

Figure 10. Diagram of correlation between Energy demand for cooling (KWh) and both the surface-to-volume ratio S/V and the width to length W/L in a) 0°N. b) 45°N. c) 90°N. d) 135°N.

While the statistical results indicate a significant relationship between the variables x and y, which are the surface-to-volume ratios S/V and the demand for energy for cooling purposes in buildings. A moderate relationship has been found between the variable x, which is the ratio of width to length, and the variable y, which is the demand for energy for cooling purposes. The width to length ratio W/L is correlated with cooling energy required for cooling with R2= 0.7279, 0.655, 0.4901, 0.6673 For the following orientations 0°N, 45°N, 90°N, and 135°N respectively. This is due to the fact that the surface-to-volume ratios S/V account for all geometric building dimensions, including the building's height. Meanwhile, the width to length ratio ignores the height of the building. **Fig 11** depicted the relationship between cooling energy demand and influencing factors such as (L/W), (S/V), and building orientation.

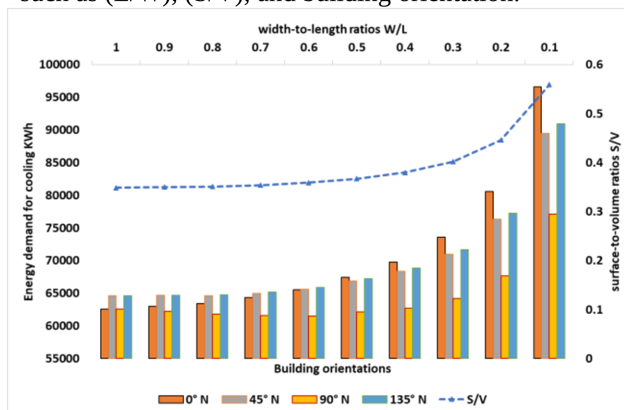


Figure 11. The energy demand for cooling, in conjunction with Factors influencing it as (L/W), (S/V), and building orientation

5. Conclusion

Egypt consumes a significant amount of energy, particularly in the building sector, and energy demand is growing as new cities spring up across the country. The effects of various building proportions on the amount of energy required for cooling in Aswan are investigated in this paper. Different building width to length ratios (W/L) and building surface-to-volume ratios (S/V) were investigated, as well as different building orientations. The research reveals that the building proportions have a significant impact on the amount of energy required for cooling. To be more specific, the best building orientation is for the building width to face west, and the building width to length ratios (W/L) should not be less than 0.4, and the building surface-to-volume ratios (S/V) should be as low as possible to reduce the amount of direct solar radiation that faces the facades. Furthermore, for all studied orientations, a significant correlation has been discovered between building surface-to-volume ratios S/V and energy demand for cooling with R2 equal to or more than 0.97. To summarize, the simulation tool could be beneficial to architects and decision-makers during the design phase. Other building orientations, as well as several variables such as window-to-wall ratios and glazing types, should be studied in relation to the building surface-to-volume ratios S/V and the building width-to-length ratios W/L in the future.

6. Recommendations

Based on the study's findings, the following recommendation has been presented:

- The total area of facades and roofs directly exposed to solar radiation for each climatic region should be considered in order to reduce heat transfer through these surfaces by investigating building proportions whilst also keeping these surfaces as small as possible.
- For the hot arid regions, it is recommended that the building's width to length ratio (W/L) be greater than 0.4 and its surface-to-volume ratio (S/V) be as low as possible.
- The significance of using climate simulation software early in the architectural design process to assess building envelope efficiency in terms of energy demand for cooling and heating.

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