Effect of Building Proportions on the Thermal Performance in the Mediterranean Climate of the Gaza Strip

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Abstract—This paper examines the effect of building proportions and orientations on the thermal performance of housing units located in the Mediterranean climate of the Gaza Strip. The study is carried out using computer programs, namely, ECOTECT and IES. The study concluded that the surface to volume ratio of buildings is considered the main geometrical parameter affecting the thermal performance of different geometric shapes. About 39% of energy consumption can be reduced through choosing the optimum building width to length ratio (W/L), which is 0.8. The roof to walls ratio has a considerable influence on the thermal response of buildings. Using the (roof/ walls) ratios, which range between 0.4 to 0.6 is preferable for both cooling and heating requirements. The horizontal arrangements of residential apartments are thermally better than the vertical arrangements of the same (S/V) ratio. Therefore, the study recommends to apply passive solar design strategies, especially with regard to geometric shape and orientation of buildings in the first stage of the design process.

Index Terms— Surface to volume ratio, Thermal performance, Energy saving, Efficient building design.

I INTRODUCTION

The building form is one of the main parameters, which determines the building envelope and its relationship with the outdoor environment. Hence, it can affect the received amounts of solar radiation, the rate of air infiltration and as a result the indoor thermal conditions. Some forms such as H-type or L-type can provide self-shading of surfaces, which can decrease the direct solar radiation [1]. Also, the building form affects wind channeling and air flow patterns, and the opportunities for enhancing the use of natural daylight [2]. Generally, geometry variables including length, height, and depth control the area and volume of the building [3]. The amount of heat coming through the building envelope is proportional to the total gross exterior wall area [4].

The main proportions affecting the geometric shape are the surface-to-volume ratio and the width to length ratio. The surface to volume ratio is a rough indicator of urban size, representing the amount of exposed ‘skin’ of the buildings, and therefore, their potential for interacting with the climate through natural ventilation, day lighting, etc [5]. However, the counter-indication to a high surface to volume ratio is the increase in heat loss during the winter season and heat gain due to exposure to solar radiation during the summer season [6]. Ling *et al.* (2007) [7] mentioned that the exposed surface-to-volume ratio (S/V ratio) for geometric shape depends on the width to length W/L ratio. Geometric shapes with higher value of W/L ratio contained lower value of S/V. They indicated that the main factors that determine the relationship between solar insolation level and building shape are W/L ratio and building orientation [7].

Different studies have dealt with the form aspects. AlAnzi *et al.* (2008) [8] developed a simplified method to predict the impact of shape on the annual energy use for office buildings in Kuwait. Basically, the study depends on the relative compactness (RC) of the building and correlates it with the annual energy use. The relative compactness based on the ratio between the volume of a built form and the surface area of its enclosure compared to that of the most compact shape with the same volume. The results of this study indicated that the effect of building shape on total building energy use depends on the relative compactness, RC, the window- to-wall ratio, WWR and glazing type. Also, it is found that the total energy use is inversely proportional to the building relative compactness independent of its form. Pessenlehner and Mahdavi (2003) [9] criticized the use of relative compactness in evaluation of the energy efficiency as it does not capture the specific three-dimensional massing of a building's shape, which can affect the thermal performance via self-shading for example. Also, changing orientation and distribution of glazing changes the building morphology, shading potential and its thermal performance without changing the relative compactness. They examined the annual heating load and overheating index for 12 different shapes with 3 glazing area options and 5 glazing distribution options and 4 orientations as a function of the relative compactness (RC). The results indicated a significant association between the values of compactness indicators RC and simulated heating loads of buildings with various shapes, orientation, glazing percentage, and glazing distribution [9]. However, these indicators do not appear to capture the geometry of a building to the extent necessary for the predictive assessment of the overheating risk.

Ling *et al.* (2007) [7] studied the effect of geometric shapes on the total solar insolation received by high-rise buildings in Malaysia. The study based on variations in the width to length ratio (W/L) and orientation for two generic building shapes (square and circular). The study didn't correlate the percentage of increasing in the width ratio with the percentage of decreasing in the surface to volume ratio (S/V) and the percentage of decreasing in the total solar insolation. Behsh, (2002) [5] suggested the relation between the roof area and walls area and the relation between the walls areas according to their orientation to be effective in evaluating the thermal response of different forms. Nevertheless, he simulated complex shapes and multistory shapes with different (S/V) ratio, which makes this ratio to be the main dominate for the thermal response. Catalina *et al.* (2011) [10] studied the impact of building form on the energy consumption. Their study based on using the building shape factor (L_b) (also called building characteristic length), which is defined as the ratio between the heated volume of the building (V) and the sum of all heat loss surfaces that are in contact with the exterior, ground or adjacent non-heated spaces. They examined the heating demand of several shapes with various building shape factor and in different climates.

It is found from all the previous studies that the surface to volume ratio is the main factor responsible for the thermal response in different geometric shapes. However, the impact of building geometries with the same (S/V) ratio has not been discussed extensively to find out the effect of self shading obtained by these geometries on the thermal performance. Generally, any specific shape can have different (S/V) ratios depending on its proportions, such as the width to length ratio (W/L) (also called the aspect ratio) and the roof to walls ratio. Building height is another important factor in determining the thermal response of buildings with the same (S/V) ratio. Understanding the relation between the building geometry, proportions, ratios and the thermal performance can be obtained by investigating the main parameters, which define the building form. These integrated parameters, which are the surface to volume ratio, the width to length ratio, the roof to walls ratio and the building height were handled in 3 cases as follows:

- The First Case: Studying the Effect of Width to Length Ratio (W\L) with Constant Volume.
- The Second Case: Effect of (W\L) Ratio and (Roof/Walls) Ratio on the Thermal Performance.
- The Third Case: Effect of Height with Constant Surface to Volume Ratio on the Energy Consumption.

II. SIMULATION TOOLS

ECOTECT is a software package with a unique approach to conceptual building design. It offers a wide range of internal analysis functions, which can be used at any time while modeling. These provide almost instantaneous feedback on parameters such as sun penetration, potential solar gains, thermal performance, internal light levels, reverberation times and even fabric costs [11]. ECOTECT based on the CIBSE steady state methods. This method uses idealized (sinusoidal) weather and thermal response factors (admittance, decrement factor and surface factor) that are based on a 24-hour frequency [12].

The Integrated Environmental Systems (IES) software is an integrated suite of applications linked by a Common User Interface (CUI) and a single Integrated Data Model (IDM). This means that all the applications have a consistent "look and feel" and that data input for one application can be used by the others, [13]. Simulations were performed using the ECOTECT software. Also, the virtual environment (IES) software was used to validate the simulation results. The 3D models were created using *ModelIT*. Then the solar shading analysis was performed using *SunCast*. Finally, a dynamic thermal simulation was carried out using *ApacheSim*. The simulation results were expressed in terms of annual total loads (in MWh).

A. Study Assumptions

Simulations were carried out during the months of January–December. The internal spaces were assumed to be fully air conditioned with the heating and cooling set points were assumed to be 18.0^0C and 26.0^0C respectively. Using of buildings (hours of operation) was assumed to be on continuously. As the study focuses on the incident solar radiation as one of the most important variables in the Mediterranean climate affecting the heating and cooling energy consumption, the internal heat gain from occupancy and appliances as well as the ventilation heat gain weren't considered in the study. Other environmental parameters, including natural ventilation, and daylight are also considered out of the research scope. External walls have U-values of 1.77 (W/m2. K) in ECOTECT and 1.9487 (W/m2. K) in IES. The roof U-values are 0.896 (W/m^2. K) in ECOTECT and 0.9165 (W/m^2. K) in IES. Glazing U-values are 6 (W/m^2. K) in ECOTECT and 5.5617 (W/m^2. K) in IES. The values of Thermal Transmittance, U-value for walls, roof and floor were assumed to achieved the minimum requirements of the U-values as recommended by the Palestinian code for energy efficient building (2004) [14]. For solar radiation calculations, ECOTECT uses hourly recorded direct and diffuse radiation data from the weather file.

B. CLIMATE

The Gaza Strip is a coastal area in the west-southern part of Palestine, with an area equals (365 km^2) [15]. The geographical coordinates of the Gaza Strip are 31° North, and 34° East [16]. According to ARIJ, (2003) the Gaza Strip forms a transitional zone between the sub-humid coastal zone of Palestine in the north, the semiarid loess plains of the northern Negev Desert in the east and the arid Sinai Desert of Egypt in the south [15]. According to the Koppen system for climatic zoning, Gaza has a Mediterranean subtropical climate with dry summer and mild winters. This climate is classified as C_{sa} indicating that the warmest month has a mean temperature above 22°C. the average daily mean temperature which ranges from 25°C in summer to 13°C in winter [15], see Appendix 1.

III. THE FIRST CASE: Studying the Effect of Width to Length Ratio (W\L) with a Constant Volume

A. The Study Parameters

The study correlated the percentage of increasing in the width to length ratio (W/L) with the percentage of decreasing in the surface to volume ratio (S/V) and the percentage of decreasing in the total solar insolation. Ten width to length ratios were adopted for the rectangular shape ranging between 0.1 to 1 in one degree steps. The area, height and volume for all the ten cases were kept constant. The area was taken to be 500 m^2 , which represents one of the common options in multi story residential buildings in Gaza. Also, the building height was taken to be 20m (6 storeys) and the volume was taken to be 10000 m^3. Table 1, illustrates the ten cases. Combinations of parameter values analyzed in this study are summarized in Table 2. Ten values of orientation were considered, namely 0°E, 10°E, 20°E, 30°E, 40°E, 50°E, 60°E, 70°E, 80°E and 90°E as shown in Figure 1.

TABLE 1
Parameters of the Investigated Cases

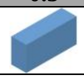
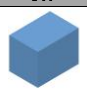
W\L	0.1	0.2	0.3	0.4	0.5
Perspective					
S/V Ratio	0.36	0.29	0.26	0.24	0.23
W\L	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Perspective					
S/V Ratio	0.23	0.23	0.23	0.23	0.23

TABLE 2
Combination of Parameters Investigated in the Study

Shape	W\L ratio	Orientation
Rectangular	0.1- 0.2- 0.3- 0.4- 0.5-0.6- 0.7- 0.8- 0.9- 1	0E- 10E- 20E- 30E- 40E- 50E- 60E- 70E- 80E- 90E

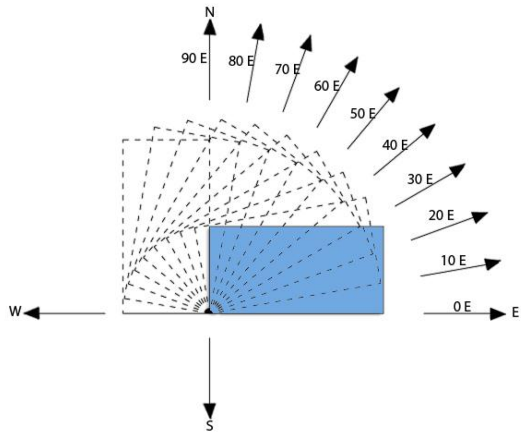


Figure 1. The Ten values of building's orientations considered in the study

B. Results

- Effect of Width to Length Ratio (W/L)

Figure 2,3 show the effect of changing the (W/L) ratio at different orientations on the total loads throughout the year using the ECOTECT and IES. The results indicate that the total loads for the simulated shapes are reduced by 39.6% with increasing the width to length ratio (W/L) from 0.1 to 1 at the East- West orientation (0°E) in ECOTECT. It is noticed that the reduction in the total loads is more remarkable with increasing the (W/L) ratio from 0.1 to 0.5. About 37.4% of reduction in the total loads occurs with increasing the (W/L) ratio from 0.1 to 0.5 while only 3.5% of the reduction occurs with increasing the (W/L) ratio from 0.5 to 1. It is noticed that the optimum width to length ratio is 0.9 with a slight effect of changing the width ratio from 0.5 to 1. So, it is advisable to select the building's (W/L) ratio in the range of 0.5 to 1 in order to reduce the energy consumption. The same trend can be observed using IES as about 31.8% of reduction in the total loads occurs as a result of increasing the width to length ratio (W/L) from 0.1 to 1 at the same orientation.

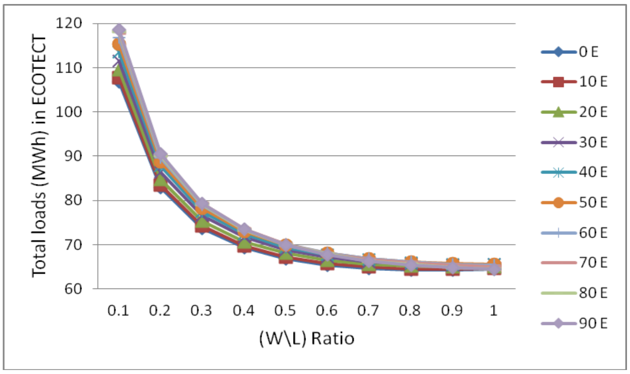


Figure 2. Effect of (W/L) ratio on the annual loads, using Ecotect

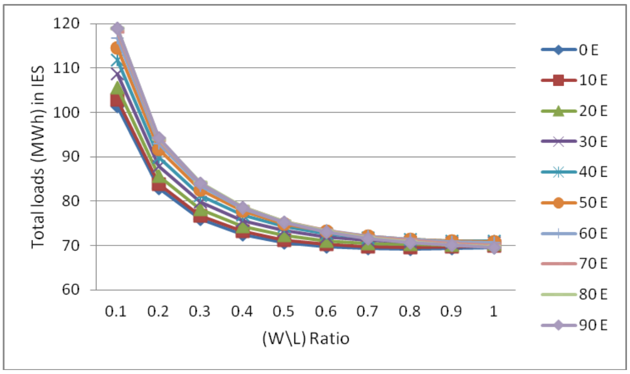


Figure 3. Effect of (W/L) ratio on the annual loads, using IES

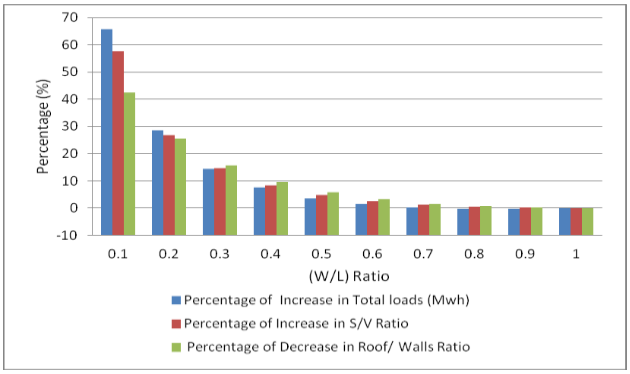


Figure 4. Effect of changing (W/L) , (S/V), (R/W) ratios on the total loads

Changing the building orientation from the East- West orientation (0°E) to the North- South orientation (90°E) can increase the effect of the width to length ratio. The total loads are reduced by 45.7% with increasing the width to length ratio (W/L) from 0.1 to 1 at the North- South orientation (90°E) in ECOTECT. Also, increasing the width to length ratio (W/L) from 0.5 to 1 reduced the total loads by about 7.9% and 7.5% in ECOTECT and IES respectively in the North- South orientation comparing with only 3.5% and 1.5% of reduction in the case of the East- West orientation in ECOTECT and IES respectively. So that, more attention must be paid to the width ratio in the North- South orientation even between the shapes with (W/L) ratios range between 0.5 and 1.

It is noticed that changing the (W/L) ratio affects the total exposed surface and the relation between its two main components, the roof and the walls. As the (W/L) ratio increases and the building reaches to the square shape (W/L= 1), the exposed surface decreases at the same trend of decreasing the total loads. Taking a fixed roof area in all cases, it is reasonable that the (roof/walls) ratio increases with increasing the (W/L) ratio. The square shape (W/L= 1) was taken as a reference shape. The percentage of difference between the other nine shapes and the reference shape in the four variables; (W/L) ratio, (S/V) ratio, (Roof/Walls) ratio and the total loads was evaluated.

Figure 4, summarizes the relation between the percentage of changing in the (W/L) ratio and the (S/V) ratio, (Roof/Walls) and the total loads as a consequence. It can be mentioned that decreasing the (W/L) ratio by 90% from the reference shape (W/L= 1) to the worst ratio (W/L= 0.1) can increase the (S/V) ratio by about 57.7% and decreasing the (roof/walls) ratio by 42.5% and increasing the total loads by 65.7%. So it is recommended to decrease the (S/V) ratio and increase the (Roof/ Walls) ratio and increase the (W/L) ratio.

- Effect of Orientation

Figures 5,6 illustrate the effect of changing the form's orientation on the total loads for various width ratios using both ECOTECT and IES respectively. Changing the orientation of the simulated shapes with different width to length ratios (W/L) is seen to have the ability to change the required energy, as it affects the amounts of solar radiation falling on the various components of the building surface. The results indicate that the total loads for the simulated shapes are increased by 11% with changing the orientation from the East-West orientation (0°E) to the North-South orientation (90°E) for the shape with width to length ratio (W/L) equals to 0.1 in ECOTECT. This ratio is decreased to reach 9.1% in the case of the shape with width ratio (W/L) equals to 0.2 and 7.6% in the case of the shape with width to length ratio (W/L) equals to 0.3.

As the shape approaches to a square, the effect of orientation in changing the total loads is decreased. This is due to the four equal sides of the square shape, which makes the East-West orientation (0°E) and the North-South orientation (90°E) have the same performance. Contrary, the worst orientation in this case is (45°E) with unnoticeable difference in the total loads, which reaches to 1.8%. In IES results, changing the orientation from the East-West orientation (0°E) to the North-South orientation (90°E) increased the total loads by about 17.3%, 13.6% and 10.7% in the case of the shapes with width to length ratios (W/L) equal to 0.1, 0.2 and 0.3 respectively. The ratio decreased to reach about 1.9% between the East-West orientation (0°E) and (45°E) orientation in the case of the square shape.

It should be mentioned that the trends of Ecotect and IES results are almost identical. The small variations in the values of the results are referred to the deference in the thermal properties of the building materials used in the two programs. This clearly validates the results and indicates high reliability of the archived buildings performance.

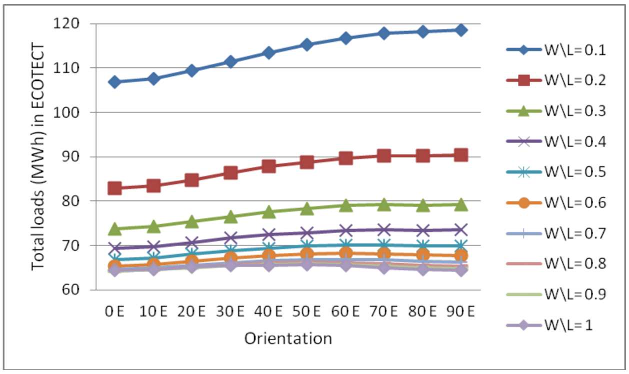


Figure 5. Effect of orientation on the total loads, using ECOTECT

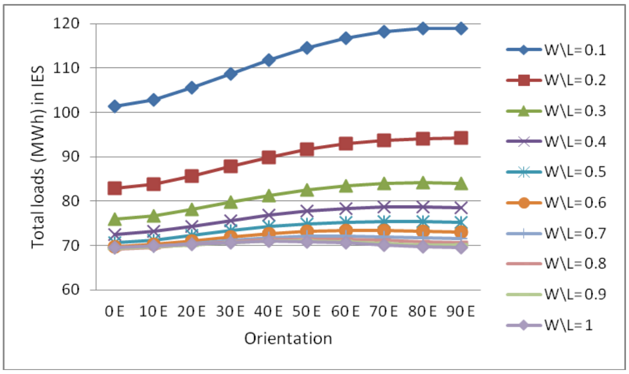


Figure 6. Effect of orientation on the total loads, using IES

- Incident Solar Radiation

The results indicate that the shapes with (W/L) ratio equals to 0.1 receives the highest amounts of incident solar radiation on the south façade, as shown in Figure 7. It is considered that this shape has the highest area of the south façade, which exceeds by about 216% that of the shape with (W/L) ratio equals to 1. This explains the worst thermal performance of this shape from the energy consumption point of view. It is observed that the shape with (W/L) equals to 0.1 receives about 56.7% of its total solar radiation on its south façade comparing with 27.3% and 19.8% for the shapes with (W/L) equal to 0.5 and 1 respectively. The south façade forms about 39.2% from the total exposed surface area of the shapes with (W/L) equals to 0.1.

It is evident that the percentage of incident solar radiation on the south façade is the main responsible factor affecting the energy consumption of the three considered simulated shapes with (W/L) ratio equals 0.1, 0.5 ,1. For more illustration, Figure 8, shows the same trend for the percentage of incident solar radiation on the south façade and the total required energy for the three simulated shapes.

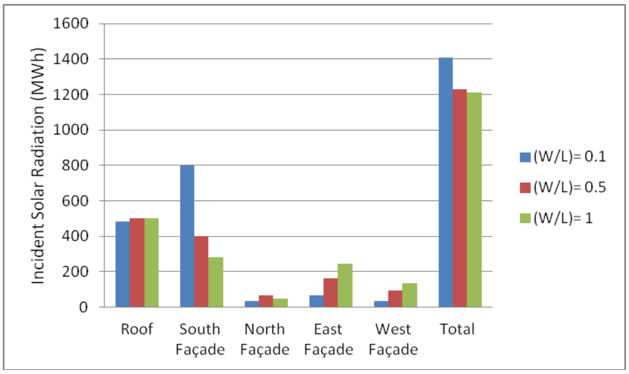


Figure 7. Incident solar radiation on the forms' surfaces

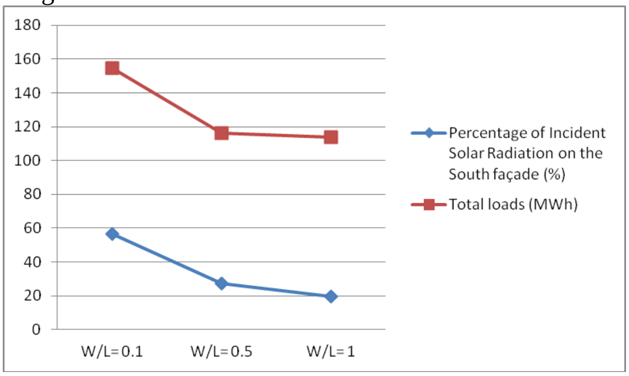


Figure 8. The relationship between the solar radiation on south elevation of the form and the total loads

IV. THE SECOND CASE:

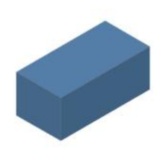
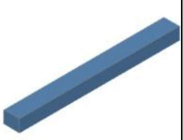
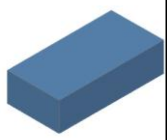
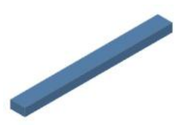
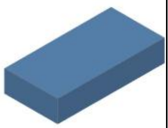
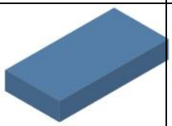
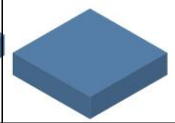
Effect of (W\L) Ratio and (Roof/Walls) Ratio on the Thermal Performance

A. The Study Parameters

The study introduces the main relations affecting the form morphology. Building morphology can be determined throughout the relationship between its components. The main relation in this case is that between the roof area and the walls area, which affects the building height. The second relation is the (W/L) ratio, which affects the building elongation. For investigating the effect of these ratios, 10 (W/L) ratios ranging between (0.1-1) with 5 (Roof/walls) ratios ranging between (0.2-1) were examined. The volume of the base case was obtained from the assumption that the minimum width of the rectangular form is 4 m, as it represents the average of a room width. The maximum length can be obtained from the smallest (W/L) ratio, which equals to 0.1. This means that the rectangular length is 40 m and the area (A) is 160 m^2, which represents the average area of residential units in Gaza. The maximum height can be obtained from the (Roof/walls) ratio equals to 0.1, which mean that the walls area is 1600 m^2 and the total exposed surface area is 1760 m^2. The perimeter for the assumed base case equals to 88 m and the height equals to 18.18 m (6 storey), and thus the volume equals to 2909 m^3. All the forms investigated in this study have the same volume, Table 3 illustrates this set of forms.

TABLE 3

The Simulated Cases in the Study

Ratios	W\L= 0.1	W\L= 0.5	W\L= 1
Roof\wall = 0.2			
Roof\wall = 0.4			
Roof\wall = 0.6			
Roof\wall = 0.8			
Roof\wall = 1			

A. Results

- Effect of Width to Length Ratio (W/L)

Apparently, it can be noticed that with increasing the width to length ratio (W/L) the required loads gradually reduced at all values of (Roof/Walls) ratio, as shown in Figure 9. With increasing the width to length ratio (W/L) from 0.1 to 1 at the East- West orientation (0°E), the total loads for the simulated shapes are reduced by 31.6%, 27%, 27%, 27.2%, 27.5% for the shapes with roof/walls ratio equals to 0.2, 0.4, 0.6, 0.8 and 1 respectively. This means that the effect of the (W/L) ratio in changing the total loads reduces with increasing the (Roof/Walls) ratio.

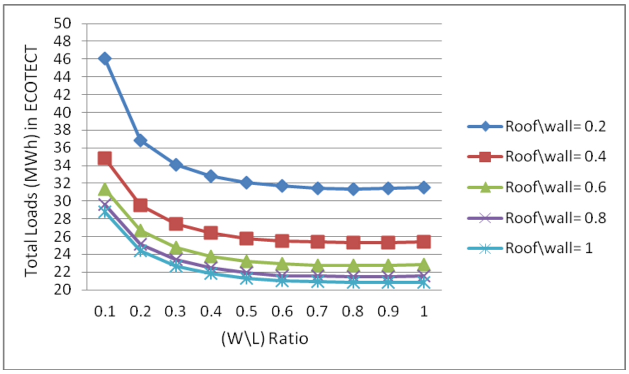


Figure 9. Effect of (W/L) ratio at various (R/W) rations on the total loads

- Effect of (Roof/Walls) Ratio

Increasing the (Roof/ Walls) ratio, which means decreasing the building height with the same volume have considerable effects on the required energy as shown in Figure 10,11. Increasing the (Roof/ Walls) ratio from 0.2 to 1 at the East- West orientation (0°E) reduced the total energy by 30.9%, 29% and 28.8% for the shapes with the width to length ratio (W/L) equals to 0.1, 0.5 and 1 respectively. This means that varying the width ratio has small effects (about 2%) in affecting the impact of the (Roof/ Walls) ratio on changing the total loads. The same trend can be observed in IES results, as increasing the (Roof/ Walls) ratio from 0.1 to 1 reduced the total energy by 22.4%, 24.9% and 26.4% for the shapes with the width to length ratio (W/L) equals to 0.1, 0.5 and 1 respectively as shown in Figure 10.

The important point to be mentioned about IES results, is that the total loads decreased with increasing the (Roof/ Walls) ratio until the ratio equals 0.6. After that the total loads increased in a slight percentage. For more explanation, increasing the (Roof/ Walls) ratio from 0.1 to 0.6 reduced the total loads by about 27.3%, 29.1% and 30.1% for the shapes with the width to length ratio (W/L) equals to 0.1, 0.5 and 1 respectively. However, increasing the (Roof/ Walls) ratio from 0.6 to 1 increased the total loads by about 4%, 3.3% and 2.9% for the shapes with the width to length ratio (W/L) equals to 0.1, 0.5 and 1 respectively.

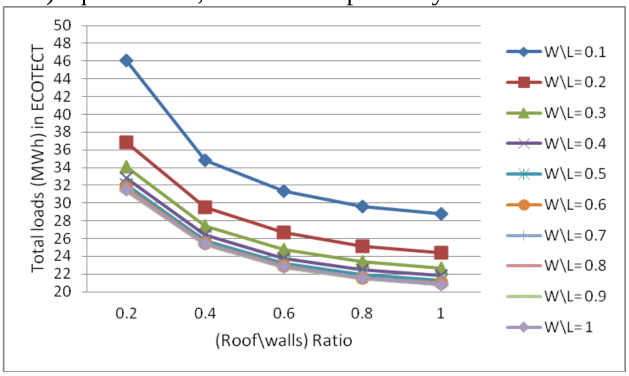


Figure 10. Effect of (R/W) ration on the total loads, using Ecotect

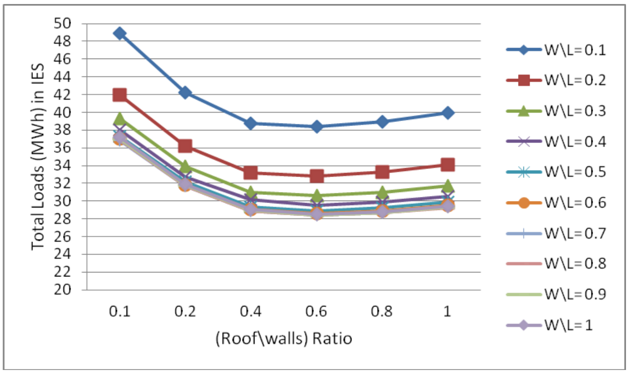


Figure 11. Effect of (R/W) ration on the total loads, using IES

In order to explain this behavior, Figure 12, shows the relationship between (R/W) ratio and (S/V) ratio for the form with (W/L) equals 0.5. It can be shown that the (S/V) ratios for the simulated cases have the same trend of the total loads. Increasing the (Roof/ Walls) ratio from 0.1 to 0.6 reduced the (S/V) ratio by about 24.9%, which is compatible with the percentage of reduction in the total loads (29.1%). Increasing the (Roof/ Walls) ratio from 0.6 to 1 increased the (S/V) ratio by about 5.4%. Hence, the thermal behavior of the simulated cases can be explained as a consequence of changing the (S/V) ratio. Determining the fabric heat gain for the same cases can also explain their behavior. As shown in Figure 13, the heat loss during the winter period (December- February) decreases by about 31% with increasing the (Roof/ Walls) ratio from 0.2 to 1, which decreases the heating loads in the shapes with higher (Roof/ Walls) ratios. However, the heat gain during the summer period decreases by about 11% with increasing the (Roof/ Walls) ratio from 0.2 to 0.6, which decreases the cooling loads. Increasing the (Roof/ Walls) ratio from 0.6 to 1 increased the heat gain by about 3%.

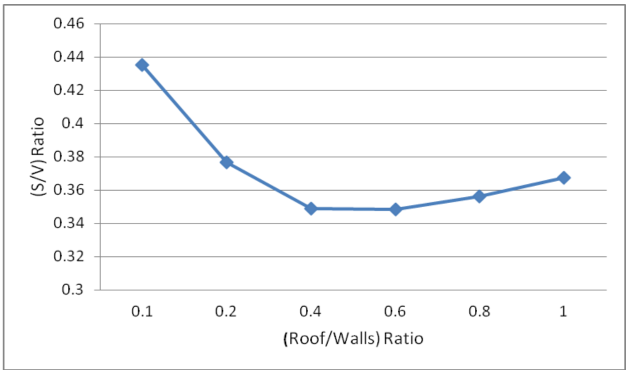


Figure 12. The relationship between (R/W) and (S/V) ratio for the form with (W/L) equals 0.5

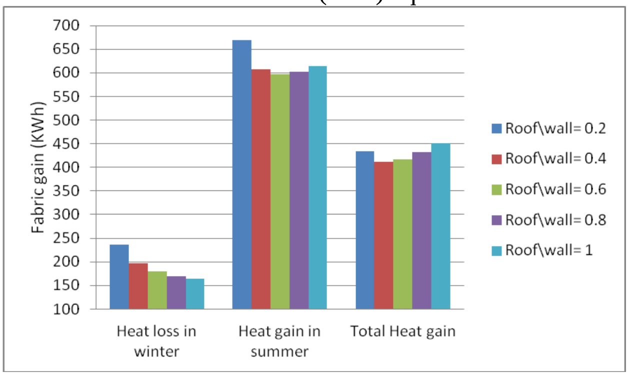


Figure 13. Fabric gain for the simulated cases

It can be concluded that the (Roof/ Walls) ratio equals to 0.6 is more preferable for both cooling and heating requirements. Taking into consideration the unnoticeable difference in the total loads between the two values of the (Roof/ Walls) ratio equals to 0.4 and 0.6, there is a flexibility in selecting the (Roof/ Walls) ratio to range between 0.4 and 0.6. Also, the width to length ratio (W/L) equals 0.8 is advisable from the energy saving point of view.

V. The Third Case:

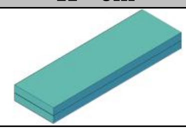
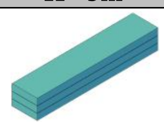
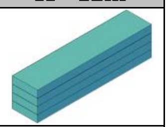
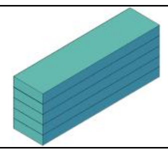
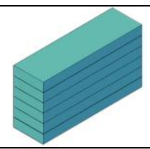
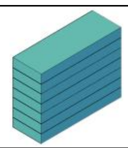
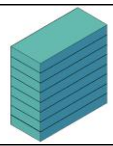
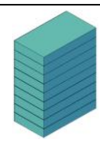
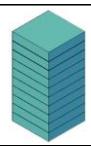
Effect of Height with Constant Surface to Volume Ratio on the Energy Consumption

A. The Study Parameters

The study investigated one of the main parameters in the building form, which is height. In order to compare the performance of buildings with different heights, the building volume was kept constant. It is evident that increasing the height would decrease the area and thus the (Roof/ Walls) ratio would change in each case. Nine heights were adapted to the rectangular shape, namely 6, 9, 12, 15, 18, 21, 24, 27 and 30 m. The storey height was taken to be 3 m, which means that each one of the simulated cases increases by one storey from the previous case. The smallest area was assumed to be 200 m^2 and the maximum height was assumed to be 30 m (10 storey) and thus, the assumed volume was taken to be 6000 m^3. The (W/L) ratio in the base case was assumed to be 1 (square shape) and the exposed surface area was considered to be 1897 m^2 and thus, the (S/V) ratio was taken to be 0.316. As the purpose of this study is to investigate the height effect, the (S/V) ratio is assumed to be fixed for all the simulated cases. In order to achieve this purpose, the area increased as the height reduced and the (W/L) ratio also increased. Combinations of the parameter values analyzed in this study are summarized in Table 4. The studied forms were simulated at different orientations ranging from 0°E to 90°E in ten degrees steps.

TABLE 4

Parameter combinations of Forms investigated in the study

Height	**H= 6m**	**H= 9m**	**H= 12m**
Perspective			
Area	1000	666.6	500
(R/W)	1.11	0.54	0.35
(W\L)	0.30	0.20	0.21
Height	H= 15m	H= 18m	H= 21m
Perspective			
Area	400	333.33	285.71
(R/W)	0.26	0.21	0.17
(W\L)	0.25	0.29	0.35
Height	H= 24m	H= 27m	H= 30m
Perspective			
Area	250	222.222	200
(R/W)	0.15	0.13	0.11
(W\L)	0.44	0.56	1

A. Results

- Effect of Height

The results indicate that the total loads for the simulated shapes are increased by 62.5% with increasing the building height from 6 m to 30 m at the East- West orientation (0°E), as shown in Figure 14. The increasing percentages are 20.6%, 33.1%, 41.7%, 47.7%, 55.5%, 58.7% and 62.5% with increasing the building height from 6 m, 9 m, 12 m, 15 m, 18 m, 21 m, 24 m, 27 m and 30 m. It can be noticed that there is a nonlinear relationship between the building height and the total loads. As the building height increases, the percentage of increasing in the total loads is decreased.

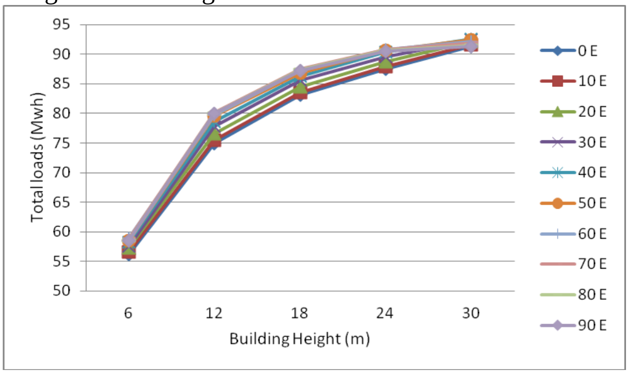


Figure 14. Effect of height on the required load

In order to determine the main factor affecting the total loads when increasing the building height, the shape with 6 m height was taken as a reference shape, because it requires the lowest energy load. The percentage of increasing in the total loads and decreasing in the (Roof/Walls) ratio and increasing in the (W/L) ratio between the other eight shapes and the reference shape was evaluated, as shown in Figure 15. It is observed that the trend of the curve of the percentage of increasing in the total loads is similar to the trend of the curve of the percentage of decreasing in the (roof/walls) ratio. It can be concluded that increasing the total loads required by the building geometries with the same (S/V) ratio as a result of increasing the height is more related to the decreasing in the (Roof/Walls) ratio which increases the vertical walls surfaces.

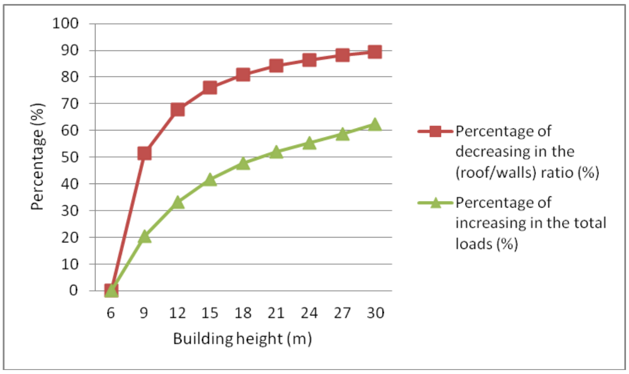
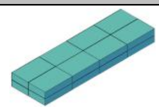
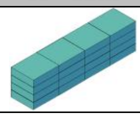


Figure 15. The relation between the percentage of increasing in the total loads and decreasing in the (roof/ walls) ratio

Three options of buildings height (6m, 12m and 24 m), which involve the same volume and exposed surface areas, were considered, as shown in Table 5. Each of them was divided into the same number of residential apartments (16 apartments), where each apartment has the same area (125 m^2), as it is considered one of the common options in the apartment buildings in the Gaza Strip. As stated above, the total loads of the geometry with 12m and 24m heights increase by 33% and 55.5% respectively with reference to the load required by the geometry of 6m height. This means that the horizontal arrangements of residential apartments are better thermally than the vertical arrangements of the same (S/V) ratio.

TABLE 5

Configuration of three building forms

Height	H= 6m	H= 12m	H= 24m
Perspective			
Percentage of increasing in the total loads (%)	0	33%	55.5%

- Effect of Orientation

The East-West orientation (0°E) was taken as a reference case, as at which forms it require the lowest amount of energy. The percentage of difference between the other nine orientations for four heights (12 m- 18 m- 24 m- 30 m) and the reference shape was evaluated. As illustrated in Figure 16, changing the orientation from (0°E) to (90°E) can increase the required heating and cooling loads by 6.8%, 5% and 3.5% for the cases of 12 m, 18 m and 24 m height respectively.

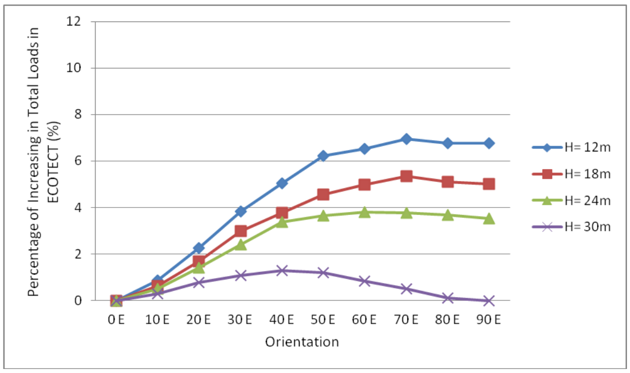


Figure 16. Effect of orientation on the total loads

VI. Conclusion

It is concluded that the surface to volume ratio is one of the most important aspect affecting the thermal performance of geometric shapes. The other form parameters including

(W/L) and (R/W) ratios have also a considerable effect on the buildings requirements of energy.

The incident solar radiation falling on the building surfaces has a significant effect on the thermal response. The compact forms, which contain the same volume with the smallest (S/V) ratio is recommended in the climate of the Gaza Strip. More attention must be paid to the width to length ratio in the North- South orientation even for the shapes of width to length ratio ranging between 0.5 and 1. About 20.5% of the cooling loads can be increased with changing orientation from the East-West orientation (0°E) to the North-South orientation (90°E) for the shape with width to length ratio (W/L) equal to 0.1. So, it is recommended to pay more attention in selecting orientations, especially for the shapes with small width to length ratios. It is recommended to use shapes with the (roof/ walls) ratios range between 0.4 to 0.6, which are more preferable for both cooling and heating requirements. It is recommended to use horizontal arrangements for residential apartments, which were found to be better thermally than the vertical arrangements of the same (S/V) ratios.

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Appendex1: Climatic Data of Gaza City

Elevation: 16 meters Latitude: 31 30N Longitude: 034 27E

- Average Temperature

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
C	19	13	14	15	18	20	23	25	26	25	22	19	15

- Average Precipitation

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
mm	300	76	49	37	6	3	---	---	---	---	14	46	70

- Average Length of Day

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Hours	12.6	10.8	11.5	12.4	13.4	14.2	14.6	14.4	13.7	12.7	11.8	11	10.6

- Average Daily Solar Radiation - Global

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mj/m2	20.6	14.2	24.1	30.4	26.9	17.6	10.2	10.9	19.3	27.9	29.1	23.2	12.8

- Maximum Daily Solar Radiation - Global

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mj/m2	20.6	14.2	24.1	30.4	26.9	17.6	10.2	10.9	19.3	27.9	29.1	23.2	12.8

- Minimum Daily Solar Radiation - Global

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mj/m2	18.7	11.1	21.9	29.4	25.8	16.4	8.3	9.9	16.2	25.3	27.1	22.4	10.8

- Maximum and mean values of hourly wind speed at 50 m height (m/s)

	Annual	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Max	23.9	24.4	22.7	23.9	19.6	20	15.1	23.7	17.2	16.6	16.5	16.4	17.3
Mean	4.2	4.9	5	4.8	4	3.9	3.5	3.4	3.5	4.5	4.8	4.8	5.1

Source of Data: http://www.weatherbase.com/