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Investigation of the Thermal Performance of Building Form in the Mediterranean Climate of the Gaza Strip

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Abstract: This paper examines the thermal performance of different forms of the housing units located in the Mediterranean climate of the Gaza Strip. The study is carried out using computer programs ECOTECT and IES. The results indicate significant thermal effects due to form's proportions. The study concluded that the surface to volume ratio is considered the main responsible for the thermal response in different geometric shapes. Energy consumption increases at the same rate of increasing in the surface to volume ratio (S/V) in the Mediterranean climate of the Gaza Strip. Convex shapes such as court, L and U shape can be used as more preferable options for building's arrangements than the rectangular shape of the same (S/V) ratio. Increasing the depth ratio in convex shapes has the ability to increase the percentage of the shaded facades which help to reduce heating and cooling energy. The roof to walls ratio seemed to have a considerable influence on the thermal response which reach to about by 45.7%, 40.9%, 48.1% and 38.6% for the rectangular, L shape, U shape and court shape respectively. Horizontal arrangements of residential apartments are better thermally than the vertical arrangements of the same (S/V) ratio. Therefore, the study recommends applying passive solar design strategies, especially with regard to geometric shape and orientation in the first stage of design process. Thermal simulation programs have to be used in order to evaluate the thermal performance of buildings.

Key Words: Building Form- Heating and Cooling Loads- Surface to Volume Ratio- Self Shading- Solar Radiation.

دراسة تأثير شكل المبنى على الأداء الحراري في مناخ البحر المتوسط بقطاع غزة

ملخص: يختبر البحث الأداء الحراري للأشكال الهندسية المختلفة للوحدات السكنية الواقعة في مناخ البحر الأبيض المتوسط لقطاع غزة، ويعتمد البحث على استخدام برامج الكمبيوتر ECOTECT و IES، وقد أظهرت النتائج تأثيراً حرارياً كبيراً للنسب والأبعاد الهندسية المحددة لشكل المبنى، هذا وقد خرج البحث بنتيجة مفادها أن نسبة السطح الخارجي إلى الحجم تعد المسئول الرئيسي عن السلوك الحراري في الأشكال الهندسية المختلفة، حيث يزداد استهلاك طاقتي التدفئة والتبريد بنفس معدل الزيادة في نسبة السطح الخارجي إلى الحجم في مناخ البحر الأبيض المتوسط لقطاع غزة، كذلك فقد استنتج البحث بأن الأشكال المركبة مثل الفناء وشكل حرف L وحرف U

يمكن استخدامها كخيارات أكثر تفضيلاً لتجميع المباني من الناحية الحرارية بدلاً من الشكل المستطيل بشرط احتوائها على نفس نسبة السطح الخارجي إلى الحجم، كما وجد البحث أن زيادة نسبة العمق في الأشكال المركبة له القدرة على زيادة نسبة الواجهات المظللة وهو ما من شأنه المساهمة في تقليل طاقتي التدفئة والتبريد، من ناحية أخرى فقد أظهرت نسبة السقف إلى الجدران تأثيراً معقولاً على السلوك الحراري والذي يصل إلى حوالي 45.7%، 40.9%، 48.1%، 38.6% وذلك للشكل المستطيل وحرف L وحرف U والفناء على التوالي، وتم التوصل إلى أن التكوينات الأفقية للشقق السكنية أفضل من الناحية الحرارية من نظيراتها الرأسية والتي تحوي نفس نسبة السطح إلى الحجم. ومن هنا فإن البحث يوصي بتطبيق استرتيجيات التصميم الشمسي وخاصة فيما يتعلق بالشكل الهندسي وذلك في المرحلة الأولى للعملية التصميمية، كما يوصى باستخدام برامج التمثيل الحراري لتقييم الأداء الحراري للمباني.

1. Introduction

Building form is one of the main parameters which determine the building envelope and its relationship with the outdoor environment. Hence, It can affect the received amounts of solar radiation, 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 direct solar radiation [1]. Self-shading of building usually depends on building shape and layout arrangement [2]. Also, building form affects wind channeling and air flow patterns, and opportunities for using natural daylight [3]. Self shading of geometry forms is considered the best solution for improvement thermal performance of buildings. Heat gain from building envelope is proportional the total gross exterior wall area [4]. Generally, geometry variables including length, height, and depth usually control the area and volume of buildings [5].

The main proportions affecting geometric shape are surface-to-volume ratio and width to length ratio. Forms with different geometric shapes of the same contained volume have different surface area. This is usually expressed by surface to volume ratio [6]. Surface to volume ratio is a rough indicator of urban size, representing the amount of exposed envelop of buildings, and therefore, their potential for interacting with environment through natural ventilation, day lighting, etc. However, the counter-indication to a high surface to volume ratio is the increase in heat loss during winter season and heat gain due to exposure to solar radiation during summer season [7]. Surface-to-volume ratio (S/V ratio) for geometric shape depends on width to length (W/L) ratio. Geometric shapes with higher value of (W/L) ratio contained lower value of (S/V) ratio [8].

Different studies have dealt with form aspects. A simplified method was developed to predict the impact of shape on the annual energy use for office buildings in Kuwait. Basically, the study depended on the relative compactness (RC) of the building and correlated 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 [9]. Using the relative compactness in evaluation the energy efficiency was criticized 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 which changes the building morphology, shading potential and its thermal performance without changing the relative compactness [10].

Another study dealt with the effect of different geometries on the solar radiation incident on equatorial-facing facades and transmitted by the fenestration of such façades. The study focused on the optimal solar exposure shape for the purpose of electricity production by the building integrated photovoltaic (BIPV). The results indicated that the number of shading facades in-self shading geometries and their relative dimensions are the major parameters affecting solar incident and transmitted radiation [11]. From the thermal point of view, the high solar exposure shape may not achieve the acceptable comfort conditions and energy reduction especially in summer period. Another study 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, it simulated complex shapes and multistory shapes with different (S/V) ratio which make this ratio to be the main dominate for the thermal response. The study concluded that the use of (S/V) ratio as an indicator is not enough in the complexes shapes. The clear idea about the thermal response of building in this case depends on the orientation conditions which have been expressed in terms of roof to walls ratio and south wall to west wall ratio [6]. The impact of building form on energy consumption was studied based on using the building shape factor (L_b) (also called building characteristic length). The building shape factor 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. The study examined the heating demand of several shapes with various building shape factor and in different climates [12].

It is found from all the previous studies that surface to volume ratio is the main responsible for thermal response in different geometric shapes. However, the impact of different geometry with the same (S/V) ratio has not been discussed extensively to investigate the effect of self shading obtained by these geometries. Also, changing proportions of a specific shape such as depth ratio (W/L) and roof to walls ratio is assumed to change the thermal response of these shapes in spite of having the same (S/V) ratio. Understanding the relation between building geometry, proportions, ratios and thermal performance can be obtained by investigating the main parameters which define building form. These integrated parameters which are surface to volume ratio, roof to walls ratio, depth ratio in the convex shapes, building geometry and self shading can be handled in 2 cases which are:

The First Case: Effect of Geometric Form on Energy Consumption

The Second Case: Effect of Self Shading on Energy Consumption

2. 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 [13]. 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 [14].

The <Virtual Environment> 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 [15]. Simulations were performed using ECOTECT software. Also, the virtual environment (IES) software was used to validate simulation results. The 3D models were created using *ModelIT*. Then solar shading analysis was performed using *SunCast*. Finally, a dynamic thermal simulation was carried out using *ApacheSim*. Simulation results were expressed in terms of annual heating loads, annual cooling loads and annual total loads (in MWh).

Simulations were carried out during months of January–December. The HVAC system was assumed to be full air conditioning with heating and cooling set point were assumed to be 18.0^{0}C and 26.0^{0}C 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 heating and cooling energy consumption, internal heat gain from occupancy and appliances as well as ventilation heat gain weren't considered in the study. External walls have a U-value of 1.77 W/m^2. K in ECOTECT and 1.9487 W/m^2. K in IES. Roof U-value are 0.896 W/m^2. K in ECOTECT and 0.9165 W/m^2. K in IES. Glazing U-value are 6 W/m^2. K in ECOTECT and 5.5617 W/m^2. K in IES. Using similar materials in both programs was considered, however, the difference of U-value in the two programs can be justified according to the discrepancy in materials and their associated thermal properties found in the programs. Values of Thermal Transmittance, U-value for walls and roof were assumed to achieved the minimum requirements of maximum U-values as recommended by the Palestinian code for energy efficient building (2004) [16]. See Appendix (1) for details of default settings for the two programs. For solar radiation calculations, ECOTECT uses hourly recorded direct and diffuse radiation data from the weather file.

3. Climate

The Gaza Strip (365 km2) is a coastal area in the west-southern part of Palestine [17]. The geographical coordinates of the Gaza Strip are 31° North, and 34° East [18]. 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 [17]. According to 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 [17].

4. The First Case: Effect of Geometric Form on Energy Consumption

4.1The Study Parameters

The first case introduced a study of 14 different geometries with different (S/V) ratio in order to examine the relation between (S/V) ratio and heating, cooling and total loads. The 14 geometric shapes are circular, square, rectangular, trapezoid, pentagon, hexagon, heptagon, octagon, L shape, T shape, cross shape, H shape, U shape and court shape. The area (A) for these shapes was assumed to be 150 m^2 as it represents the average of residential units' areas in Gaza. The height was assumed to be 6 m (2 storeys) and thus the volume equals to 900 m^3. The rectangular shape was assumed to have a width to length ratio of 0.618 as it represents a golden section (golden ratio). The golden ratio is applied also in the rectangular parts of convex shapes such as L, T, cross, H, U and court shape. The ratio of the width of the shading façade to that of shaded façade is termed depth ratio (a/b) was taken to be 1 as illustrated in figure (1) and table (1). All forms were considered as stand-alone building without overshadow from any adjacent buildings. The description of the base case reference for generic residential building is clarified in table (2).

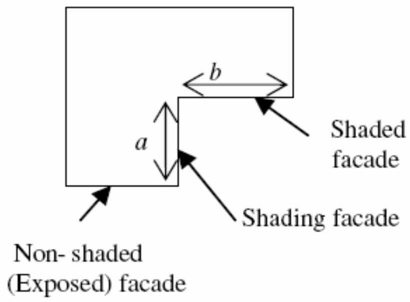


Figure 1: Depth ratio (a/b) in the self shading geometries (convex shapes)
Source: [11]

Table 1: The relative dimensions of shading and shaded façades in the self shading geometries (convex shapes)

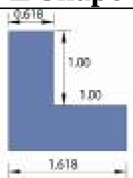
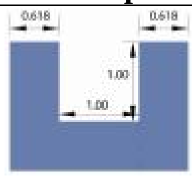
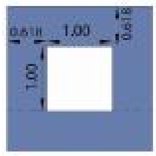
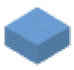
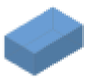
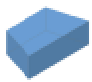
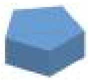
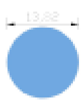
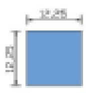
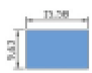
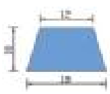
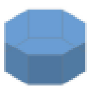
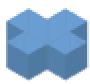
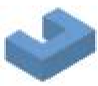
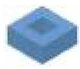
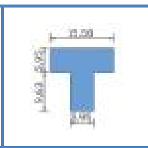
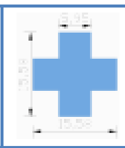
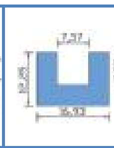
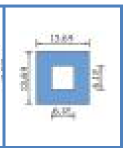
L Shape	U Shape	Court Shape
		

Table 2: Shape design parameters

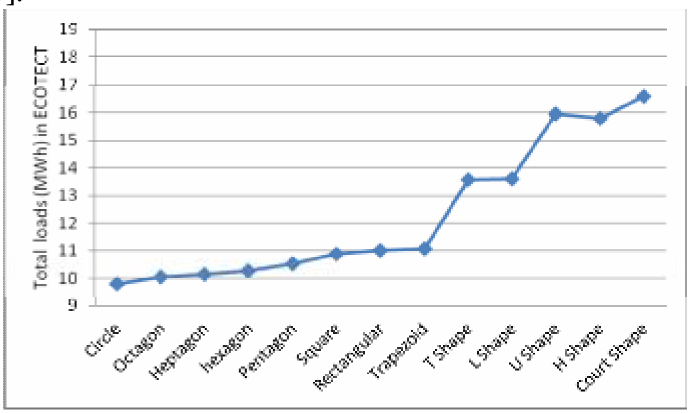
Perspective							
Plan							
(S/V) Ratio	0.4561	0.4932	0.503	0.506	0.478	0.47	0.466
Perspective							

Plan							
(S/V) Ratio	0.464	0.582 09	0.582	0.582	0.656	0.656 5	0.695

4.2 Results

The results indicate that the total loads for the simulated shapes are increased by 69% with changing geometric shape from circle to court shape at the East- West orientation (0^oE) in ECOTECT software. The circle shape achieves the lowest energy requirements so it was taken as a reference shape. The percentage of increasing in total loads from the reference shape was evaluated for the other 13 geometric shapes. In IES software, the court shape increases in total loads from the reference shape (circle) by about 52%. Figure (2) shows the effect of changing geometric shape on total loads throughout the year using ECOTECT and IES.

The discrepancy in results between ECOTECT and IES can be explained as a result of different load calculation techniques and calculation engines. ECOTECT uses the worst case annual design load while the ASHRAE load calculator uses a worst month scenario (January) for heating loads and 5 months (May-September) for cooling loads. The simulation engine and load calculation methods are different in the two programs. While ECOTECT uses the CIBSE 'admittance method' for calculating thermal loads, the 'Apache Loads' application in IES uses the ASHRAE 'heat balance' method [19].



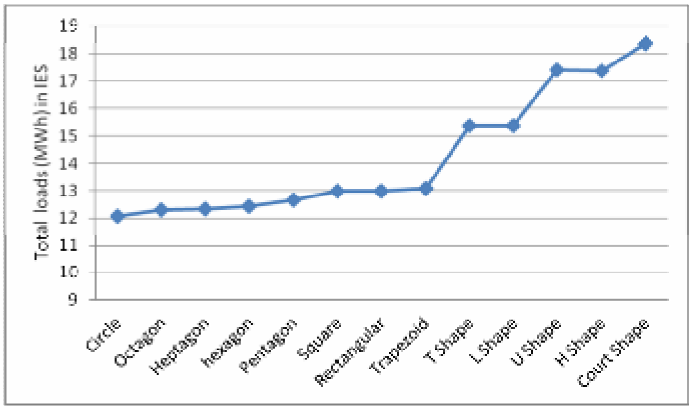
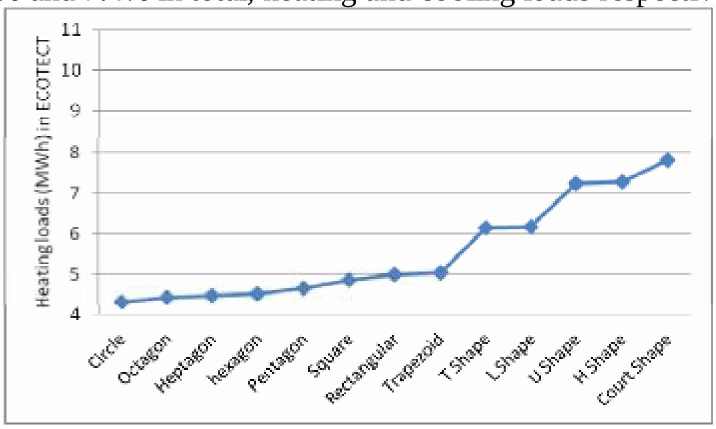


Figure 2: a: Annual Total loads of heating and cooling (MWh) by ECOTECT, b: by IES

The same trend of increasing in total loads can be noticed in heating and cooling loads in figure (3). About 80% and 50% of increasing in heating loads and cooling loads respectively as a result of changing geometric shape from the circle to the court shape in ECOTECT. It is evident that there is a slight difference between the reference shape and the square one which reaches to about 11%, 12.3% and 7.3% in total, heating and cooling loads respectively. As the largest portion of buildings especially residential have orthogonal polyhedral shapes, square shape can be considered as the optimum thermal option. Also, rectangular shape can be adopted as it has a small difference from the reference shape which reaches to about 12.2%, 15.6% and 7.1% in total, heating and cooling loads respectively. In IES software, about 53.5% and 50.8% of increasing in heating loads and cooling loads respectively as a result of changing geometric shape from the circle to the court shape. The square shape increases from the refer one by about 7.5%, 7.6% and 7.4% in total, heating and cooling loads respectively.



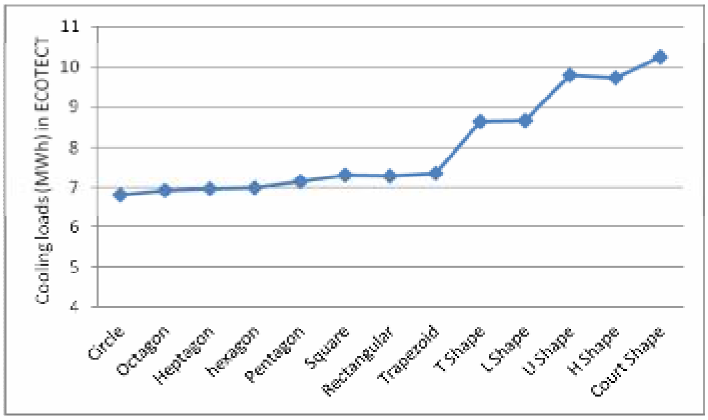


Figure 3: a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

It can be seen that there is a leap in graphs between the compact shapes (circular, octagon, heptagon, hexagon, pentagon, square, rectangular, trapezoid) and the convex shapes (T, L, U, H and court shape). Changing geometric shape from square to L, U and court shapes for example increases total loads by about 25.2%, 46.6% and 52.3% respectively. In order to investigate this behavior of increasing in total loads, the (S/V) ratio for the simulated shapes have to be obtained. It is evident that increasing in (S/V) ratio and increasing in total loads from the refer shape (circle) for the simulated shapes have the same trend. Changing geometric shape from circle to court shapes increases (S/V) ratio by about 52.4% which is more compatible with the percentage of increasing in total loads in IES and smaller than it in ECOTECT.

Figure (4) illustrates a correlation between the percentage of increasing in (S/V) ratio and the percentage of increasing in total loads, heating and cooling loads in the two programs. The coefficient of determination, R^2 (the square of correlation coefficient, r) between the two variables is 0.9997. This means that 99.97% of increasing in total loads is related to the increasing in (S/V) ratio. This means that the (S/V) ratio is the more responsible factor in affecting heating and cooling requirements. Knowing (S/V) ratio for a shape can help to predict the percentage this shape increases in heating and cooling energy from the most compact shape with the same volume. So, the more compact form which contains the same volume with the smallest (S/V) ratio is recommended in the climate of the Gaza Strip. Also, it can be concluded that increasing the (S/V) ratio can increase the energy consumption in the same percentage nearly.

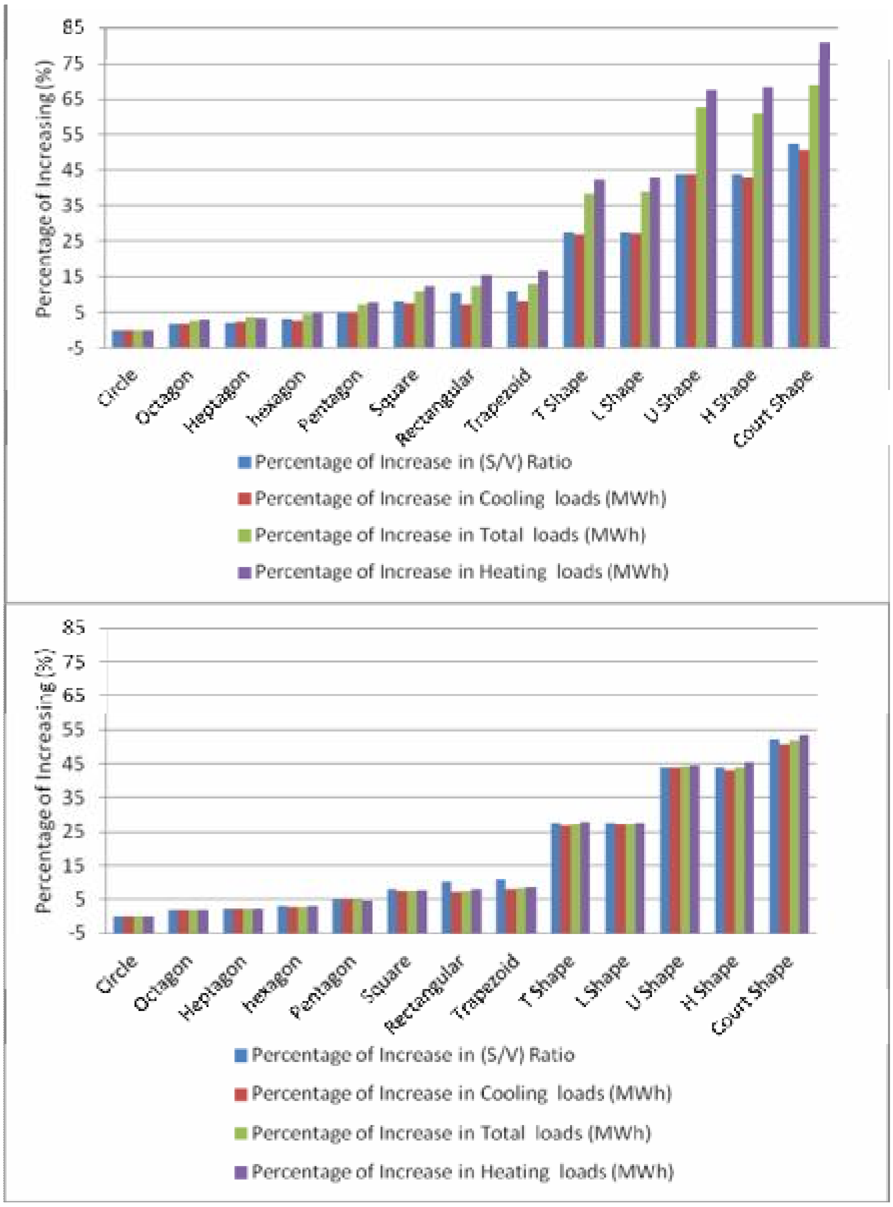


Figure 4: a: The percentage of increasing in the (S/V) ratio, cooling, heating and total loads by ECOTECT, b: by IES

5. The Second Case: Effect of Self Shading on Energy Consumption

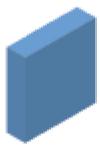
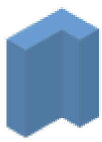
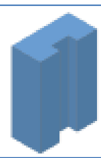
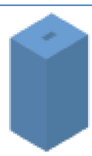
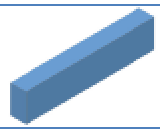
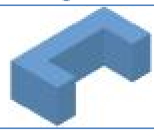
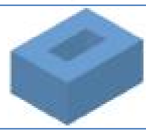
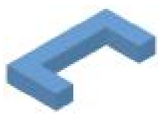
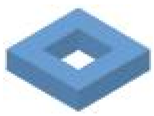
5.1 The Study Parameters

The second case was dedicated to investigate the effect of varying geometry with constant (S/V) ratio on the self shading. For this purpose, four generic forms which are rectangular, L shape, U shape and court shape were examined. The study examined 3 depth ratios which are 0.1, 0.5, 1 and 4 roof/ walls ratios which are 0.1, 0.25. 0.5 and 1. In order to evaluate the volume, it was assumed that the minimum width of L shape is 1 m. For achieving the minimum depth ratio which is 0.1, this means that the length of L shape is 10 m. Building depth was assumed to be 4 m as it represents the average of room width. This means that the area (A) of the base case is 60 m^2 and the perimeter equals to 38 m. Area of walls surfaces was taken to be 600 m^2 in order to achieve the minimum (roof/ walls) ratio which is 0.1. This means that the total exposed surface is 660 m^2. Building height can be evaluated from the walls surfaces equation which equals to the multiple of perimeter and height (walls area= perimeter* height). This means that building height is 15.7 m (nearly 5 storey). Hence, the base case volume is equal to 942 m^3 and (S/V) ratio is 0.7. Another two (S/V) ratio which equals 0.8 and 0.9 were used. Hence, about 144 cases were simulated in the study. The long axes of simulated cases were assumed to have east-west orientation. Table (3) illustrates combinations of parameter values analyzed in this study. A sample of simulated cases examined in the study is summarized in table (4) and (5).

Table 3: Parameter combinations investigated in the study

Rectangular	Basic design	0.1-0.25-0.5-1	0.7-0.8-0.9
L Shape	0.1-0.5-1	0.1-0.25-0.5-1	0.7-0.8-0.9
U Shape	0.1-0.5-1	0.1-0.25-0.5-1	0.7-0.8-0.9
Court Shape	0.1-0.5-1	0.1-0.25-0.5-1	0.7-0.8-0.9

Table 4: Combinations of various geometric shapes with various (roof\walls) ratio, similar depth ratio= 0.5 and similar (s/v) ratio= 0.7

Roof\walls= 0.1				
Roof\walls= 0.25				
Roof\walls= 0.5				

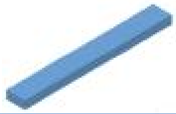
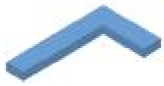
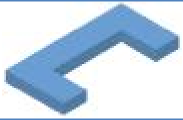
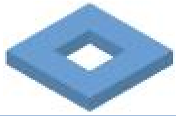
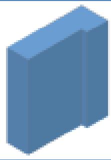
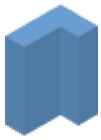
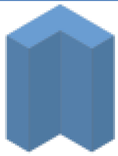
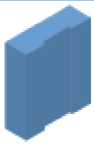
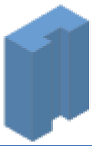
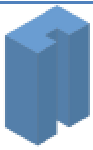
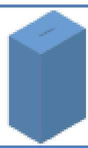
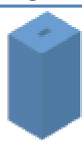
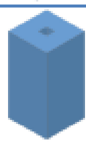
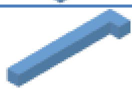
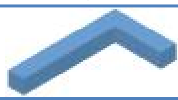
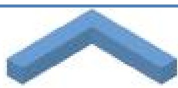
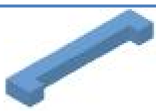
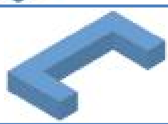
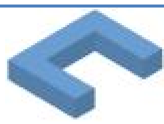
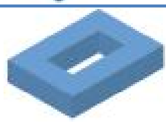
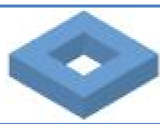
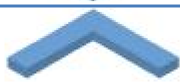
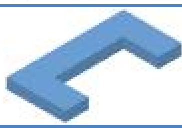
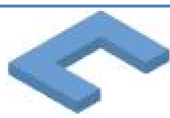
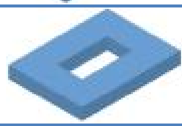
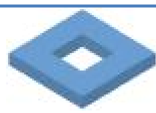
Roof\walls= 1				

Table 5: Simulated shapes combinations according to various depth ratio and (roof\walls) ratio

(Roof\walls) Ratio	**Geometric Shape**	**Depth Ratio (W\L)**		
		W\L= 0.1	**W\L= 0.5**	**W\L= 1**
Roof\walls= 0.1	L Shape			
	U Shape			
	Court Shape			
Roof\wall= 0.5	L Shape			
	U Shape			
	Court Shape			
Roof\wall= 1	L Shape			
	U Shape			
	Court Shape			

5.2 Results

Effect of Depth Ratio

The results indicate a slight effect of depth ratio on the total loads. The most important point is that the effect of depth ratio in affecting the total loads varies according to various geometric shape and (roof/ walls) ratio. Apparently, it can be observed as shown in figure (5) that with decreasing (roof/ walls) ratio the difference can be remarkable. For example, increasing depth ratio from 0.1 to 0.5 for U Shape with a (roof/ walls) ratio equal to 0.1 reduced total loads by about 8%. This ratio decreased to reach 0.8 in the case of (roof/ walls) ratio equal to 1 for the same geometric shape. This means that with increasing building height which decreases (roof/walls) ratio, depth ratio becomes more important. This can be explained as with decreasing (roof/ walls) ratio, the percentage of vertical walls from the exposed surface increased and thus the percentage of self shaded façades in convex shapes increased. As a consequence, increasing depth ratio has the ability to increase percentage of shaded façades which help to reduce total energy. This explains why the increase in depth ratio affects cooling loads in a greater manner than its effect on heating loads.

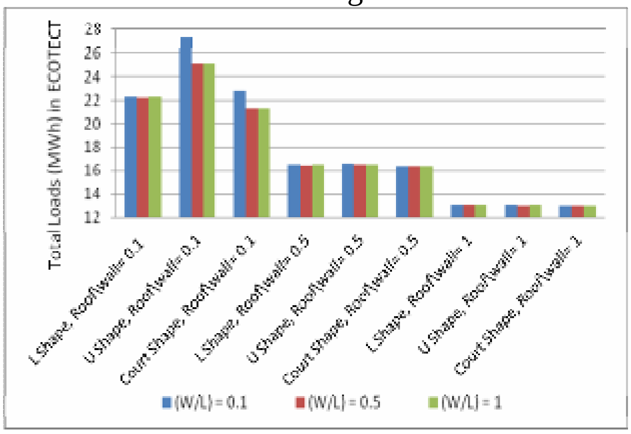


Figure 5: Total loads (MWh) for various geometric shapes

Figure (6) illustrates the effect of depth ratio on heating and cooling loads for three geometric shapes (L, U and Court Shapes) and with three (roof/walls) ratio (0.1, 0.5 and 1). Increasing depth ratio from 0.1 to 0.5 for U Shape with a (roof/ walls) ratio equal to 0.1 reduced cooling loads by about 16.6%. As the (roof/walls) ratio increases, the difference can’t be noticed. On the other hand, heating loads increased slightly by about 1.5% with increasing depth ratio from 0.1 to 0.5 for U Shape with a (roof/ walls) ratio equal to 0.1.

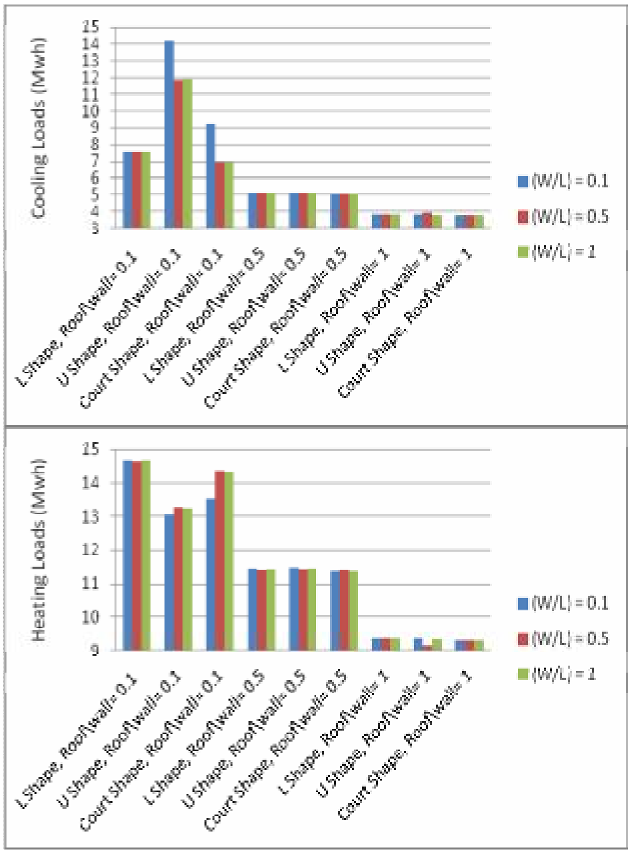


Figure 6: a: Heating loads (MWh), b: Cooling loads(MWh)

Another factor affecting the impact of depth ratio is the geometric shape. While the effect was noticeable in U Shape, increasing depth ratio in L Shape can be neglected. This can be explains as a relation between the number of shaded façades and the reduction in total loads. As the number of shaded façades increases (2 shaded façades in U Shape versus 1 shaded façade in L Shape), the effect of depth ratio can be remarkable. For Court Shape, increasing depth ratio from 0.1 to 1 with a (roof/ walls) ratio equals to 0.1 reduced total loads by about 6.7% and reduced cooling loads by about 25%. It can be concluded that the most impact of depth ratio can be noticed in cooling loads with a small (roof/walls) ratio and with a large number of shaded façades.

Effect of (Roof/Walls) Ratio

It is evident that increasing (roof/walls) ratio has a great effect in reduction total energy in any geometric shape and with any (S/V) ratio and depth ratio as shown in figure (7). The effort here is to investigate the role of these factors in affecting the impact of (roof/walls) ratio. Increasing (roof/walls) ratio from 0.1 to 1 (which means changing the building from vertical arrangement to horizontal one) reduced total loads by about 45.7%, 40.9%, 48.1%, 38.6% for rectangular, L shape, U shape and court shape respectively. Increasing (roof/walls) ratio from 0.1 to 1 reduced cooling loads by about 57%, 49.9%, 67.1%, 45.7% for rectangular, L shape, U shape and court shape respectively. While increasing it from 0.1 to 1 reduced heating loads by about 35.4%, 36.2%, 23%, 35.2% for rectangular, L shape, U shape and court shape respectively.

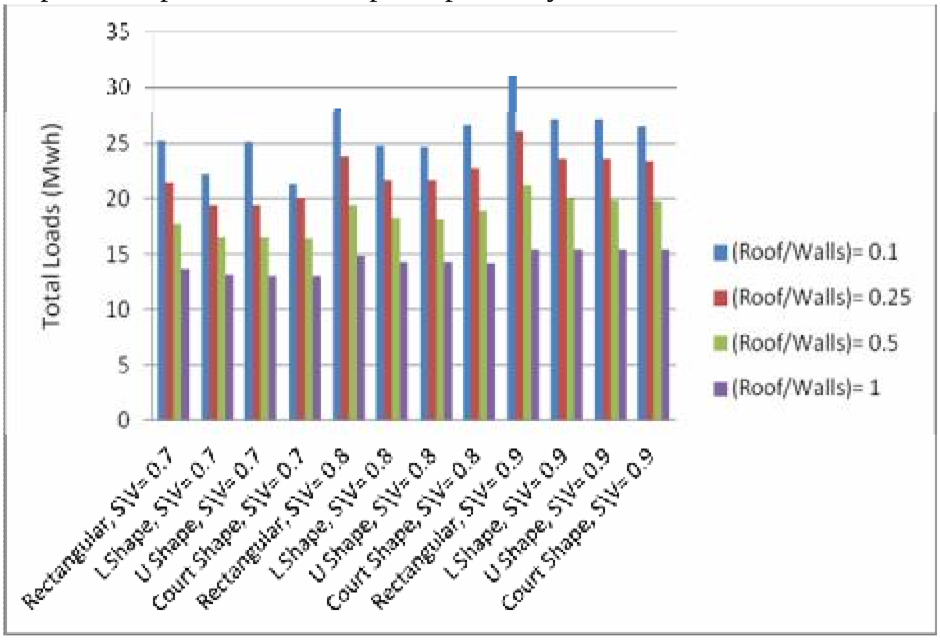


Figure 7: Total loads (MWh) for various geometric shapes, (S/V) ratio and (roof/walls) ratio

Effect of Geometric Shape

The results indicate a large effect of geometric shapes on total loads with a small (roof/walls) ratio. It is evident that U shape has the worst thermal performance in all simulated depth ratio (W/L) and (roof/walls) ratio as it require the largest amount of energy. As shown in figure (8), the difference in total loads is more noticeable as the (roof/walls) ratio decreased. Total loads reduced by about 15.4% with changing geometric shape from U shape to court shape with the same (roof/walls) ratio equal to 0.1 and the same depth ratio equal to 0.5. This percentage of reduction decreased to reach only 0.7% with a (roof/walls) ratio equal to 0.5. The court shape seems to have the lowest energy requirements with a small difference between it and L shape. The reduction in total loads reaches to about 4.3% between court and L shape and about 11.6 between L shape and U shape with a (roof/walls) ratio equal to 0.1 and a depth ratio equal to 0.5.

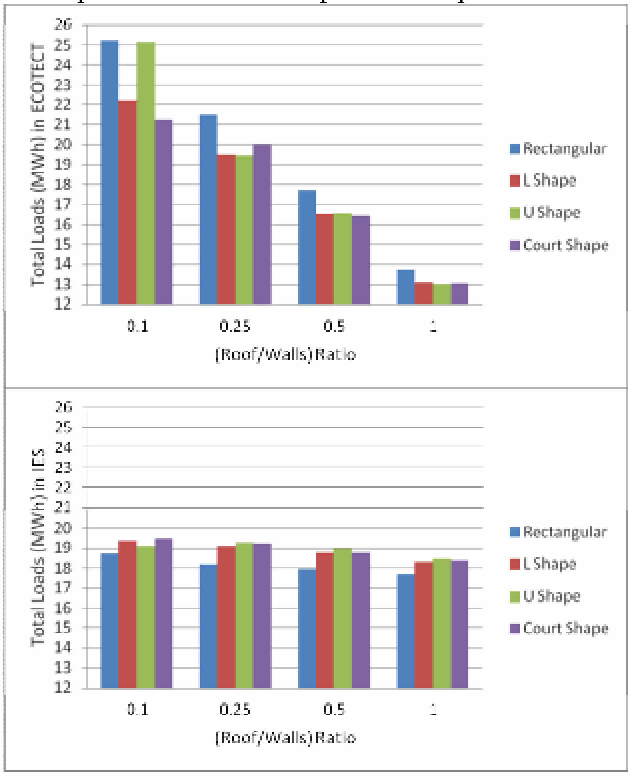


Figure 8: a:Total loads (MWh) by ECOTECT ,b: Total loads (MWh) by IES

In order to explain this thermal behavior, heating and cooling loads have to be studied. It is evident from figure (9) that U shape is more preferable in winter as it achieves the lowest heating loads. However, it is the worst shape in summer as there is a large difference between it and the other two shapes in cooling loads. There are a reduction in cooling loads by about 41.7% between U shape and court shape with a (roof/walls) ratio equal to 0.1 and a depth ratio equal to 0.5. This reduction reaches to about 36.4% between U shape and L shape and about 8.3% between L shape and court shape. This means that for achieving better cooling situations, the court shape followed by L shape and U shape is preferable. On the other hand, the U shape achieves the lowest heating requirements by a difference reaches to 8.2% and 10.5% between it and court shape and L shape respectively. This means that for achieving better heating situations, the U shape followed by court shape and L shape is preferable.

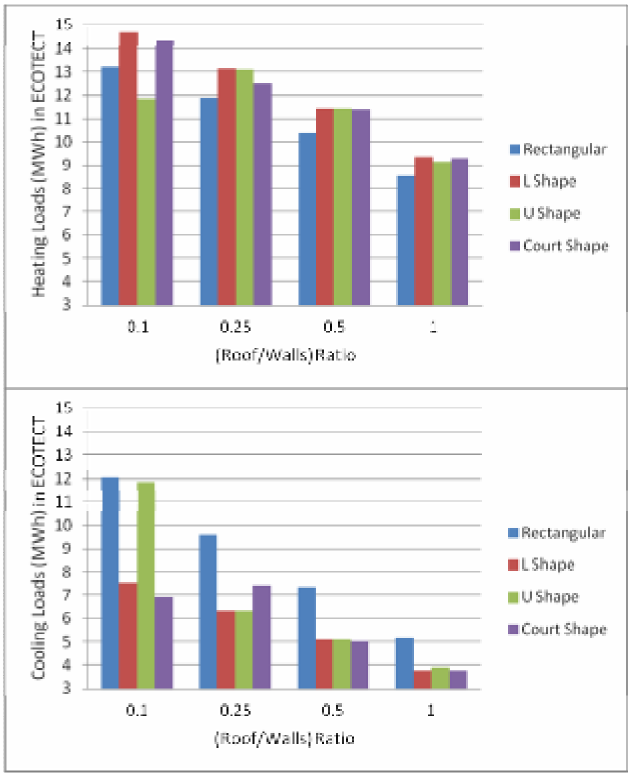


Figure 9: a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

Incident Solar Radiation

The incident solar radiation was evaluated for the four shapes (rectangular, L, U and court) with (S\V) ratio equals 0.7 and (Roof\walls) ratio equals 0.1 and depth ratio equals 0.5. The results indicate that the rectangular shape receives the highest amount of solar radiation on the south façades, followed by U, L and court shape as shown in figure (10:a). Both rectangular and U shape receive an amount of fabric heat gain during summer more than L and court shape by about 74%. However, they losses an amount of heat through the fabric during winter less than L and court shape by about 55% as shown in figure (10:b). This is compatible with heating and cooling response of these shapes as illustrated previously in figure (9).

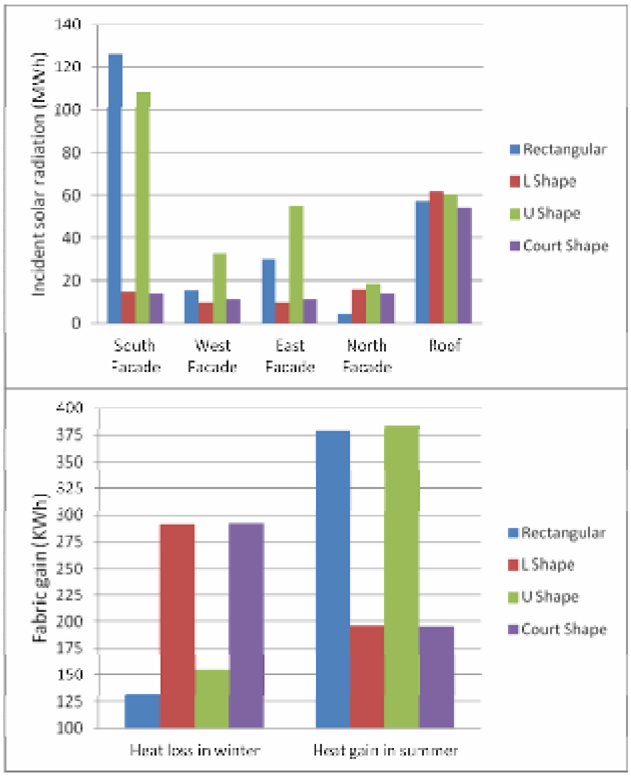


Figure 10: a: Incident solar radiation for various geometric shapes, b: fabric gain

6. Conclusion

It is concluded that surface to volume ratio is the most important aspect affecting thermal performance of geometric shapes. However, having the same surface to volume ratio in the same shape with various proportions creates a variety in thermal response and energy consumption. Self shading of different geometric shapes with the same surface to volume ratio has a considerable impact in affecting heating and cooling energy requirements. Self shading is more valuable in forms with a small roof to walls ratio as its impact appears significantly in a large area of vertical walls. The incident solar radiation falling on building is the more responsible factor on its thermal response. The compact form which contains the same volume with the smallest (S/V) ratio is recommended in the climate of the Gaza Strip.

The rectangular shape can be adopted as it has a small difference from the more compact shape (circular) with the same volume, which reaches to about 12.2%, 15.6% and 7.1% in total, heating and cooling loads respectively. Increasing (roof/walls) ratio from 0.1 to 1 reduced total loads by about 45.7%, 40.9%, 48.1%, 38.6% for rectangular, L shape, U shape and court shape respectively. Total loads reduced by about 15.4% with changing geometric shape from U shape to court shape with the same (roof/walls) ratio equal to 0.1 and the same depth ratio equal to 0.5 and the same (S/V) ratio equals 0.7. The court shape seems to have the lowest energy requirements with a small difference between it and L shape reaches to about 4.3%. It is recommended to use shapes with (roof/ walls) equals 0.5 which is more preferable for both cooling and heating requirements. It is recommended to use horizontal arrangements of residential apartments which have higher values of roof/ walls ratio as it is better thermally than the vertical arrangements (which have lower values of roof/ walls ratio) of the same (S/V) ratio.

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Appendix 1

Table 1: Default settings for ECOTECT and IES

	ECOTECT	IES
Thermal Condition		
HVAC System	Full Air Conditioning	Full Air Conditioning
Thermostat Range	18.0^{0}C- 26.0^{0}C	18.0^{0}C- 26.0^{0}C
Use of the building/ Hours of Operation	On continuously	On continuously
Design condition		
Clothing (clo)	1.0	-
Humidity	60.0	-
Air speed	0.5 m/s	-
Lighting level	300 lux	300 lux
Occupancy	0	0
Internal heat gain	0	0
Infiltration rate		
Air change rate	0	0
Wind Sensitivity	0	0
Construction		
Exterior walls		
U-value	1.77	1.9487
Roof		
U-value	0.896	0.9165
Ground-contact/exposed		
U-value	0.88	0.7059
Window		
U-value	6.0	5.5617

List of Abbreviations

Abbreviations	**Meaning**
A	Area
a/b ratio	The ratio of the width of the shading facade to that of shaded facade (the depth ratio)
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BIPV	Building-integrated photovoltaic
CIBSE	Chartered Institution of Building Services Engineers
C_{sa}	Dry-summer subtropical or Mediterranean climates
HVAC	Heating, Ventilation, and Air Conditioning
IES	Integrated Environmental Solutions
L_b	Building Shape Factor
MWh	Megawatt Hour
R^2	The square of the correlation coefficient, r
RC	Relative Compactness
S/V Ratio	Surface to volume ratio
U-values	Thermal Transmittance
W/L Ratio	Width to length ratio
WWR	Window to Walls Ratio