Passive Solar Urban Design - Shadow Analysis of Different Urban Canyons

التخطيط العمراني المستدام: تأثير التشميس على التشكيلات العمرانية المربعة والإشعاعية

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Abstract

Although thermal comfort methods on a architectural scale are at present well developed, the approach and the techniques applied on an urban scale are yet to be consolidated in order to promote a climatic responsive urban design. The main goal of the study, which is a continuation of the researcher's efforts in his PhD thesis, is to examine the relationship between different urban forms and the shadow patterns they generate, and to develop evaluation tools for deriving climatic design criteria and information suitable for use by designers. In addition, the experiment intends to verify the common method used by architects to determine the most suitable spacing between buildings to avoid overshadowing and maintain good solar accessibility, as well as to clarify its limitations. Therefore, the experiment compares patterns (radial and rectangular) with different orientations, in order to clarify the relation between the orientation and the generated shadow pattern, so that an acceptable standard of solar accessibility could always be considered with the orientation of the urban pattern in mind. Hence, the study was also performed in order to determine the urban fabric that will allow the achievement of high urban density under optimal solar insolation conditions. Finally, the paper discusses the possible application of these patterns in Palestine, in order to highlight the way that the derived results can be handled in real practice and so advance climatic urban design in Palestine. The SunCast Program which was used to conduct the experiments, provides numerical calculations for the shaded surfaces to assure a high accuracy for the required measurements.

ملخص

تهتم الورقة بدراسة التشكيل العمراني وأثره البيئي وخاصة في مسالة تأثير الظلال المتبادل للتشكيلات العمرانية على التخطيط العمراني بما يضمن إنشاء تجمعات حضرية تمتاز بكثافة بنائية مناسبة في ظل الاحتفاظ بمؤثرات مناخية تلاءم الواقع الفلسطيني سواء في الضفة الغربية أو قطاع غزة، حيث تأتي هذه الدراسة تواصلاً لجهود الباحث في هذا المجال ضمن دراسته لأطروحة الدكتوراه. ويكمن الهدف الأساسي من البحث في تقييم العلاقة بين اختلاف الشكل العمراني ونماذج الظلال الناتجة وصياغة أدوات تمكن من اشتقاق معايير بيئية يمكن الاستفادة منها في توجيه العملية التصميمية. بالإضافة إلى ذلك فان الدراسة تهدف إلى التحقق من مدى مناسبة الطرق المعتادة التي يستخدمها المعماريون لتحديد التباعد الأمثل بين المباني لتجنب الظلال الزائدة والمحافظة على القدر الملائم من التشميس. كذلك فان البحث يقارن بين نماذج عمرانية مختلفة (مكعبة وحلقية) بتوجيهات مختلفة لتوضيح العلاقة بين التوجيه والظلال المتكونة، بحيث يتم الأخذ بعين الاعتبار اتجاهات الكتل العمرانية عند تحديد المعايير المثلى للنفاذية الشمسية. وبالتالي فان الدراسة ستساعد في توضيح التشكيلات العمرانية التي يمكن أن تسهم في زيادة الكثافة البنائية نسبيا عن نظيراتها من التشكيلات الأخرى في ظل المحافظة على نفس الظروف التشميسية الجيدة. في النهاية تبحث الورقة في إمكانيات تطبيق هذه النماذج في الواقع الفلسطيني لتوضيح كيف يمكن لهذه النتائج المستخلصة أن يستفاد منها على ارض الواقع لتفعيل التخطيط العمراني المستدام في فلسطين. هذا وقد تم استخدام برنامج محوسب لحساب الأسطح المظللة، حيث يقدم البرنامج حسابات رقمية تضمن توفر الدقة المطلوبة.

Introduction

Finding a relation between the geometry of the form and the received solar radiation is very important. Under cold conditions, radiation will be welcomed and the form should receive as much radiation as possible, while under conditions of excessive heat, the same form should decrease undesirable solar impacts. An optimum urban form for a given site would give maximum radiation during the underheated period while simultaneously reducing insolation to the minimum during the overheated period.

Previous studies were mainly concerned with examining simple shapes and less attention was given to examine more sophisticated forms, especially forms that can create self-shading effects. Previous studies were mainly focused on examining rectangular forms with respect to solar rights and behaviour. These shapes are more suited to the grid urban pattern (Figure 1). However, there are other common urban patterns (such as the radial system) within the urban structure, in which other more complicated shapes are usually found, such as crescent and radial blocks (Figure 2). These forms usually tend to be adapted to road networks. These forms are also used to diversify the urban structure and for their aesthetic value and unique shapes.

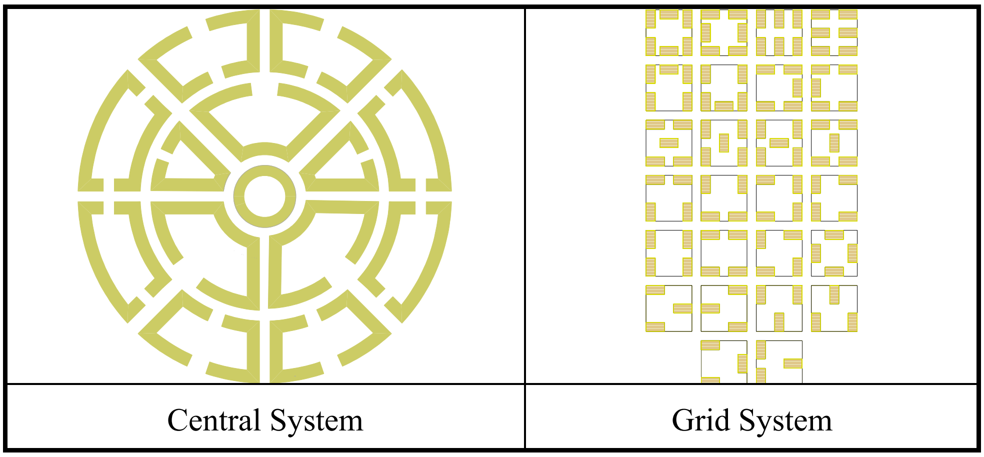


Figure (1): Urban Planning Systems**.**

In some locations, the urban pattern constitutes several kinds of forms, includes cubic and curvilinear shapes. Although radial forms are not very common within the current urban structures (mainly due to constructional and compositional aspects), clarifying their characteristics from the solar point of view could encourage the use of such types of forms. Previous researches examined simple shapes due to the difficulties associated with more sophisticated ones, such as the generated shadow pattern. The radial form has no simple direction and, in order to be examined, it has to be divided into many parts, as the simulation has to be done for a surface with a specific azimuth surface angle. In this case, the radial form has to be simulated as a number of segments which need to be summed at the end. A higher number of segments, by which the radial surface is divided, will produce more accurate results. Thanks to technological advances during the last decades, computer software has become more capable of investigating more complex urban forms.

Figure (2): Curvilinear Buildings (Brantacan, 2002).

Background

Urban areas should be designed and developed to maximize the benefit of sunshine (Una McGeough et al. 2004). The design of the urban form can play a major role in the energy efficiency of a building (Vivienne Brophy et al. 2000). Numan et al. (1999) indicated that the geometrical parameters of the building envelope can offer beneficial advantages in controlling the residential buildings energy performance. The urban form and the shape it takes in a region of a given climatic character will affect the microclimate of the site and, to certain extent, the immediate macroclimate of the region (Golany, 1983). Geometry is a variable that may be controlled for the amelioration of bioclimatic conditions, besides other functional, socioeconomic and symbolic aspects of the urban form (Assis et al., 1999). It seems clear that urban geometry as an urban design tool is more important in urban climate amelioration than other factors, at least in the small-to-medium scale. Yet this issue has not been widely addressed.

In his well known study of the impact of external thermal forces on buildings, Olgyay (1992) considered boxlike forms having the same volume and type of construction. He attempted to find the optimum form, which loses the minimum amount of heat in winter and gains the least amount in summer for a particular climatic region. He concluded that the optimum form in different climates is a rectangle in plan, having a certain proportion, with the length being in the east-west direction. His study has shown that the minimum solar radiation input in summer and the maximum in winter can be achieved by orientation in which the long walls of a boxlike building are perpendicular to the north-south axis.

Although, the study illustrates how far thermal forces influence buildings, the study was mentioned just as a device for improving thermal conditions, no quantitative evaluation concerning the effect of having different types of urban patterns and radial forms in particular being discussed. The association between the boxlike form, mentioned in Olgyay's studies (Figure 3), and the optimum thermal performance of the form has affected further experimentation in this area. Olgyays' experiment on boxlike buildings has influenced researchers towards the investigation of simple objects and therefore some experiments of a similar kind have been presented in many studies. In addition, the tendency to have the form preciously elongated east-wset, as was mentioned in Olgyay's experiment, has directed designers towards more experimentation with rectangular shapes; forms which have different physical features, and radial forms in particular, have been neglected.

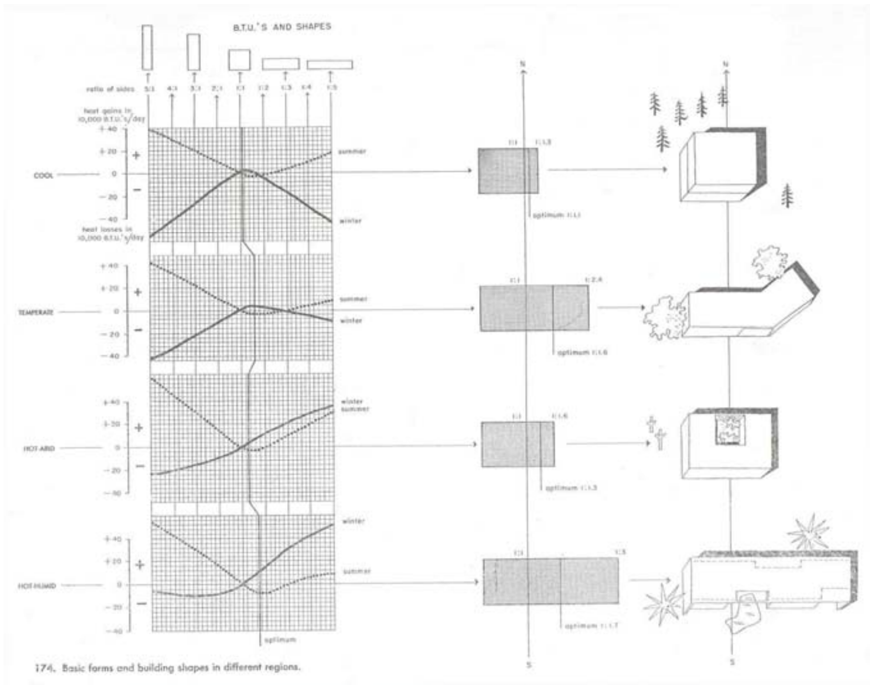


Figure (3): Regional Effects on House Shapes: Basic Forms and Building Shapes in Different Regions (Olgyay, 1992).

In addition, Martin and March (1966, 1972) examined a number of simplified or archetypal forms (Figure 4) in order to limit the complexities found in real urban textures, at a time when the abilities of computer software were limited. These simplified archetypes became very popular in research studies and were extensively adopted. "The adoption of Martin and March's archetypal urban forms has been extensive during the last three decades in various kinds of researches, specifically those aiming at assessing aspects of the environmental behaviour of urban form" (Ratti et al., 2003). For example, Gupta (1984) was involved in evaluating the thermal performance of non-air-conditioned building forms in hot climates. He applied three building forms (pavilion, street canyon and courtyard) and attempted to investigate the link between the solar exposure and thermal performance of buildings with respect to some form parameters. Again utilizing generic urban forms, Martin and March's simplified forms have influenced various scholars to employ simple forms, thus eliminating the complexities found in real urban structure.

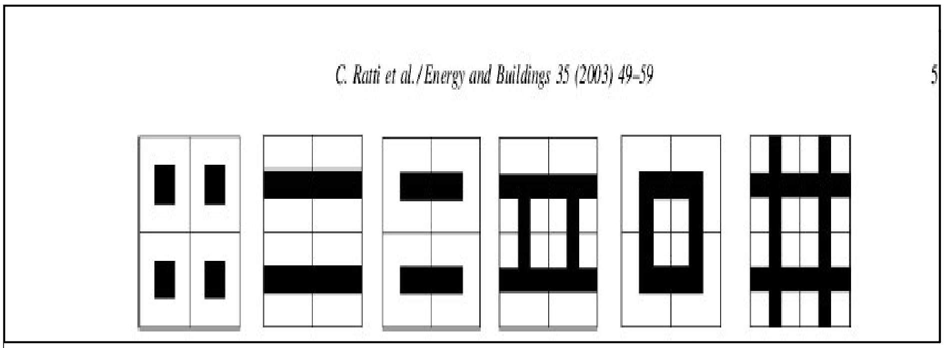


Figure (4): Generic Urban Forms, Based on Martin and March (Ratti et al., 2003)

The experiment aimed to examine the solar performance of the curvilinear form in comparison to the rectangular one. An optimum urban form for a given site would give maximum radiation during the underheated period while simultaneously reducing insolation to the minimum during the overheated period. Therefore, a comparison between the two forms, with regard to the total generated shadow in both winter and summer periods, was conducted. Also, the generated shaded area during the whole year was calculated to investigate the form which could be most suitable for heating requirements and the one that is most suitable for cooling.

The experiment also intends to establish a methodology by which the urban form can be investigated in terms of the generated shadow pattern. This methodology aims, not only to give information about the variation in the annual shaded percentage between the two forms, but also to give details about the season when this variation is greater. In addition, it will clarify the sides where this variation is maximal and will also indicate the period during the day when this variation is more significant. Moreover, it will indicate the period during the day where this variation is more significant. This approach gives an explanation of the status of the generated shadow, which allows for the best interpretation of the results and, in turn, the maximum benefit from it.

Radial forms can be easily found within urban structures, especially in areas with radial arrangements of road network. One of the characteristics of the radial form is that it can create a space which is surrounded and defined by walls (Figure 5.2). This principle is very useful within residential areas, because these spaces are used as the main outdoor living space for children’s playgrounds, for common social activities and human contacts.

The rectangular form is more common than the radial one in the current urban structure, mainly due to some constructional and compositional aspects. However, discovering some advantages of the radial building and understanding its solar behaviour could give such forms the opportunity to be more beneficial. The experiment attempts also to prove that analysing such complicated forms, often ignored by researchers due to their difficulty, can be successfully handled. A comparison between radial and rectangular forms, with regard to the generated shadow patterns and thermal performance, was conducted in order to explore the solar behaviour of the radial form.

1.2 Method and Approach

Shading is an important design consideration. Ahmed (1996) pointed out that the exposure of building surfaces to direct radiation leads to high temperature in the surrounding ambient. The protection of the facade from direct solar radiation can significantly reduce the absorbed solar energy (Belakehal et al., 2000). Therefore, reduction of heat gain and increase in shading can be considered as a major step in controlling overheated conditions.

“Direct solar radiation is the main source of external thermal excitation to which the form is exposed. The contribution of the scattered radiation from the sky is of less importance” (Mohsen, 1979). It is known that exposure of building surfaces to direct solar radiation not only affects the surrounding environment, but also affects the thermal comfort inside the building itself. As different urban forms produce different shadow patterns, surfaces exposed to solar radiation vary from one form to another and a shadow analysis simulation is used to investigate the solar performance of the examined forms. Calculating the shaded area means that average direct solar radiation received by forms is indirectly examined (assuming that surfaces which are not shaded are exposed).

"It is found that solar exposure per unit surface area of building is related to the discomfort index and the former is therefore a good indicator of the relative thermal performance of buildings in different urban layouts" (Gupta, 1984).

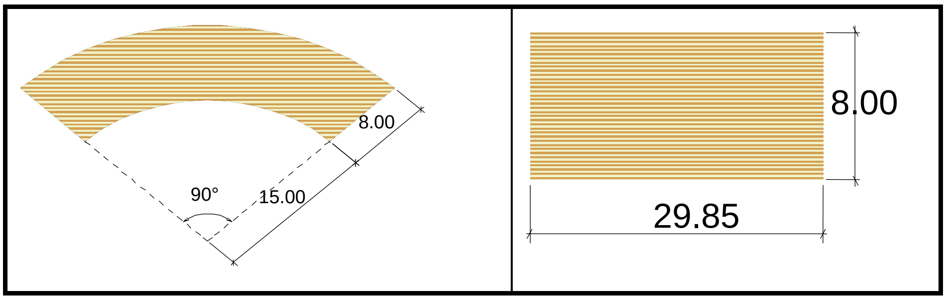
It is very well known that solar heat gains to the building take place through the building envelope. Most buildings in Palestinian urban structures are poorly insulated and have very lightweight external walls and roofs, especially in the Gaza Strip and refugee camps, where thin and hollow cement blocks are predominantly used. Thus, solar exposure can provide a good indication of the possible heat gains, as the actual heat gain to the building interior will not be greatly reduced by the thermal resistance and thermal capacity of the envelope. More important will be the variation in the pattern of exposed and shaded area that occurs over the facades of buildings.

As it was stated in Lloyd Crossing sustainable urban design plan: "The planned massing and location of new development is crucial to optimizing solar exposure for the daylighting, heating and cooling of buildings" (Matt Hennesse et al. 2004). Hence, the control of thermal performance of the indoor spaces can be achieved by natural means through the control of insolation on the external surfaces of the forms. These exposed surfaces reflect some of the received radiation to the surrounding environment. Also, the amount of reradiated solar radiation from these surfaces to the sky dome varies according to the extent of the closure of the layout. However, some of the reflected radiation remains within the urban canyon and contributes to heating the outdoor living space. An optimum form for a given site would provide maximum radiation in the underheated period while reducing insolation to a minimum in the overheated period.

The research not only intends to make a comparison between the performance of the two forms, but also to establish a comprehensive approach and methodology by which any urban form can be fully investigated in terms of the generated shadow pattern. These analyses can be divided into two groups. The first will evaluate the amount of the shaded area generated in the two forms and the second will evaluate the distribution of the shaded area during the daytime period.

The distribution of the shaded area in the main facades of the two forms is analysed. This analysis was of significant importance in bilateral types of buildings where it is necessary to consider more homogenous insolation in the two sides of the forms. The latitudinal location of the site, orientation, time, month and the hour of experiment are required for generating the shadow. Jerusalem climate data were suggested (31^{o} 47) due to the central location of the city, approximately in the middle of the Palestinian territories. Other climatic variables have been maintained the same, in order to isolate the effect of the geometry of the forms. In addition, the effect of airflow pattern has been eliminated in the simulation and all other variables have been neutralized. The SunCast Program which was used to conduct the experiments, provides numerical calculations for the shaded surfaces. This assures a high accuracy for the required measurements of this experiment, as the variation in the shaded area between the forms is expected to be relatively small.

1.3 The Urban Site



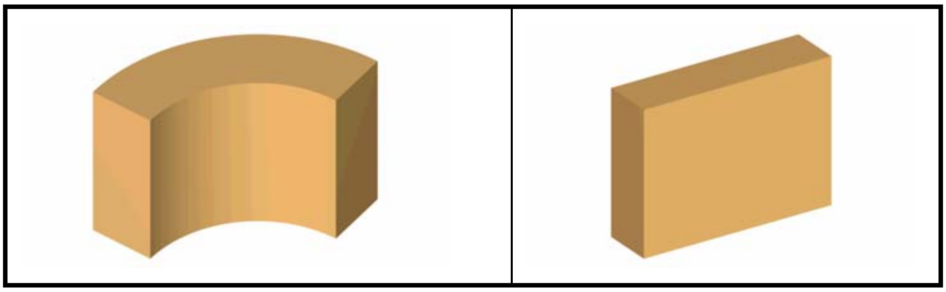


Figure (5): The Dimensions of the Radial and Rectangular Forms.

Two forms are suggested (the rectangular and curvilinear) in this experiment. The height of the forms is 16 m and the depth of the blocks is 8 m. The two forms have the same built volume (3820.8 m^3) and the same floor area (238.8m^2) (Figure 5). As the two forms have the same height and the same perimeter (75.7m), the external surface areas for the two forms will also be identical (1211.2m^2). These physical dimensions are congruent with the usual urban pattern in the new large-scale housing projects in Palestine which are, in general, five-storey residential blocks. The experiment is conducted for the radial form with the concave facade facing the south, and for the radial form with the concave facade facing north. Then the two radial forms with the same built volume and different orientations are examined.

1.4 A Comparison between the South-facing Radial Form and the Rectangular Form

i. Shadow Patterns in summer

The Rectangular Form			The South-facing Radial Form		
South Facade	North Facade	Average	South Facade	North Facade	Average
57.14 %	42.86 %	50 %	64.34 %	51.43 %	57.88 %
The Variation				The Variation	
14.28 %			12.91 %		
The Average Daily Shaded Area per Hour in Summer					

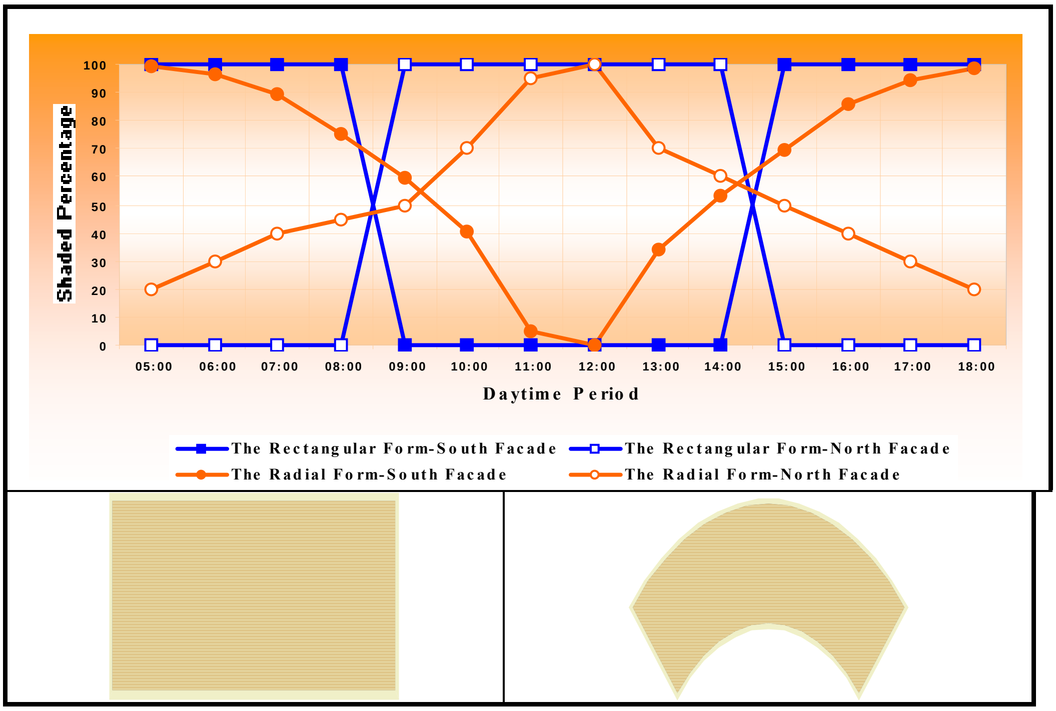


Figure (6): The South-facing Radial Form and the Rectangular Form: Shadow Patterns in summer.

The graph shows the generated shadow pattern in the two opposite facades for both forms in the summer period (Figure 6). The horizontal axis represents the daytime period in one-hour intervals. The vertical axis represents the percentage of the shaded area of the facade in units of 10%.

This graph illustrates that, in the radial form, the two opposite facades could be partially exposed at the same time, as the sunrays can simultaneously reach some parts located in both opposite facades. The variation between the two facades is maximal at noon, where the south facade is completely exposed and the north facade is completely shaded at the same time. In general, the radial form is more shaded and has less variation between the two opposite facades. In both forms, the north facade is more exposed than the southern one.

ii. Shadow Patterns in winter

The Rectangular Form			The South-facing Radial Form		
South Facade	North Facade	Average	South Facade	North Facade	Average
0 %	100 %	50 %	6.8 %	96 %	51.42 %
The Variation			The Variation		
100 %			89.2 %		
The Average Daily Shaded Area per Hour in Winter					

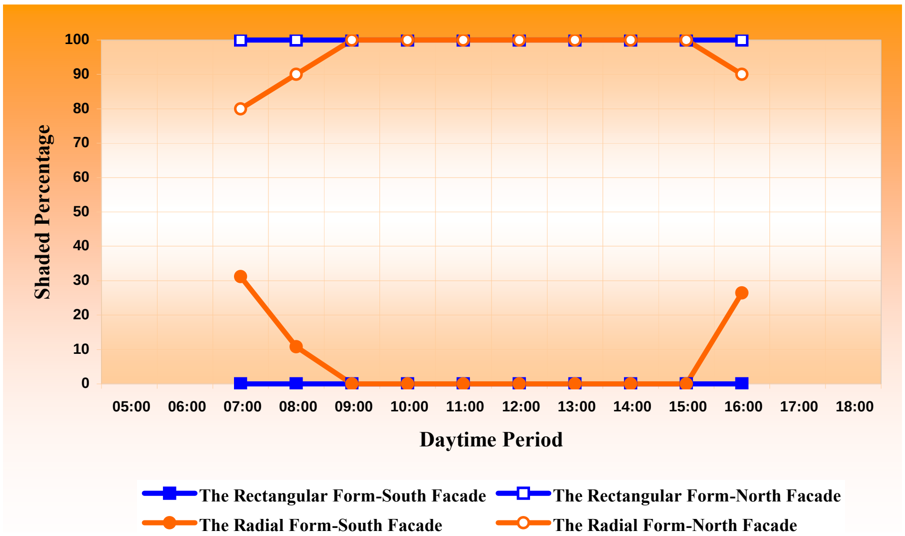


Figure (7): The South-facing Radial Form and the Rectangular Form: Shadow Patterns in winter.

The graph reveals that, in the rectangular form, the north facade does not receive any sunrays during the daytime period, as the sun mainly comes from the southern positions in winter. Conversely, the south facade is completely exposed all the time and the variation between the two facades is maximal (Figure 7).

From studying this graph, it can be observed that, in the radial form, a small part of the south facade is shaded during the early morning and the late afternoon, while less of the north facade is exposed during the same period. The north facade is less shaded than its rectangular counterpart and the radial facade can be partially exposed in the early morning and the late afternoon, as the convex north facade still has the possibility of receiving sunrays in these periods. The south facade of the radial form is slightly more shaded in the morning and afternoon periods than the rectangular one. In general, the radial form is more shaded and has less variation between the two opposite facades.

By studying the previous graphs, it can be concluded that the self-shading effect of the radial facade is maximal in summer, especially in the forenoon and afternoon periods, because sunrays in these periods are more parallel to the long axis of the forms and the altitude angle of the sun is smaller. Self-shading in these periods also lasts for a longer time, as the sun’s azimuth changes at a slower rate in the morning and the afternoon. In contrast, this effect will be at a minimum during the noon period, as sunrays are coming directly from the south, perpendicular to the long axis of the forms. In this noon period the radial facade has the maximum shading or exposure, and the performance of the radial facade is approximately similar to the rectangular one in this case (especially in winter time).

1.5 The Application of the Radial Forms in Palestine

The possible application of these studies in Palestine is investigated in order to underline the focal point of the research. In addition, it will reveal the benefits that can be derived from these results in real practice. In Palestine and in other temperate and semi-arid regions, the situation is not so definite: a proposed solution for the winter conditions might not be appropriate for the summer conditions, and vice versa. In general, temperate climates, which have cold winters and hot summers, usually require passive solar heating systems during the winter and passive solar cooling solutions in summer.

1.5.1 Radial Forms with Bilateral Distribution

In bilateral types of buildings, it is important to ensure homogeneous distribution of sunrays for all residential units. It is necessary in this case to adapt the solar performance of the form and the insolation of the two opposite facades in such a way that ensures the access of the sunrays to all residential units located in both sides of the form. The optimal form will be the one with minor differences in exposed areas in both opposite facades in winter and summer periods.

The bilateral distribution of residential units is a very common urban pattern in Palestine for large-scale housing projects. Such a design is preferable from an economic point of view as the cost of the residential unit in this design could be lower. In this case, the vertical communication could serve more than one residential unit on each floor. In addition, the entire construction process and material cost will be reduced. According to the location of Palestine, and as was proved by the shadow analysis, the north facade of the rectangular forms receives no sunrays in the wintertime (Figure 5.7). In bilateral types of buildings, this means that one or more of the residential units on the northern side of the building will receive no sunrays in winter. This could be disadvantageous from a hygienic, aesthetical and psychological point of view. In addition, there will be an imbalance in the provision of thermal comfort. This situation gives advantages to the units located on the southern side and undermines the northern units.

The radial form can improve this situation. As was proved by the previous investigations, the radial form still has the winter sunrays on both facades (northern and southern). So the radial form could improve thermal comfort in winter for all residential units on adequate and fairer manner (Figure 8).

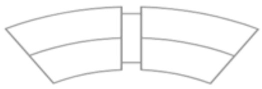
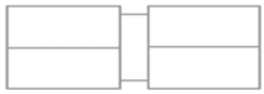
	
More Suitable for Bilateral Type of Buildings	Less Suitable for Bilateral Type of Buildings
In the radial forms, the residential units in the northern side can enjoy sunrays in wintertime, while no sunrays can reach the northern side of the rectangular form at the same period	

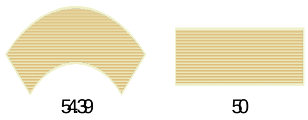
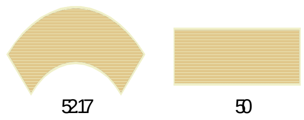
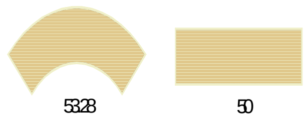
Figure (8): Radial and Rectangular Forms with Bilateral Distribution.

The fact that the two opposite facades in the radial form could be exposed to sunrays simultaneously could be very useful in planning the architectural design concept. The residential units located in the north facade will be able to receive sunrays in winter. In addition, some architectural aspects could be maintained in the opposite sides. For example, bedrooms in the residential units, located in both opposite sides of the building, could be situated in such a way to receive sunrays in the morning. This concept could be applied if the designer preferred to make the sunrays rouse people and facilitate the access of sunrays into bedrooms so that people might experience the beginning of the day in more pleasant manner.

1.5.2 Open and Closed Layouts

The rectangular form can be considered as representative of the open layout, while the radial one can be considered representative of the closed layout (or a layout which is less open). Conducting a comparison of the shadow analysis of the two forms (radial and rectangular) in winter and summer periods proves the adequacy of the rectangular form (open layout) for heating. It also proves the suitability of the radial form (closed layout) for cooling, as the radial form generates more shadow than the rectangular one over the whole year (Table 1).

Table (1): The Average Daily Shaded Area for the Radial and Rectangular Forms in the Two Seasons.

The Shaded Area in Summer Period					
The Rectangular Form			The South-facing Radial Form		
South	North	Average	South	North	Average
57.14 %	42.86 %	50 %	64.34 %	51.43 %	54.39 %
The Shaded Area in Winter Period					
The Rectangular Form			The South-facing Radial Form		
South	North	Average	South	North	Average
0 %	100 %	50 %	6.8 %	96 %	52.17 %
The Average Shaded Area in the Two Seasons					
The Rectangular Form			The South-facing Radial Form		
South	North	Average	South	North	Average
28.57 %	71.43 %	50 %	35.57 %	73.715	53.28 %
					
Shaded Area in Summer		Shaded Area in Winter		The Average in the Two Seasons	

Reviewing these tables, it becomes evident that the rectangular form generates (in both the summer and winter periods) less shaded area than the radial one, due to the self-shading effect of the radial form. However, the exposed area in winter in the rectangular forms is concentrated in one facade: the southern one.

The differences between the radial and rectangular forms are more apparent in the summer period, as the variation between the exposed areas in identical facades in the two forms is the greatest (Table 2). This demonstrates that the radial form is more advantageous in areas where avoiding summer heat and generating more shadow is required.

The Exposed Areas of the Facades During Summer					
	The South F.	The East F.	The North F.	The West F.	Average
The South-facing Radial Form	35.66%	53.57 %	48.57%	53.57%	45.6%
The Rectangular Form	42.86%	50%	57.14%	50%	50%
The Variation					4.4%
The Exposed Areas of the Facades During Winter					
	The South F.	The East F.	The North F.	The West F.	Average
The South-facing Radial Form	93.2 %	80 %	4 %	80 %	47.83 %
The Rectangular Form	100 %	50 %	0 %	50 %	50 %
The Variation					2.17 %

The Average Exposed Area for the Facades Per Hour in the Two Seasons	
The South-facing Radial Form	46.715 %
The Rectangular form	50 %

In Palestine, the radial form will be preferable, where the major concern is to avoid summer heat (the coastal plain). In areas where the major concern is to receive sunrays in winter (the mountain area), the rectangular form will be more beneficial (Figure 9).

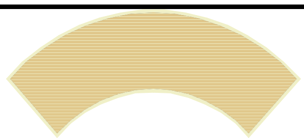
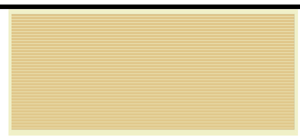
	
More Suitable for Cooling Requirements (The Coastal Plain)	More Suitable for Heating Requirements (The Mountain Area)
The Radial Form (Closed Layout)	The Rectangular Form (Open Layout)

Figure (9): The Applications of the Radial and Rectangular Forms in Palestinian Territories.

The calculation of Ew (Table 3) for both forms reveals that the insolation efficiency is better in the case of the radial form; thus it is more suitable in temperate climates. The southern facades produce the main variation in the insolation efficiency between the two forms. This is of more importance in unilateral types of buildings, since it is common to have the south facade as the main facade in northern latitudes. In this case, the south-facing form can be more suitable in unilateral types of building than the north-facing form, as it has better insolation efficiency for the south facade.

Table (3): Solar Insolation Efficiency of the Radial and Rectangular Forms.

The Solar Insolation Efficiency of the South Facades in the Two Forms			
	The Exposed Area of the South Facades		
	Summer	Winter	Ew
The South-facing Radial	35.66 %	93.2 %	261.36 %
The Rectangular Form	42.86 %	100 %	233.32 %
The Solar Insolation Efficiency of the North Facades in the Two Forms			
	The Exposed Area of the North Facades		
	Summer	Winter	Ew
The South-facing Radial	48.57 %	4 %	8.24 %
The Rectangular Form	57.14 %	0 %	0 %

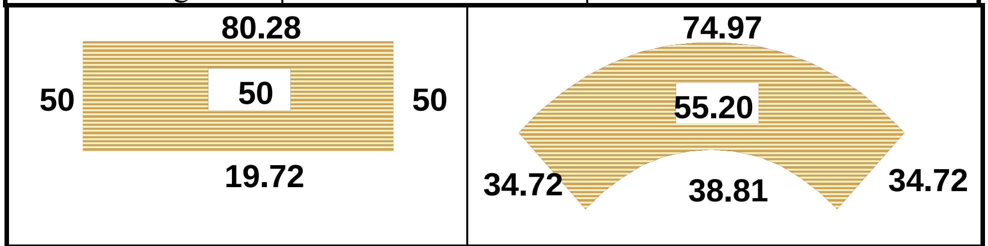
… Continue table (3)

The Solar Insolation Efficiency of the two Opposite Facades in the Two			
	The Exposed Area of the Two Opposite		
	Summer	Winter	Ew
The South-facing Radial	84.43 %	97.2 %	115.12 %
The Rectangular Form	100 %	100 %	100 %

1.5.3 The Annual Shaded Area Generated by the Forms.

i.A Comparison between the Rectangular Form and the South-facing Radial Form

The Average Annual Shaded Area per one Hour		
	The Rectangular Form	The South-facing Radial Form
The West Facade	49.31 %	34.72 %
The Outer Surface-North Facade	80.56 %	74.97 %
The East Facade	51.04 %	34.72 %
The Inner Surface-South Facade	19.79 %	38.81 %
Total Average	50 %	55.20 %



More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure (10): The Average Annual Shaded Area for the South-facing Radial Form and the Rectangular Form.

The radial form is more suitable for cooling requirements as it generates more shadow over the whole year. The rectangular form is more suitable for heating requirements as it generates less shadow over the year (Figure 10).

It can be also viewed from the two forms that the side facades have the same shaded area over the year. This is because the two sides are symmetrically arranged in relation to the sun's path. In the rectangular form, one facade is constantly exposed for the first half of the daytime period (the eastern facade) and the other facade is exposed in the second half of the day (the western facade).

Table (4): The Variation between the Two opposite Facades with Regard to the Generated Shaded Area.

The South-facing Radial Form		The Rectangular Form	
The South Facade	The North Facade	The South Facade	The North Facade
38.81 %	74.97 %	19.79 %	80.56 %
The Variation		The Variation	
36.16 %		60.77 %	
The Radial Form is More Suitable for Bilateral Type of Buildings			

Another aspect which confirms the suitability of the radial form for the bilateral types of building is the annual shaded percentage distributed in the two opposite facades. The variation in the shaded percentage between the two opposite facades (Table 4) in the case of the radial form (36.16 %) is less than the variation between the two opposite facades in the case of the rectangular form (60.77 %). This means that the exposed area in the case of the radial form is distributed in a more impartial manner, and thus the radial form is more advantageous for bilateral types of building.

Table (5): The Average Annual Exposed Area Per Hour for Vertical Surfaces in Jerusalem.

The East Vertical Surfaces	50 %
The West Vertical Surfaces	50 %
The South Vertical Surfaces	80 %
The North Vertical Surfaces	20 %

As the rectangular form does not generate any self-shading effect, measurements in this case could be applicable to any vertical surface in Palestine. Although it is well-known among architects in Palestine that the south facade is better exposed than the northern one, this does not recognise clearly the ratios between the exposed areas in the two facades over the year. This outcome demonstrates that the ratio between the exposed area in the north facade and the south facade is 1: 4 respectively and the south facade gets approximately 80% of the daylight during the year, while the northern one gets only 20% of the daylight during the year (Table 5). The average annual shaded area per hour for vertical surfaces in Jerusalem for each month is also indicated in the table 6.

Table (6): The Average Daily Shaded Area per Hour for Vertical Surfaces in Jerusalem in Each Month.

	West	**North**	**East**	**South**	**Total**
Jan	50 %	100 %	50 %	0 %	50 %
Feb	50 %	100 %	50 %	0 %	50 %
Mar	50 %	100 %	50 %	0 %	50 %
Apr	50 %	76.92 %	50 %	23.08 %	50 %
May	50 %	53.57 %	50 %	46.43 %	50 %
Jun	50 %	42.86 %	50 %	57.14 %	50 %
Jul	50 %	50 %	50 %	50 %	50 %
Aug	50 %	69.23 %	50 %	30.77 %	50 %
Sep	50 %	100 %	50 %	0 %	50 %
Oct	50 %	100 %	50 %	0 %	50 %
Nov	50 %	100 %	50 %	0 %	50 %
Dec	50 %	100 %	50 %	0 %	50 %

2. Mutual Shading of Urban Canyons

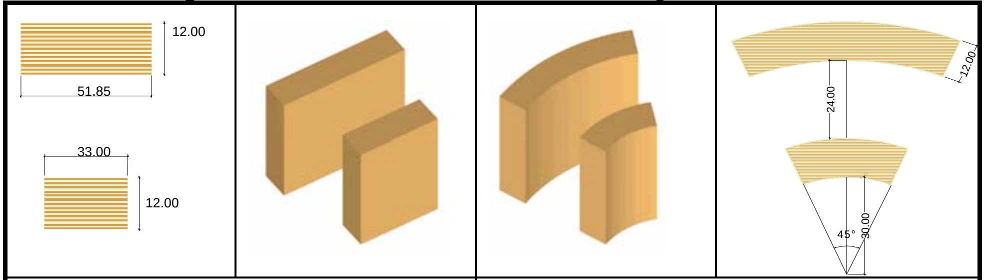
2.1 Urban Canyon Configuration

Littlefair (2001a) described overshadowing as a key issue in daylight design, particularly the reduction of light to existing buildings. Gupta (1984) has indicated that the mutual shadowing of buildings in urban layouts changes the rate of solar radiation around buildings. Santamouris et al. (1999) emphasised the importance of sunlight in the design process because it can greatly affect thermal and visual comfort. The provision of daylight to nearby buildings is very important, as an unskilful planned development may make adjoining properties gloomy and unattractive.

Littlefair (2001b) pointed out that in urban areas building layout is the most important factor influencing the gained heat of sunlight and solar insolation reaching a building. It also affects sunlight in open spaces, ventilation and wind shelter. "The two main factors for mutual shading are confinement and orientation" (Littlefair, 2001b). Sakakibara (1996) reported that the urban thermal environment depends on the urban canyon configuration. Therefore, it is necessary to take into account the impact on existing nearby buildings when planning a new development. New development may often restrict solar gain to other existing buildings nearby.

Mazouz (1998) has pointed out that a great deal of research work on the optimisation of the shape and orientations of single buildings has been carried out. However, little research seems to have been done in examining the overall performance of clusters or groups of buildings apart from a few pioneering works such as those by Knowles (1974), Hawkes (1982), Los (1988) and Gupta (1984). Littlefair (2001a) believed that much has been written on solar resource accessibility on unobstructed sites, but much less has been produced on the effects of obstruction. The attention of previous researches into energy-related aspects of the built environment has been mainly focused at the scale of the individual building or of the city as a whole. The interactions between buildings can be as significant as the individual buildings themselves. Hence, more investigations into the built environment at a scale intermediate between individual buildings and cities are required.

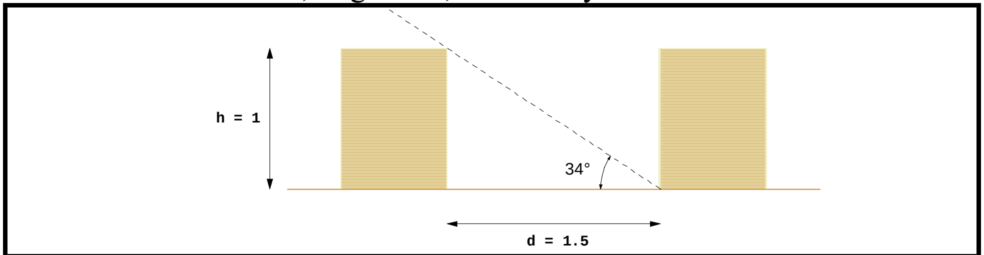
2.2 A Comparison between Radial and Rectangular Urban Patterns.



A Plan of the Rectangular Pattern	A Plan of the Radial Pattern

Figure (11): The Urban Site - East-West Pattern.

The Urban Site: Two patterns of urban canyons are suggested (rectangular and radial). Both patterns consist of two blocks with the same separating distance (Figure 11). The two patterns have the same built volume and the same canyon facade area. In addition, the two patterns occupy the same floor area. As the two patterns have the same heights and the same perimeters, the external surface areas for the two patterns will be the same. The height is supposed to be 16 m and the depth of the blocks is 12 m. These physical dimensions are congruent with the usual urban pattern in a lot of new large-scale housing projects in Palestine which are, in general, five-storey residential blocks.



h = Roof height, d = Roof to face spacing to prevent overshading for a given sun angle, α = Solar Altitude

{h = 1, midday solar altitude for latitude of Jerusalem (31° 47) on December 21st (α) = 34^0}

No winter overshading will occur with roof to face distance of 1.5

Figure (12): The Urban Canyon Sections - Urban Canyon Ratio (H/W): 1: 1.5.

The minimum distance required between buildings to avoid overshading can be calculated using local solar data. Pitts (1989) believed that “the restrictions imposed on layout by distance between buildings for minimum overshading will usually be more than adequate to satisfy the requirements for privacy”. When calculating the most suitable separating distance between the two blocks for the Jerusalem latitude by using the common method in order to avoid overshadowing and maintain good solar accessibility, it is noted that the required spacing between the two blocks has to be 1.5 the height of the block (24m) (Figures 12 and 13). This method usually takes the depth of winter (21st December) as the determinant for the required spacing between buildings. Thus, the urban canyon ratio (H/W) is (1: 1.5). The urban canyon ratio here is considered as the ratio of the height (H) of the blocks to the width of the canyon (W). The experiment is conducted for patterns with the urban canyon located on the east-west axis and also for patterns with the long axis of the canyon lying north-south.

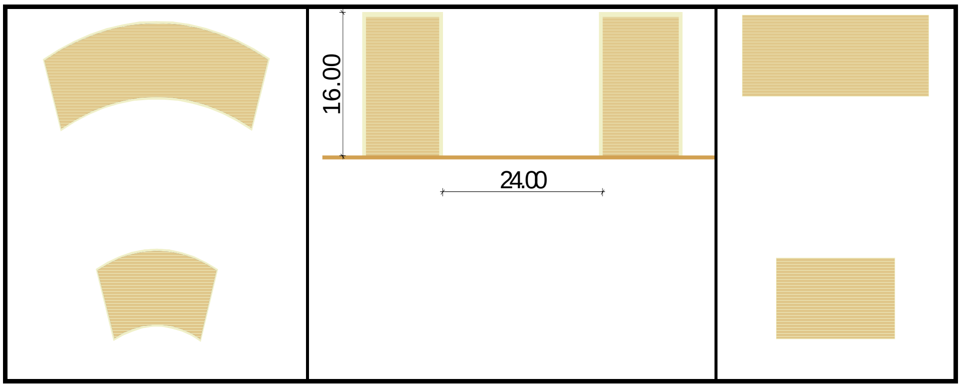
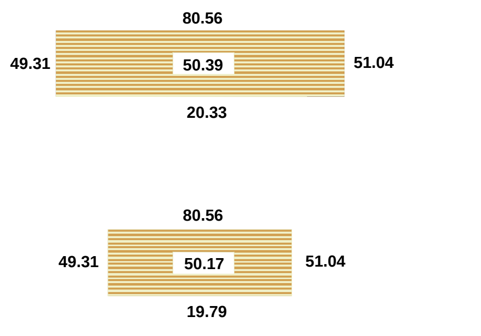
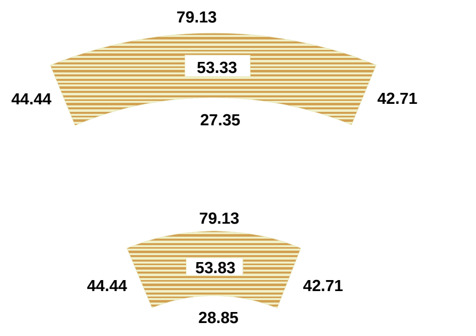


Figure (13): The Urban Canyon Sections of the Two Patterns.

2.2.1 The Shadow Analysis for the Canyon Located on the East-West Axis: The Annual Shaded Area Generated in the Two Patterns.





50.30 %	54.76 %
More suitable for heating requirements	More suitable for cooling requirements

Figure (14): The Annual Shaded Area Generated in the Two Patterns.

As the annual shaded percentage, in the case of the radial pattern, is more than the rectangular one, it can be derived that the radial pattern is more suitable for cooling requirements, while the rectangular one is more suitable for heating requirements (Figure 14). In the case of Palestine, the rectangular pattern could be more advantageous in the West Bank area where heating requirements in winter are more important, while the radial pattern could be more beneficial in Gaza where cooling requirements are more essential in summer. The concave facades in the radial pattern have more shaded percentage than their counterparts in the rectangular pattern due to the generated self-shading effect. In each pattern, the side facades in the same block have approximately the same shaded percentage, as they are arranged symmetrically in relation to the sun's path. Also, the identical side facades of the two blocks have the same shaded percentage as they have the same azimuth surface angle. The side facades in the radial pattern are less shaded, as they are more turned towards the south.

2.2.2 The Shadow Analysis for the Canyon Located on the North-South Axis: The Annual Shaded Area Generated in the Two Patterns.

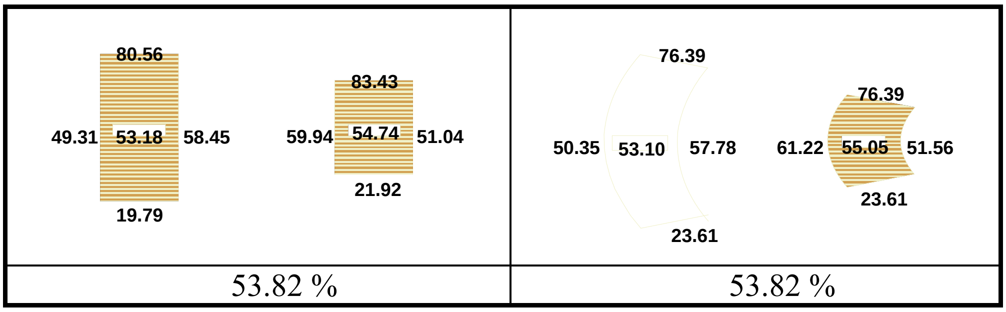


Figure (15): The Average Annual Shaded Area per Hour.

The calculations of the average annual shaded area in the two patterns (Figure 15) show that the two patterns have approximately the same shaded area and therefore there are no major differences between the two patterns with regard to heating and cooling requirements. This is because the self-shading effect of the radial pattern is expected to take place during the noon period (when sunrays parallel the long axis of the forms). In this case the sun is high in the sky and this period is very short, as the azimuth of the sun changes rapidly during the noon period. This minimises the generated self-shading in the radial form. Thus, the variation between the generated shaded areas in the two patterns is insignificant.

2.3 A Comparison between the Two Urban Patterns with Different Orientations: The Average Annual Shaded Area per Hour.

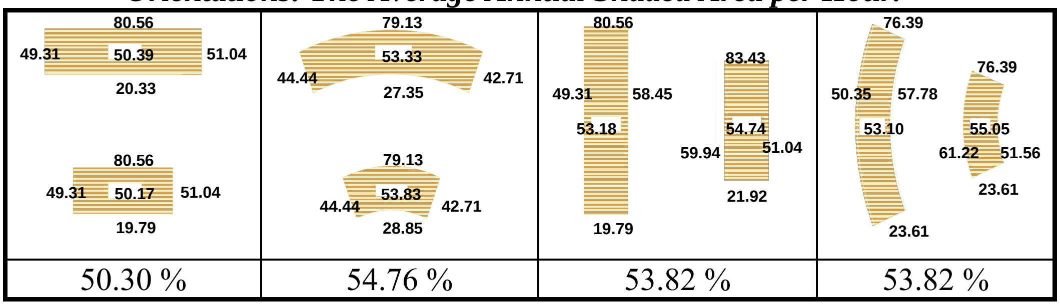


Figure (16): The Average Annual Shaded Area per Hour.

The comparison between the two patterns reveals that the rectangular pattern with the canyon on the east-west axis has less shaded area than the rectangular pattern with the canyon on the north-south axis (Figure 16). The situation with the radial form is the opposite. The variation in the shaded percentage between the radial and the rectangular patterns is greater in the case of the canyons oriented east-west. This results from the bigger self-shading effect of the radial facades in the pattern with the urban canyon axis oriented east-west. Most of the self-shading takes place when sunrays match the long axis of the urban canyon. In the case of the east-west canyon elongation, this occurs in early morning and late afternoon, when the sun is closer to the horizon and its azimuth changes at a slower rate, resulting in a maximal self-shading effect (Table 7). Conversely, the radial pattern with the canyon located on the north-south axis has approximately the same amount of shaded area as the rectangular one, because the self-shading of the radial forms, which is expected to take place during the noon period, is minimised due to the high position of the sun in the sky at midday.

Table (7): The Radial Forms in the East-west Canyon Generate more Self-shading Effect.

The Shaded percentage			
The South Block-The South Facade		The East Block-The East Facade	
The Rectangular Pattern	The Radial Pattern	The Rectangular Pattern	The Radial Pattern
19.79 %	28.85 %	51.04 %	51.56 5
The Variation = 9.06 %		The Variation = 0.52 %	

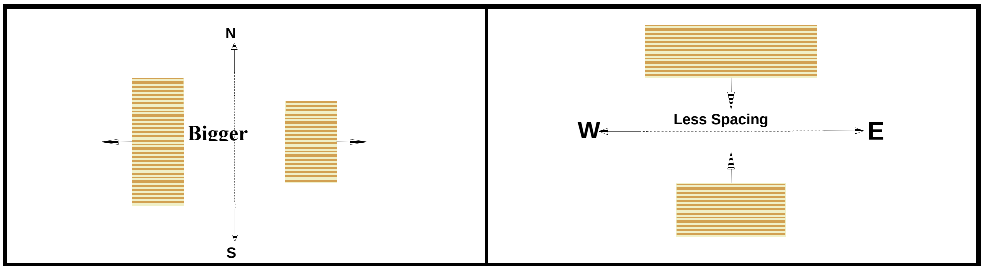
The shadow caused by one block to another is bigger in the case of the pattern with the urban canyon axis oriented north-south, as the shadowing occurs early in the morning or late in the afternoon when sunrays are more horizontal and changes in the azimuth angle of the sun are slower. The shadow from the south block to the north one in the east-west canyon is limited, as this shadowing takes place during the noon period when the sun is high in the sky (Table 8). By studying these results, it becomes evident that the main variations in the shadow patterns between the two urban patterns are created by the behaviour of the individual radial block, while the effect from one block to another is approximately the same in the two patterns.

Table (8): The Shaded Percentage from one Block to the other in Both Patterns.

The East-west Pattern		The North-south Pattern	
The Shadow From the South Block to the North One		The Shadow From the East Block to the West One	
The Rectangular Pattern	The Radial Pattern	The Rectangular Pattern	The Radial Pattern
0.54 %	0.6778 %	7.41 %	6.97 %
		The Shadow From the West Block to the East One	
		The Rectangular Pattern	The Radial Pattern
		10.63 %	10.87 %

2.4 Building Intensity

The experiment proves that an urban canyon ratio (H/W) of 1:1.5 is reasonable for maintaining the solar right for buildings, as the shaded area caused by shadowing from the neighbouring block is relatively small. However, this ratio has to be considered with reference to the urban canyon orientation, as the modelling simulation results show a definite influence of the canyon orientations on the shading. Therefore, the spacing between the two blocks within the urban canyon located on the north-south axis has to be greater than the spacing between blocks within the urban canyon oriented east-west if it is required that the same standard of solar accessibility is maintained (Figure 17).



More Spacing	Less Spacing

Figure (17): Solar Right: The Spacing between the Two Blocks.

The outcomes of the experiment show that the most intensified use of the site can be achieved with canyons on the east-west axis. The required size of the site with canyons located on the north-south axis must increase if it is to host the same number of residents and maintain the same quality of sunlight. This means a reduction of resident density per reference area in the case of the pattern with an urban canyon axis oriented north-south. A more significant increase of site size with this orientation occurs due to longer morning and afternoon shadows during the year, which dictate a larger distance between the buildings. So, arranging the blocks on the site in such a manner to have the axis of the urban canyon located in an east-west direction can allow for greater building intensity, while maintaining the same quality of sunlight (Figure 18).

The best use of the building site is possible when the urban canyon axis is oriented east-west where for the same area of building site, the density of residents per reference area is the highest.

Figure (18): The Relation between the Building Intensity and the Orientation of the Canyon.

This finding could be of significant benefit to urban designers in Palestine, as the question of building intensity is very important due to the lack of land and the high population density. Applying such concepts will enable Palestinian urban designers to meet the challenge of accommodating millions of Palestinian refuges and returnees in these relatively undersized territories.

3. Conclusion

One of the clear implications of the first part of the study is that the shaded and exposed periods in the rectangular facade start and finish suddenly and the two periods exchange their influence on the facades. In the radial form, the shaded and exposed periods start and finish gradually and the two opposite facades can be exposed to sunrays simultaneously. As the concavity of the radial form is relatively small, the variation between the amounts of generated shadow in the two patterns (radial and rectangular) during the whole day is relatively small, while the main differences are in the distribution of the shaded area during daytime. This variation in the shadow patterns is more significant in the summer period due to the increased self-shading effect of the radial form in this period. As regards the comparison between the radial and rectangular forms, it was concluded that the insolation efficiency is better in the case of the radial form and is thus more suitable in temperate climates. In general, the radial form is more suitable for cooling requirements as it generates more shadow over the whole year, while the rectangular form is more suitable for heating requirements. In Palestine, the radial form will be preferable, where the major concern is to avoid summer heat (the coastal plain). In areas where the major concern is to receive sunrays in winter (the mountain area), the rectangular form will be more beneficial. In bilateral buildings, the radial form will be more suitable, as the form has minor differences between the two opposite facades with regard to the exposed areas over the whole year. Also, applying the south-facing radial form in unilateral buildings could be beneficial as it has better insolation efficiency for the south facade.

In the second part of the study, and as the annual shaded percentage in the case of the radial pattern, with a canyon lying east-west, is more than the rectangular one, it can be derived that the radial pattern is more suitable for cooling requirements, while the rectangular one is more adequate to meet the requirements for heating. In terms of the potential application of these models in Palestine, it is found that the rectangular pattern could be more advantageous in the West Bank area where heating requirements in winter are more important, while the radial pattern could be more beneficial in Gaza where cooling demands are more essential in summer. Finally, the experiment proves that an urban canyon ratio (H/W) of 1:1.5 is reasonable for maintaining solar right for buildings, as the shadowing caused by one block to another is relatively low. However, this ratio has to be considered with reference to the urban canyon orientation. The spacing between the two blocks within the urban canyon located on the north-south axis have to be more than the spacing between blocks within the urban canyon oriented east-west if it is required to maintain the same standard of solar accessibility. Thus, the most intensified use of the site can be achieved with canyons on the east-west axis.

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