Sustainable Urban Design and Climate: With Reference to Palestine

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Sustainable Urban Design and Climate
(With Reference to Palestine)

By

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Abstract

It seems evident that the geometry of the urban form as an urban design parameter is crucial. The layout of the structure can modify the urban climate through proper design, thus improving the thermal comfort both outside and inside buildings, even reducing energy demands for heating and cooling requirements. Although solar design potentials on an 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 climatic responsive urban design. This thesis is concerned with a method to evaluate solar energy in urban design. The emphasis of the thesis is to study the relationship between the urban form and solar insolation and to establish a comprehensive approach which can evaluate the urban forms, with respect to the generated shadow pattern, and can be applicable to all types of urban configurations.

Among the considerations which have also been investigated, is the inter-relationship between solar insolation and thermal performance of urban patterns. The thesis discusses the possible application of these forms in Palestine, in order to highlight the way that the derived results can be handled in real practice. While the analysis was mainly related to the Palestinian climate, the techniques employed may be applicable to other countries. The main structure of this thesis is arranged in two parts. The first part identifies the conceptual framework of the sustainable urban design in order to provide the reader with basic information about the subject. The principal aim of this part has been to outline the research area on which the present work was set. Secondly, parametric studies have been performed to bridge the gap in the previous studies. The parametric studies are structured into four chapters. Each study raises separate but overlapping issues and the four studies together cover the basic classified types of urban forms.

The first study compares radial and rectangular forms in order to explore the solar behaviour of the radial form, as opposed to the rectangular one and to illustrate the methodology adopted in this research work to evaluate the urban forms with regard to the generated shadow patterns and thermal performance. The second study compares radial and rectangular urban canyons to clarify the influence of the self-shading effect of the radial form. The experiment evaluates the most suitable spacing between buildings to avoid overshadowing and maintain good solar accessibility. The study was also performed to determine the urban fabric that allows the achievement of high urban density under optimal solar insolation conditions. The third part contains studies related to aspects of solar insolation in bilateral types of building. The study compares different radial forms varying in the extent of their concavity to find out the one with the minimum variation of exposed areas between the two opposite facades.

The final chapter of the parametric studies deals with the evaluation and analysis of the radial forms and the rectangular U-shape. This experiment aims to prove the capability of the methodology which was developed in this research, to evaluate such complex forms. Simulation studies encompass shading and thermal analyses. Based on the simulations, design recommendations were derived. The resulting framework provides a significant step forward in understanding the built environment and demonstrates the rich potential in using passive design as a means of influencing urban design. Finally, the thesis draws conclusions and identifies areas for further research into the consideration of solar energy in urban design.

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Nomenclature (Chapter 5, Solar Geometry and Shading, Page 107 – 123)

G_{sc}	Solar Constant (1353 W/m^2)		
G_{on}	Extraterrestrial Solar Irradiance		
E	The Equation of Time		
L_{loc}	The Longitude of the Location	L_{st}	The Standard Meridian for the Local Time zone
B	[(360 (n – 81))/364]	n	Day of the Year, $1 \leq n \leq 365$
ø	Latitude: The angular location north or south of the equator, north positive $\{-90 \leq ø \leq 90\}$		
δ	Declination: The angular position of the sun at solar noon with respect to the plane of the equator, north positive $\{-23.5^0 \leq \delta \leq 23.5^0\}$		
β	Slope: The angle between the plane surface and the horizontal $\{0 \leq \beta \leq 180\}$		
γ	Surface Azimuth Angle: The deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, west positive $\{-180 \leq \gamma \leq 180\}$		
ω	Hour Angle: The angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour, morning negative afternoon positive.		
θ	Angle of Incidence: the angle between the beam radiation on a surface and the normal to that surface.		
θ_z	The Angle of Incidence is the Zenith Angle of the Sun		
ω_s	The Sunset Hour Angle		
N	The Number of Daylight Hours $[2/15 \cos^{-1} (-\tan ø \tan \delta)]$		
R_b	Ratio of Beam Radiation on Tilted Surface to That on Horizontal Surface ($\cos \theta / \cos \theta z$)		
H_o	The Integrated Daily Extraterrestrial Radiation on a Horizontal Surface		
τ_b	The Atmospheric Transmittance for Beam Radiation (G_{bn}/G_o)		
a_o, a_1 & k	Constants	a_o^*	$0.4237 - 0.00821 (6 - A)^2$
a_1^*	$0.5055 + 0.00595 (6.5 - A)^2$	K^*	$0.2711 + 0.01858 (2.5 - A)^2$
A	The altitude of the observer in kilometres	r_o, r_1 & r_k	The correction factors
G_{cnb}	The Clear Sky Beam Normal Radiation	G_{cb}	The Clear Sky Horizontal Beam Radiation
τ_d	The ratio of diffuse radiation to the extraterrestrial radiation on a horizontal plane (G_d/G_o)		
T_s	Sol-air Temperature (°C)		
T_o	Outside Air Temperature (°C)		
G	Total Incident Solar Radiation (W/m^2)		
a	Solar Absorptance of Surface (0-1)		
Qs	Total Direct Solar Gain in Watts (W)		
U	The U-Value of the Specified Element (W/m^2K)		
A	The Surface Area of the Element (m^2)		
abs	The Surface Absorption of the Element		
R_{so}	The Outside Air-film Resistance		
Q	The Resultant Heat Flow (Watts)		
ΔT	The temperature difference between the warm and cold sides of the material (K)		
H	Height to be given in meters above sea level (m ASL)		

Abbreviations

SOLALT	Solar Altitude Angle	SOLAZM	Solar Azimuth Angle
LONG	Longitude of the Given Locality	LSM	Longitude of the Standard Time Meridian
EOT	The Equation of Time	DEC	Solar Declination Angle
AST	Apparent Solar Time	GHA	Greenwich Hour Angle
UV	Ultraviolet	NIR	Near Infrared
1 AU	1 Astronomical Unit (1.496×10^{11}m)		

INTRODUCTION

Introduction
I. Background

Much of the energy consumed by societies is used to run buildings. Large quantities of non-renewable fossil fuel are used to generate this energy, fuel that will not be available to future generations. The processes involved in the conversion of fuel into energy also have a lasting negative effect on the environment through the emissions they cause. This situation calls for a rapid and fundamental reorientation in our thinking, particularly on the part of designers involved in the process of urbanisation. The form of our future built environment must be based on a responsible approach to nature and the use of the inexhaustible energy potential of the sun. This can be achieved by developing the urban structure in configurations that demand less energy for the thermal needs of buildings.

Bioclimatic urban design involves arranging the forms and fabrics of buildings to increase the benefits of renewable energy for heating, lighting and ventilation, and consequently to reduce the consumption of conventional fuel (Littlefair, 1998). It is essential that urban designers, whose plans influence the spatial structure of settlements, should understand this relationship and incorporate energy considerations into the design process. In many cases, climatic urban design can be achieved with little or no extra cost. The importance of understanding the inter-relationships between energy and the built environment has been given new impetus by the energy crises within the western world, especially at this period of time, when major environmental problems have occurred. The energy crises of 1973 accelerated attempts to find advanced tools for the design and evaluation of shading solutions.

Santamouris et al. (1996) pointed out that the layout and structure of a settlement can influence the local climate of an area and can even modify it. This can be achieved through appropriate design, hence improving the thermal comfort conditions, both outside and inside buildings, and reducing energy demands for heating and cooling. 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 improvement of bioclimatic conditions, besides other functional, socioeconomic and symbolic aspects of the urban form (Assis et al., 1999). Bioclimatic urban design contributes towards making human life more comfortable, safe and healthy. The effects of the geometry of the urban space, and the shape and orientation of individual buildings and structures, are among the major factors which can contribute to creating a more liveable microclimate.

One of the fundamental concerns of bioclimatic urban design is to increase and sustain the liveability of urban spaces in cities, where comfort, particularly thermal comfort, is an important criterion. As solar design moves into the city and becomes more widely established, the issue of urban form design and the mutual effects between buildings will become increasingly important. While mankind has to struggle with the intermediate-scale climatic behaviour and patterns, he is quite at liberty to modify the micro-scale climate to suit his needs. The ability to moderate thermal stress by eliminating or reducing extreme conditions would certainly benefit the users of urban outdoor spaces. This would also indirectly benefit indoor conditions as well, as it would mean reducing the stresses on buildings. 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.

This thesis concerns itself with an approach to the evaluation of solar energy in urban design. The research attempts to help the designer to understand the relations between urban forms and thermal performance, thus creating more environmentally-friendly urban design. The target of the research is to enable designers to produce comfortable, energy efficient buildings surrounded by pleasant outdoor spaces within an urban context that itself aims to minimise energy consumption and the negative effects of pollution. The thesis explores ways in which passive solar principles of saving energy can influence the design of urban form. The aim is to achieve an urban form that will assure the exposure of the buildings to the sun during a desired period in winter. Moreover, the form should guarantee their protection from the undesirable summer sun.

Parametric studies have been performed to fill the gap in previous researches. In addition, the possible application of these studies in Palestine is discussed, in order to enhance the research work and to highlight the focal point of the research. The parametric studies are oriented to satisfy two main points. The first goal will be to overcome the shortcomings in previous studies in this field. Secondly, studies will investigate the solar behaviour of common urban forms, which can be suitable for the Palestinian climate, thus enhancing the development of the urban design process in the region.

In Palestine, excellent conditions exist to advance climatic responsive urban design, as Palestine's sunny climate makes it perfect for utilising solar energy over the year. Palestine also does not own any of the traditional energy resources. In addition, the small area of Palestinian territories and its overpopulation makes the conservation of the environment crucial. Moreover, the large-scale housing projects, which are expected to be established in Palestine in the future, for rebuilding refugee camps or to accommodate returnees, are a good opportunity to make designs and experimental models that facilitate the use of solar energy. It is hoped that the studies discussed in this research will lead towards a development of design guidelines for urban design in Palestine based on local climatic and socioeconomic criteria.

II. Problem Identification

Although the approach of solar potential in architectural scale is currently well developed, the methods and techniques for the assessment of solar aspect in urban scale are yet to be advanced in order to enhance climatic responsive urban design (Assis, 1999). Understanding issues of urban comfort is a stepping-stone in the design and the evaluation of the climate responsive space. The issue of sustainable urban form does not appear to have been explored sufficiently. However, there is an increasing awareness of the relation between the geometric characteristics of the urban pattern and its insolation efficiency. Although the importance of the relationship between buildings has been recognised and the effect of buildings on the thermal comfort inside the indoor environment is well-known (Fanger, 1970), the shortage of proper analytical work on the mutual effect of buildings must be acknowledged (Mazouz, 1998). A substantial amount of work has been done in the area of indoor comfort, while urban design issues are attracting research interests only recently.

Previous researches on human thermal comfort have mostly focused on the indoor environment. Shaviv et al., (1998) pointed out that in the recent years, the presented guidelines in studies for energy efficient design deal mainly with the design guidelines of a single building and only a few of them deal with the urban scale. Golany (1995a) stated, "there has been considerable literature published on the subject of climate and single building indoor architecture, but there is very little, if any, literature about urban design scale as it relates to climatic considerations". Matthews (1985) has mentioned that the attention of research into energy-related aspects of the built environment has been focused at the scale of the individual building, or of the city as a whole. Research is well established at the building scale, but comparatively little work has been done at the intermediate scale, where urban and architectural factors interact (Hawkes et al., 1987).

Due to the influence of climate on the urbanisation process, it is important to establish an approach that may help in the formulation of some design guidelines for the urban designer. There has, until recently, been a conspicuous lack of knowledge or concern about the way in which solar insolation is utilised in the built environment. The situation has been one in which the designing of the spatial structure of developments has proceeded without any concern whatever for the impact of the urban geometry on the microclimate of the settlement. Urban designers are still largely uninformed on the significance of their decisions for energy use. In recent years, however, interest has grown in the idea that the geometry of the form might be recognised in a way which would ensure a more rational use of available energy resources.

The long-term minimisation of energy use has not been given adequate consideration in urban design. The overall thermal performance of buildings is usually enhanced by techniques such as thermal mass, surface to volume ratio and shading devices, and planning regulations are established mainly for single buildings. However, what might be true for a single building may not necessarily be true for a complex layout of several buildings (Mazouz, 1998). In recent years there is also a growing recognition among designers that in the current building activity not enough emphasis is given to climatic and energy-conscious aspects. This can be seen in the new urban developments which are being built with almost no consideration to climatic and energy aspects. This situation represents a missed opportunity to promote quality of living in the built environment while assuring efficient use of energy (Capeluto et al., 1998). Pearlmutter (1998) stated, “while urban design guidelines have been developed for responding to climate in various regions, these recommendations are often based more on intuition or sporadic observation than on an integrated microclimatic analysis of thermal comfort conditions”. Therefore, designers should be able to accept that one of their prime goals is the establishment of acceptable levels of energy use within settlements and must devise and use methods for organising the components of urban structure into more efficient spatial relationships. There is still more that can be done to keep a building’s external environment within the boundaries of the human comfort zone. The design of urban form and the use of urban elements should also address the environmental impact of the geometry of the urban form.

i. The Shortcomings of Previous Studies

Previous research has given more attention to examining individual forms and less care has been given to examine the whole urban pattern which can include more than one block. Less attention has also been given to evaluate the mutual effect between building blocks and the amount of castable shadow from one block to another. It is important that this mutual effect is investigated, especially in areas where the urban structure is very dense. This is the case in Palestinian territories, where the land is very small and the local population is expected to increase, especially after the return of over 5 million refugees.

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 mainly focused on examining rectangular forms with respect to solar rights and behaviour. These shapes are more suited to the grid urban pattern. 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. 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. 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 structure (mainly due to constructional and compositional aspects), clarifying their characteristics from the solar point of view could encourage the use of such types of form. Previous researches examined simple shapes due to the difficulties associated with more sophisticated shapes, 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.

Previous studies placed more effort in examining the optimum orientation of the long axis of buildings with respect to solar radiation accessibility, regardless of the distribution of the living spaces within the form. This assumed that for best living conditions (i.e. warmth in winter, coolness in summer) the principal facades of buildings should face south (or the long axis of buildings is oriented east - west). Facades facing southeast and southwest are colder in winter and warmer in summer than facades facing south. East and west exposures are warmer in summer and colder in winter than south, southeast and southwest exposure. However, in many cases, the living areas of buildings face orientations other than the optimum one. This occurs if a building is not a unilateral type, but has the living areas locating in different directions. The most common type is the bilateral where the living areas are located in opposite directions. This can be a back-to-back arrangement of residential units within the storey or through a type in which the two sides belong to the same apartment. In this case, the determination of the suitable orientation is more complicated and depends more on the individual design and the distribution of spaces within buildings.

Previous studies concentrated more on analysing the total shaded area generated in the urban forms without considering its distribution in the individual facades and surfaces. The analysis of the generated shadow pattern in these facades is very important to have the form appropriately investigated and to gain the most benefit from the study. These analyses are of more importance in bilateral types of building and can be directly reflected on the design process. The study attempts to establish a comprehensive approach which can be applicable to all types of urban forms and can fully evaluate the urban forms with respect to the generated shadow patterns. In addition, the integrated methodology produced allows a comprehensive means for comparing geometric alternatives and generating guidelines which can help in developing urban design under climatically similar conditions.

Finally, previous researches did not clarify the inter-relationship between solar insolation and the thermal performance of urban patterns. The studies are adopted to show the benefits of establishing the relationship between the two aspects. The resulting framework provides a significant step forward in understanding the relationship between the shaded area and the collected solar radiation.

ii. The Development of the Urban Design Process in Palestine

It is well known that in arid zones, the closed court acts as a shield from the excessive solar radiation, and that the open layout is more suitable to cold climates to maximise solar heat gains. In Palestine and other temperate climates, a layout which is semi-closed or semi-opened, could be more advantageous. In this research, different types of urban forms were examined which could be a midway between the closed and open layout (such as the radial form or the rectangular U-shape). The research investigates the possible application of these forms in Palestine, with respect to the possible unilateral and bilateral distribution of the living units. The studies aim to focus on bilateral buildings, which is a very common urban pattern in Palestine. This pattern can allow for greater building intensity, which is a crucial aspect for urban design in Palestine due to the lack of land and the need to accommodate millions of refuges. In addition, the experiments intend to verify the common method used by architects to determine the most suitable spacing between buildings, as well as to clarify its limitations. Hence, the studies were also performed in order to determine the urban fabric that will allow the achievement of high urban density under optimal solar insolation conditions.

III. Aims and Objectives

The main aim of the study is to investigate the relationship between different forms of urban physical features and the shadow patterns they generate, and to develop evaluation tools for deriving climatic design criteria and information suitable for use by planners and designers. The research is also concerned with the development of a design index for planning and urban form design of human settlements in Palestine based on local climatic criteria. The research attempts to establish a relation between the urban form and solar energy resources. This will save energy and adapt the urban design process to the climatic conditions, thus creating more environmental and friendly urban design. The research is building on design data some of which are directly related to the climate in Palestine.

The experiments aim to examine the solar performance of the curvilinear form in comparison to the rectangular one. Different shapes and layouts produce different shading patterns. A comparison of the shadow analyses between the two forms, in terms of the total generated shadow in both winter and summer periods and for the whole year is conducted to investigate the form which could be more suitable for heating requirements and the one that is more suitable for cooling requirements. The experiments also intend 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. 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.

The overall research programme includes four parts. The first one assesses the radial and the rectangular forms separately. The second part examines the performance of both forms within an urban pattern, where the shadow cast from one block to another is considered. The third experiment investigates the suitability of radial forms for bilateral types of building. The fourth part attempts to compare the rectangular U-Shape and the radial form, where both forms can create a self-shading effect. The possible application of these forms in Palestine, with respect to unilateral and bilateral arrangements of living spaces, is discussed.

IV. Method and Approach

Shading is an important design consideration. The significance of shading as an important design tool was recognised by researchers more than forty years ago (Olgyay and Olgyay, 1957). 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. 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. 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 mass of the envelope. More important will be the variation in the pattern of exposed and shaded area that occurs over the facades of buildings.

Hence, the control of thermal environment in the 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 re-radiated 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.

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 (surfaces which are not shaded are exposed). The main objective in using the simulation technique is to establish the influence of urban geometry and building orientation on the solar performance of different urban forms, namely rectangular and radial forms. The shading analysis of the urban surfaces aims to evaluate their performance in terms of solar radiation and the received amount of generated shadow over the whole year. The experiment is based on the fact that under cold conditions, radiation will be welcome and the building should receive as much radiation as possible, while under conditions of excessive heat, the same building should decrease undesirable solar impacts. An optimum form for a given site would give maximum radiation in the under heated period while, at the same time, reducing insolation to a minimum in the overheated period. In order to establish the relation between shadow patterns and thermal performance of urban forms, some thermal calculations will be conducted. Furthermore, urban forms will be investigated by using different environmental profiles in order to illustrate the universality of the work.

For a comprehensive understanding of the solar behaviour of urban forms, the generated shadow pattern will be analysed in different ways. Each analysis will be clarified using numerical and graphical methods. 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.

i. The Evaluation of the Generated Shaded Area in the Urban Forms

This evaluation will include four main parts:

a) The Annual Shaded Area Generated by the Urban Forms

The goal of the analysis is to find out the form which will be more shaded during the whole year. This will indicate the form which will be more suitable for cooling requirements. The form with less shaded area will be more suitable for heating requirements. The shaded area will be calculated for the whole year as in the following: As the variation in the shaded percentage between forms is expected to be relatively minimum, and in order to assure the highest standard of accuracy, it was necessary to conduct the simulation by using software which has the ability to give a numerical calculation for the shaded area. The SunCast program was used to calculate the shaded area, as the program is capable of producing a numerical calculation for the shaded area (Appendix B1). SunCast produces a shadow analysis each hour during the daytime period. The program records the measurements for the generated shaded area at the middle of each hour.

The daily average shaded area for both forms was calculated for each month. The daily average shaded area generated in each month is represented by the amount of the shaded area generated during the middle day of the month (i.e. the 15th of each month). The annual shaded area calculated by the program is represented by the shaded area of 12 days, each representing one month of the year. To achieve better accuracy, the shadow analysis was conducted during two days each month (the 15th and the 21st), then the average amount was taken as representative of the daily average shaded area during the month.

The main unit that was adopted in this research to evaluate the results was the average annual shaded area per hour. This unit was taken as a scale unit to compare the shadow behaviour of the two forms.

*The average annual shaded area per hour = the shaded area generated in the 12 days that represent the year/[12(the number of months)*12(the average daytime period)]*

b) The Distribution of the Shaded Area in the Over and Under-heated Periods

The objective of this analysis is to investigate the period when the differences in the shaded area between the two forms are maximal and the period when these differences are minimal. The simulation was performed for two days, the 15th and the 21st of December and for the 15th and the 21st of June. The average results for the two days were conducted as representative of each period to assure a high level of accuracy for the experiment.

This investigation will enable the evaluation of the expected differences in the shaded area between the two forms in more specific way. The intention of the analysis is to determine whether the major differences in the shaded area between the two forms take place in the winter or summer period. This analysis intends to relate the performance of the form to the special thermal requirements of each season. The analysis also helps to calculate the insolation efficiency (Ew) of the forms, which is the main indicator of a building's usefulness in a temperate climate.

c) The Shaded Area Generated by the Outer and the Inner Surfaces Over the Year

The analysis will investigate the side of the forms where the maximum differences in the shaded area, generated over the whole year, take place and the side where these differences are minimal. Shadow patterns influence the distribution of living spaces within buildings. In addition, unilateral and bilateral buildings can be greatly affected by shadow distribution.

d) The Shaded Area Generated by the Outer and the Inner Surfaces in the Over and Under-heated Periods

For each season, the analysis will investigate the side of the forms where the maximum differences in the shaded area between the two forms take place.

ii. Evaluating Shadow Patterns during the Daytime Period

This investigation includes four cases:

a) Distribution of the shaded area in the two forms during the daytime period over the whole year.
b) Distribution of the shaded area in the two forms during the daytime period in the over and under-heated periods.
c) Distribution of the shaded area generated in the inner and the outer surfaces during the daytime period over the whole year.
d) Distribution of the shaded area generated in the inner and the outer surfaces during the daytime in the over and under-heated periods.

The aim of the analysis is to investigate when maximum differences in the shaded areas between the two forms take place during the daytime period. The investigation will also clarify the distribution of the generated shaded area over the daytime period for the four previously mentioned cases.

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.

V. The Structure of the Thesis

The significant limitations which are identified in the context of sustainable urban design, provide the motivation for the development of a new framework which is able to integrate the different dimensions of solar insolation in the built environment. To achieve this goal, the structure of the thesis attempts to generate a framework within which the above objectives can be promoted and achieved. The research outline includes two main parts (Figure 1). First, for clearly setting the present area and its boundaries, a comprehensive discussion is presented, in order to map the field and position of the research within the context and in order to identify the gap which the research could fill. This theoretical approach also gives the required background to establish the theoretical framework and the methodological focus. This part of the thesis investigates the processes and principles relating to the topic based on the current knowledge. Developing an understanding of the issues involved is important for the analysis of field results on comfort and in the further development of urban design strategies.

Secondly, experimental and parametrical studies have been performed to bridge the gap in the previous studies and to enhance the theoretical approach of the research. The parametric studies are the major part of the thesis and encompass shading and thermal simulations which have enabled the study of a wide range of urban configurations. Evaluations were undertaken with respect to design factors, such as geometry and orientation, as they affect the urban microclimate. The possible application of these experimental models in Palestine is discussed in order to validate the experimental work and to highlight the focal point of the research.

The investigations mainly include four parts. The first one assesses the radial and the rectangular forms separately. Also the experiments examine the behaviour of both forms within an urban pattern, where the shadowing from one block to another is considered. In addition, a comparison between different radial forms, varying in the extent of their concavity, is performed. There is also a comparison between the rectangular U-Shape and the radial form, where both forms can create a self-shading effect. Lastly, the implications of these results are shown through their application to local Palestinian climatic zones. As a result of these studies, it has become evident that some building forms are preferable, in terms of passive solar design, to alternative built form proposals.

The research outline is fulfilled in the following chapters as summarised below:

Chapter 1: Human Shelter And Climate: This chapter aims to give some basic information about the relation between the human shelter and climate; it also illustrates some ancient human attempts to deal with and control climatic conditions to make the shelter more habitable.

Chapter 2: Basic Urban Design Principles: This chapter provides information about the factors, mainly climatic and socio-economic that influence urban design. As each urban form creates its own microclimate, the chapter also discusses the mutual effects of urban design and climate. The chapter also mentions the role that vegetation can play in enhancing the liveability of the urban outdoor space, and the importance of landscape elements in connecting the urban form with the natural environment. Understanding other factors that influence urban design are essential for clarifying the effect of climate on urban design, as the generated urban design is usually derived from all these factors acting together.

Chapter 3: Passive Solar Urban Design Characteristics: The chapter describes the features of optimal solar urban design. It is focused on the methods and measurements that can be undertaken to enhance the environmental principles in urban design. This includes criteria of site selection and design. In addition, the chapter discusses the criterion of optimal urban form, which can improve the urban microclimate. This includes the criterion of optimal urban form in terms of solar orientation and wind flow patterns.

Chapter 4: An Overview Of The Palestinian Built Environment: The main illustrated topics in this chapter are the geographical and climatic elements of Palestine. Detailed information is presented for the current Palestinian territories (the West Bank and the Gaza Strip). The situation of energy in Palestine is clarified in general and then renewable energy resources and their possible adaptation to the Palestinian built environment are highlighted. Other socio-economic factors that influence the urban design process in Palestine are also presented.

Chapter 5: A Comparison Between Radial And Rectangular Urban Forms: Two forms are suggested (rectangular and curvilinear). The two forms have the same built volume, the same floor area and the same external surface area. 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. A comparison between the two forms in terms of the generated shadow pattern was conducted.

Chapter 6: Mutual Shading Of Different Urban Patterns: In order to examine the variation in behaviour between the two forms in terms of the generated shaded area, a comparison between the two patterns was conducted. Two patterns of urban canyon are suggested (rectangular and curvilinear). Each pattern constitutes of two blocks with the same separating distance. The two patterns have the same built volume and the same canyon facade area. In addition, both have the same external surface areas. The experiment is conducted for patterns oriented east-west and also for patterns oriented north-south.

Chapter 7: A Comparison Between Radial Forms With Different Concavities: The experiment discusses the possible application of radial forms in Palestine, with respect to the possible Unilateral and Bilateral Distribution of the living units. A comparison between different radial forms, varying in the extent of their concavity, is conducted. Also, a comparison between radial forms with different orientation was performed.

Chapter 8: A Comparison Between The Radial Form And The Rectangular U-Shape: The experiment aims to investigate the main characteristics of the curvilinear form as opposed to the rectangular U-Shape in terms of the generated shadow pattern. The two forms have the same built volume and the same external surface areas. The experiment is conducted for forms with open spaces facing south, north and east.

Chapter 9: Overall Conclusions And Further Research: This final chapter evaluates the results of these studies, draws some general conclusions, and makes some recommendations for further research. It consists of three parts: the first part presents the main contributions of the thesis to new knowledge. The second part discusses the possible general utilisation of the conducted shadow analyses. Finally, in the third part some recommendations for future research are presented.

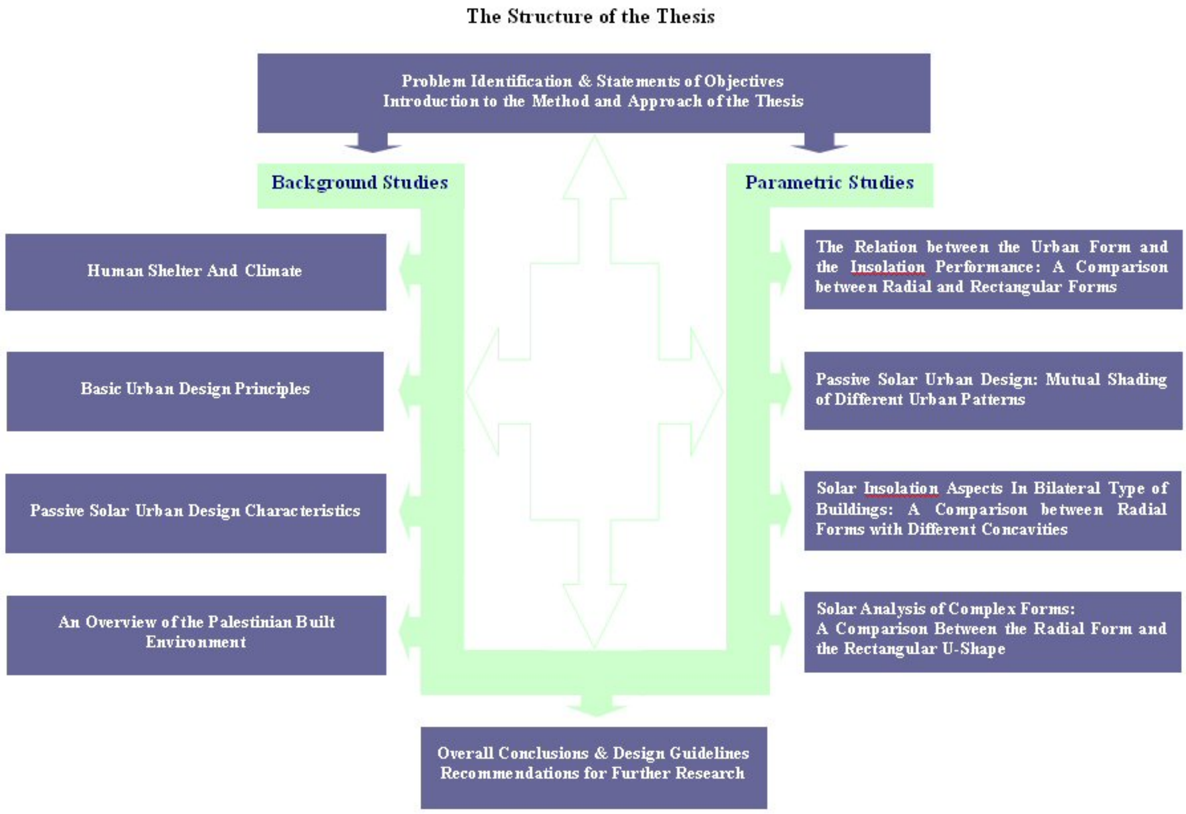


Figure 1: The Structure of the Thesis

PART 1: BACKGROUND STUDIES CHAPTER 1

HUMAN SHELTER AND CLIMATE

1. Human Shelter and Climate

1.1 Introduction

Housing and all buildings are structures of components designed to mediate the existing environment, which is less satisfactory in some way, into more comfortable and satisfactory surroundings. Moore (1993) pointed out that historically, shelter has been built to reduce the range of local climatic variations; to avoid some of the sun's heat in hot climates and to conserve heat in cold climates. In addition, shelter has been designed to welcome the breezes when they can provide the desired cooling, and to avoid winds when it exacerbates problems of an already cold climate.

Herzog et al., (1996) asserted that the natural resources available in a given location, especially sun and wind, should be harnessed for the climate conditioning of buildings and should be reflected in the design of their layout and form. The various patterns of building will enter into a special reciprocal relationship with the climatic data (elevation of sun, seasonal or regional range of sunlight, air temperature, wind factor and direction, periods when wind occurs, quantities of precipitation, etc). Olgyay (1992) believed that certain shapes are preferable to others in a given surrounding.

Sun's heat is influential both positively (in cold periods) and negatively (in hot periods). Winds occurring at the under-heated period should be intercepted; cooling breezes should be utilised in the over-heated period. The criteria for balance are minimum heat-flow out of buildings in wintertime, minimum heat-gain in the structures during the over-heated period. A balance can be found between the under-heated period when we seek radiation, and the overheated period, when we want to avoid it. In general, sites which show better characteristics in the winter-summer relationship, are more adequate for living.

1.2 Early Urban Centres

The four main early urban civilisations (Mesopotamia, Egypt, the Indus Valley and Northern China) are valuable examples in terms of the climatic impacts on the earliest urban evolution in the ancient world. The rise of these four civilisations (Figure 1.1) was an example of successful adaptation to the environment. According to Golany (1995b), a common denominator among these four urban civilisations was their location in a hot-dry climate. Also Morris (1994) affirmed that climate has been identified as one of the important determinants of the earliest urban form, along with topography, construction material and technology. Ahmed (1996) pointed out that the existing vernacular settlements in the respective regions are often the physical evidences of a climate conscious design.

Figure 1.1: The Four Old-World River Valley Cultures (Brooklyn, 2001)

The city is the largest, most complicated project ever conceived in the history of humankind. Golany (1995b) indicated, "The city is composed of historical layers whose physical formation and evolution have been shaped, interwoven and integrated by diversified social, behavioural, economic, climatic and environmental factors".

All early urban centres were located in river valleys: these centres are Mesopotamia, Egypt, the Indus Valley and China. These areas share many common characteristics in their environment, climate and evolutionary processes.

1.2.1 Mesopotamia

Figure 1.2: Mesopotamia (The Oriental Institute, 1997)

Mesopotamia is located in southwestern Asia (Figure 1.2) in the valley of two major rivers, the Tigris and the Euphrates. The hot-dry climate, where this civilisation rose, is characterised by high radiation, especially in the summer, and great amplitude between day and night temperatures. It is believed by scholars and archaeologists that the earliest cities appeared around the middle of the fourth millennium B. C. in the southern part of Mesopotamia.

Urban design and planning as a preconceived concept certainly did exist in the public buildings, monuments, religious buildings and palaces of Mesopotamia (Figure 1.3, 1.4). A great deal of both effort and creativity went into the ziggurat as a religious and observation tower, the palace of the king, and most importantly, the temple itself.

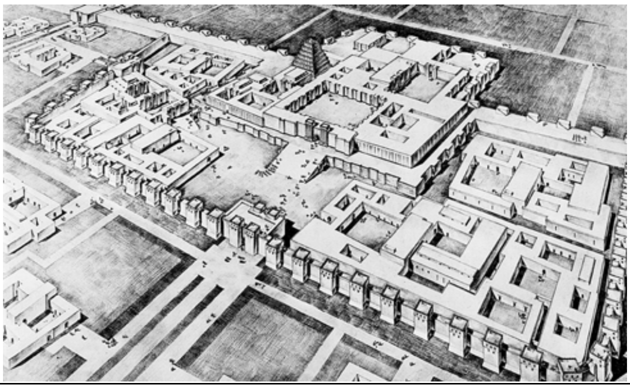


Figure 1.3: The Royal Palace of King Sargon II (The Oriental Institute, 1997)

Figure 1.4: The Oval Temple at Khafajah (GAP, 2001)

Public buildings were architecturally monumental, standing clearly above their surroundings and representing the religious and secular power of the Mesopotamian civilisation. These monumental buildings were elevated on a ramp and were significantly higher than the rest of the city's skyline with the ziggurat being the highest of all (Figure 1.5). These buildings were balanced and symmetrically designed.

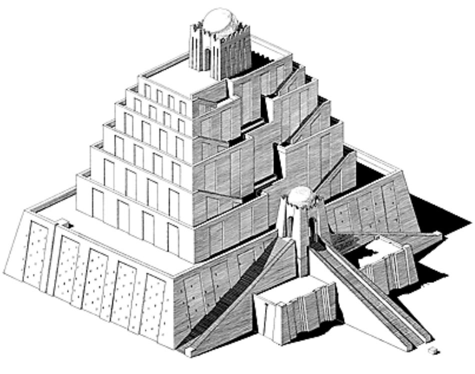


Figure 1.5: Ziggurat of Nabonidus (The British Museum, 2001)

Golany (1995b) reported that one of the main aspects which created the city form was to place the maximum number of people within a minimal amount of land. This was the result of the need for defence and for preserving land for agriculture. This also reflected the social need of residents themselves for social closeness. In addition, it reflected climatic considerations, because compact cities provide more shadowed areas. Usually, the cities were round in shape.

Streets in the ancient Mesopotamian cities were developed in three levels at least. The widest was the main street, leading to major monumental buildings and dividing neighbourhoods. The second was narrower and penetrating into the neighbourhoods. The third was the dead end, usually surrounded by a conglomerate of houses that were attached side-to-side and back-to-back. Dead ends provided protection against hot and dusty winds during the day and, to some extent, retained heat longer than the wide-open spaces during the evening when it was most desirable. In most cases, these streets ended in a patio that provided great privacy, safety and security. These dead-end alleys, as well as second-level streets, were very narrow and were curved or zigzag in pattern. This characteristic provided more privacy and protection from the intense heat and dust storms and from enemies.

The design principle of the Mesopotamian house was the patio style surrounded by rooms. Because Mesopotamian cities were densely developed, they did not have any significant green area or public open space within the city. However, the distance from the middle of the city to the open, yet mostly agricultural, space outside the city wall was an acceptable walking distance. The archaeological indicators provide evidence for abrupt wind, temperature and humidity changes coincident with the abandonment of sedentary urban settlements (Manzanilla, 1997).

1.2.2 Egypt

Egypt is a good example of the great impact the environment can have on urban and social development. Egypt's climate is more stressful than that of Mesopotamia, the Indus Valley or Northern China. The climate is defined in general as a hot-dry one with extreme aridity. Rain is limited to the shores of the Mediterranean in northern Egypt and rarely occurs in the southern part of the country (Golany, 1995b). The Nile, which runs from south to north, was the source of survival.

All human activities were focused exclusively in the cities and villages along the Nile River. Due to the fact that population was never congregated into large demographic aggregates, as in the case of Mesopotamia, Egypt was characterised as a civilisation without cities, because population was more or less homogeneously distributed along the Nile margins (Manzanilla, 1997). The lack of urban centres in Egypt eliminated the contrast between rural and urban centres that was characteristic of Mesopotamia.

Figure 1.6: Ancient Egyptian Urban Centres (The Oriental Institute, 1997)

Because of the delta's location (Figure 1.6) along a major international thoroughfare running from Asia through North Africa, delta cities were ethnically mixed, heterogeneous and culturally enriched. Although the Nile was used as a transportation link, the first cataract prevented it from becoming a major water thoroughfare. Despite its distance from the geographical centre of the country, the delta became home for almost all of the capital cities throughout the history of ancient Egypt.

These cities were never designed with protective walls because there was no threat from either side of the river. The only protective cities developed throughout the history of Egypt were in the delta region or those established at the political border between Egypt and the Nubian tribes at the first cataract in southern Egypt. Egyptian agriculture was exclusively based on irrigation and all of the economic and social conditions of the civilisation resulted from that system.

Except for monumental buildings, such as temples, palaces, etc., buildings in Egyptian cities were built exclusively of mud. The climatic aspects were very obvious in the design of Tell El-Amarna (City of Akhetaten). The houses were oriented toward the north or west to take advantage of the cool wind (Figures 1.7, 1.8).

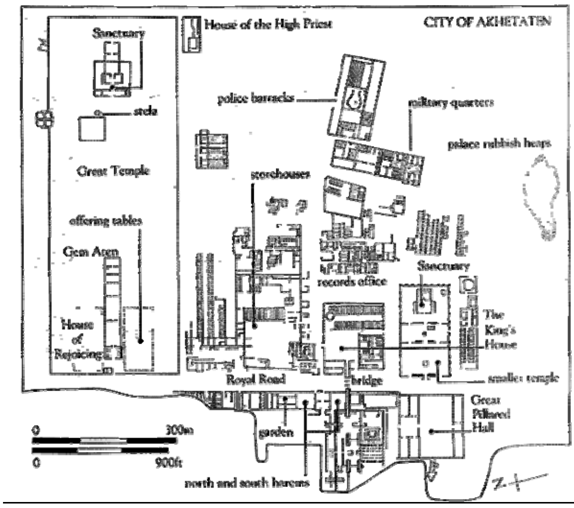


Figure 1.7: Plan of Tell El-Amarna (JEBF, 2001)

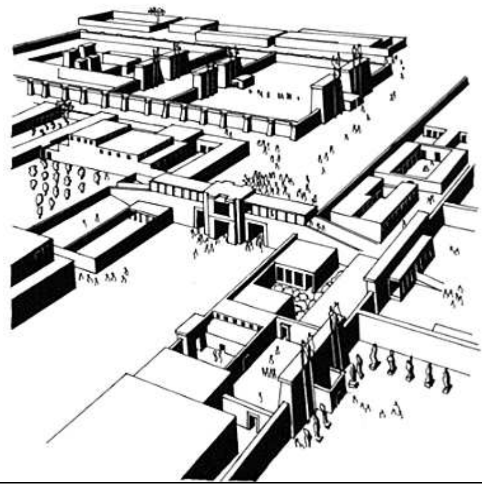


Figure 1.8: Tell el Amarna, Reconstruction of the Housing Area (JEBF, 2001)

The workmen's neighbourhoods were planned by the government. The overall pattern consisted of small units attached mostly in linear form with very narrow streets. The structures were geometrically standardised with all units being the same (Golany, 1995b).

Monumental buildings were usually made of stone. The impressive monumental buildings, with heavy masses of masonry against vast open spaces, were typical of the ancient Egyptian cities. The temple was the core of the city and became the centre around which the residential and the commercial complex of buildings developed.

The first collapse of a state in Egypt was related to climatic change (Manzanilla, 1997). Lower agricultural productivity as a result of low Nile floods caused widespread famine and anarchy. The area of fields under cultivation diminished, the harvest season decreased, and the numbers of livestock were reduced, of course, this was only one factor within a more complex process of social and political disintegration that included the collapse of centralised authority.

1.2.3 The Indus Valley

The urban centres of the Indus Valley developed along the Indus River in the Himalayan Mountains (Figure 1.9). These centres were developed around the middle of the third millennium B. C. and lasted until around the middle of the second millennium B. C. Geographically, the Indus Valley was the major crossroads of transportation north and south along the Indus River and east to west from India to Persia. In the Indus Valley the climate is also hot and dry.

Figure 1.9: The Indus Valley (Washington State University, 2001)

Urban settlements in the Indus Valley were characterised by a high standard of design, regularity, hierarchical street design and high-quality city services, including municipal facilities and sanitation arrangements. The design also was affected by the environment, climate, local building materials and site conditions (Golany, 1995b). Mohenjo-Daro can be considered among the first cities of its time to introduce a systematic, preconceived design.

Golany (1995b) reported that the two distinctive characteristics of Mohenjo-Daro’s urban design are the semi-grid systems of streets and the independent government citadel. The streets themselves were divided into three hierarchical levels. The first level consisted of wide straight streets and the second level consisted of narrower streets, almost straight and running parallel to the major street. The streets in the third level were the narrowest, with some right angles running perpendicular to the first two levels of streets; dead ends were almost nonexistent. The unique government citadel was close to the city but completely separated from it and combining many different functions.

Homes in Mohenjo-Daro shared some common characteristics with those in Mesopotamia. They were also patio style homes with two storeys of rooms surrounding the open courtyard. Access to homes mainly came from the second or third level of streets. Mohenjo-Daro apparently was of mixed social and economic classes, since houses of varying sizes were clustered together (Golany, 1995b).

1.2.4 China

The cradle of Chinese civilisation, which included the urban centres, was situated in the northern part of China along the Wei He and the Huang He rivers (Figure 1.10). The climate of this region is arid and semi-arid and becomes more arid toward the north and northwest.

Figure 1.10: The Cradle of Chinese Civilisation (World History, 2001)

The region as a whole has plenty of water along the Huang He and the Wei He rivers, which enabled the development of intensive agriculture. The peak eras of the ancient Chinese urban centres were during the Han Dynasty (206 B.C. – A. D. 220), and later the Tang Dynasty (A.D. 618-907), and the Song Dynasty (A.D. 960-1279).

The principles of ancient Chinese urban design were best expressed in the capital cities. Most of these cities were located in central and some in northern China. Most of the capitals were built as new towns and from a preconceived plan prepared by theoreticians, philosophers and builders. There are several design principles evident in the ancient Chinese urban design centres. These include the use of open space, the use of belowground space, and the integration of residential and commercial needs. Courtyards were used throughout the cities as a common public space. Gardening and natural landscaping were combined with sources of water to enhance the quality of the environment.

Within the city, two types of land-use patterns were dominant. One pattern, which was used only in the marketing areas, combined markets on the ground floor with residences on the second floor. In all other areas, residential and commercial buildings were separated. Housing concentrated around an internal open space enclosed by walls. The family home usually turned its back on the street and focused around an internal courtyard. The same design was true for entire neighbourhoods which were collections of these houses enclosed within a larger wall and arranged around an internal open space that was common to all houses. Thus, each grouping created a nesting pattern from the core of the city to its outer edge (Golany, 1995b).

1.2.5 Comparison of Early Urban Centres

In comparing the four case studies presented here, we can outline some of the commonalities of these early urban centres of the world. Location and site selection of the hot-dry climate area are a common denominator among the four case studies. All these civilisations developed in arid zones with differing degrees of aridity. Rivers were the source of life and the spine of each of the four civilisations with villages, cities and transportation developing in a linear pattern along their banks. The river was the source of fishing, drinking-water, transportation, and most importantly, for agricultural development.

Ultimately, climatic conditions may have been the major factor in the selection of the location and the evolution of human settlements throughout early civilisations. People were pushed away from the tropical zone by the continuous threat of illness and diseases resulting from heavy rain, swamps, dense vegetation and the difficulty of coping with the discomfort of the rainy, humid tropical climate. It may be that the high density of wild animals, reptiles and insects threatened life and health even more. Similar pressure may have occurred from the temperate zone falling north of the arid zone because of the stressful cold climate of snow and blizzards that characterises those zones. In either case, the zones that were left relatively comfortable for humans were the arid and semi-arid regions (Golany, 1995b). In addition, the hot-dry climate of the arid zone, especially that of the Middle East and the Fertile Crescent, provided vast open space, cloudless skies and views unobstructed by forests.

1.3 Climatic Effects on Human Shelter

Studies of vernacular types of buildings tend to confirm that the grouping of buildings together seems to take into account climatic effects according to the latitude (Mazouz, 1998). Climate effects on human shelter include the choice of location for new settlements; the shape and spatial patterns of settlements (Figure 1.11); the orientation of the urban mass; the spatial organisation of land utilization within and around the settlements; the alignment of major vehicular and pedestrian routes; and the intensity of use.

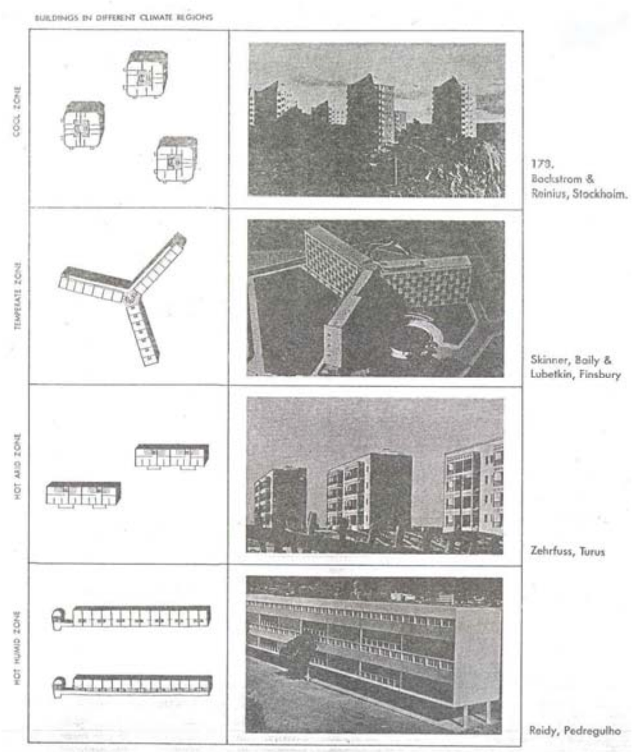


Figure 1.11: The Climatic Effects on the Urban Form (Olgyay, 1992)

1.3.1 Shelters for Hot-Dry Climates

The climate is characterised by extremely hot summers and moderately cold winters (Moore, 1993). Humidity is continuously moderate to low. There is little or no cloud cover to reduce the high intensity of direct solar radiation. As a result of the characteristically high intensity and duration of insolation in the arid regions, solar irradiance and its control by minimising its thermal and glare effects becomes the most important environmental physical field (Mazouz, 1998). As a result of clear skies and low humidity, which allow intense sunshine during the day and rapid night radiation back to the clear night sky, there is a great temperature variation between day and night. The dry air, low humidity and minimal rainfall discourage plant life, and the dry, dusty ground reflects the strong sunlight, producing an uncomfortable ground glare. Local thermal winds often carry dust and sand (Koenigsberger, 1974).

1.3.1.1 Traditional Shelters

As a result of excessive heat and glaring sun in hot-dry climates, the shelter has to be designed to reduce the impact of heat and to provide shade. The tribes often built communal structures for mutual protection from heat. Olgyay (1992) reported that structures such as the pueblo of San Juan (Figure 1.12) were constructed of massive adobe roofs and walls which have good insulative value to delay heat impacts for long hours, thus reducing the daily heat peaks. By packing buildings together, the amount of exposed surface was reduced. Pueblo structures usually extend on an east-west axis, thereby reducing morning and afternoon heat impacts on the two end walls in summer and receiving a maximum amount of the southern sun in the winter months when its heat is welcome.

Figure 1.12: The Pueblo of San Juan (NMEDD, 2001)

The indigenous shelters of this region appear in many ways like those of the cold region. Both share severe and inhospitable conditions. As in the cold region, a compact geometry and thick insulation were used to minimise heat transfer. Thick adobe construction or underground construction was used to delay the effect of high outside temperatures. The ultimate in thermal mass is the underground construction. The house has the advantage of notable thermal stability underground (Moore, 1993).

In desert climates, such as in Saudi Arabia, urban settlements are usually densely packed with common-wall adobe constructions and courtyards to provide self-shading and minimal exposure to the sun. Because of the high daytime air temperature and the intense exposure to sunshine, window and door openings are kept to a minimum to reduce direct solar gains. Shutters are usually used on the windows; these are kept closed during the daytime period and opened during evening hours in order to allow night ventilation.

1.3.1.2 Design Criteria

Thermally massive external walls can delay the passage of heat from the peak hot period outside, so that it arrives at the internal surfaces later during the day (Figure 1.13). Large thermal mass absorbs excess heat and helps the interior of buildings to stay cool for longer.

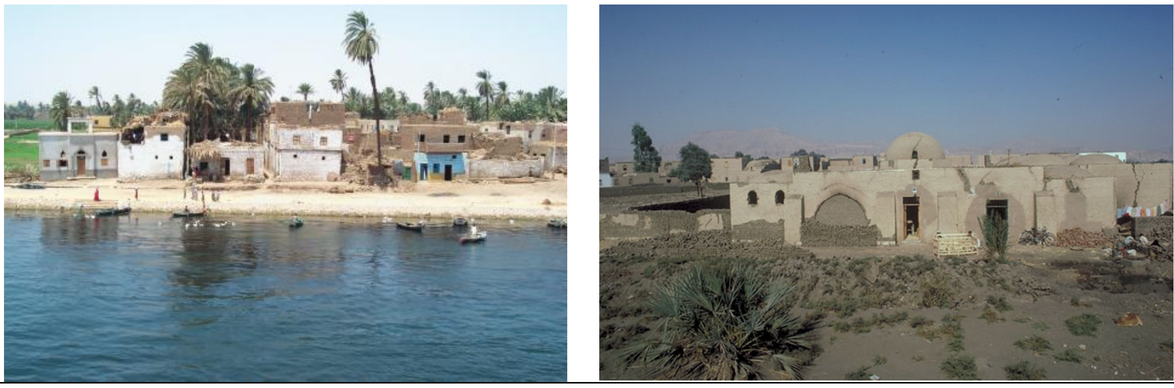


Figure 1.13: Traditional Egyptian Houses (SCC, 2001, ARCHNET, 2001)

Often design for protection from hostile outdoor conditions (heat, wind, dust and glare) results in inward looking buildings, sometimes with courtyards. Ponds and vegetation may be contained in courtyards, especially in areas with very low humidity; the use of fountains, pools, water streams and plants is desirable to provide evaporative cooling. Evaporative cooling is effective. However, in such climates, water is often in short supply and so needs to be conserved. The best external space in this type of climate is the courtyard. Konya (1980) stated that, “When the courtyard is provided with water and plants it acts as a cooling well and modifies the microclimate”. Vegetation can be used to shade building elements, for cooling by transpiration, for trapping cooled air, and for filtering dust.

1.3.1.2.1 Site Layout

Figure 1.14: Morocco-Merzouga Oasis (CiAS, 2001)

Figure 1.15: Traditional Berber House in Morocco (AR, 2001)

In hot dry climates, shading is more important than ventilation. Settlements are characterised by a dense layout (Figure 1.14). It is usually preferable to have compact planning for groups of buildings to provide mutual shading and minimum exposure. Openings should be small to admit little sun and to prevent glare (Figure 1.15). Enclosed, compactly planned and inward looking buildings are most desirable (Konya, 1980). The tendency here is to have close groups of buildings, narrow roads and streets, arcades, colonnades and courtyards, in order to obtain the maximum amount of shade and coolness. Buildings in many cases are arranged around courtyards which are used to provide shade to adjacent spaces. By aligning buildings close to each other, especially if east and west walls are placed close together, mutual shading will decrease heat gain on the external walls.

As it is common in a warm climate, many daily activities take place in the outdoor space; it is therefore necessary to treat external spaces just as carefully as the building itself. Adjacent buildings, pavements and dry grounds heat up quickly, causing both a painful glare and reflected heat radiation towards the building during the day. The enclosure of outdoor space by walls, which can be themselves shaded, will help to avoid such undesirable effects. Trees, plants and water in the enclosed space will cool the air by evaporation; will help to keep dust down and will provide shade, and visual and psychological relief.

1.3.1.2.2 Urban Form

Outdoor conditions are so hostile in this climate that both buildings and external living spaces need to be protected against intense solar radiation. An enclosed, compactly planned and inward-looking building is preferable (Figure 1.16).

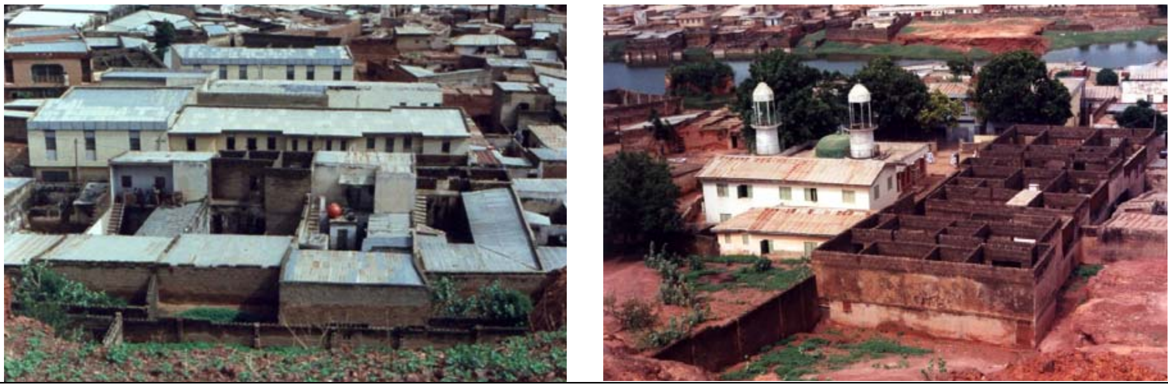


Figure 1.16: Mud Houses in Kano (The University of Northern Iowa, 2001)

Surfaces exposed to sun should be reduced as much as possible. During summer, in low latitudes, the roof is the surface that is most exposed to solar radiation, followed by the east and west walls. Therefore, the larger dimensions of a building preferably face the north and south, as these elevations receive the lowest heat loads from solar radiation. Developing rows of houses, detached or terraced, with long facades facing south-north can maximise winter solar exposure and provide shading during summer (Santamouris et al., 1996). To minimise the effects of the hot sun, buildings should be designed so that their major window exposures face the north and south. The north facade of a building has less direct exposure to the sun. Although the south facade is exposed to sunlight, it can be controlled, as in the summer season, the angle of the south sun is quite high at midday so that a porch, overhang or similar device will provide effective protection. In winter, the lower angle of the southern sun allows sun to pass through the building. The effect of sun on the east and west facades is more difficult to control since sun angle is lower in the morning and afternoon. The worst orientation is the west. Although solar radiation is similar on the east and west elevations, peak intensity on the west coincides with the highest air temperature, causing a higher total peak load. Shading of roofs, walls and out-door spaces is critical. Projecting roofs, verandas, shading devices, trees and the utilisation of surrounding walls and buildings are familiar techniques to overcome this challenge.

1.3.2 The Hot-Humid Area

The prominent characteristics of this climate are the hot, humid conditions and the continual presence of dampness. Air temperature remains moderately high, with little variation between day and night. Moisture in the air, combined with moderate heat and high rainfall, is favourable to the growth of vegetation. The plant cover of the ground reduces the reflected radiation and lessens the heating up of the ground surfaces.

Humidity is high during all seasons. Heavy cloud and water vapour in the air act as a filter to direct solar radiation; it is thus reduced and mostly diffused. Day to night temperature swings during summer are insignificant because of the extensive humidity and cloud cover which prevent re-radiation from earth at night (Moore, 1993). Evaporative cooling will be neither effective nor desirable, as it would increase humidity.

1.3.2.1 Traditional Shelters

Olgyay (1992) indicated that the hot-humid area, presents two major problems; the avoidance of excessive solar radiation and moisture evaporation. To cope with this problem, the tribes built their village to allow free air movement, and the scattered individual units were mixed into the shade of surrounding flora. The Seminoles raised large gable roofs to cast large areas of shadow over the dwellings. The steep angle and extensive overhang of this roof offered also a good protection against rainfall. The floors were elevated to keep them dry and to allow air circulation underneath (Figure 1.17).

Figure 1.17: House on an Island in Queensland (The Australian Greenhouse Office, 2001)

Koenigsberger (1974) explained that the traditional shelter is often elevated on stilts and is constructed from local timber or a bamboo frame with open-weave matting, timber or split bamboo walls, floors, doors and shutters. Thatch or built up layers of leaves cover a bamboo or timber roof-frame, which usually has broad overhanging eaves. The lightweight timber construction holds little heat and cools adequately at night. The elevated position provides better security and better air movement. The thatched roof is an excellent thermal insulator. The board eaves shade the walls and openings, provide protection from driving rain and sky glare, and permit the openings to be kept open most of the time.

1.3.2.2 Design criteria

Buildings are usually separated and scattered with free spaces between them to utilise airflow (Konya, 1980). As air movement is the only available relief from climatic stress, therefore vital to indoor comfort, buildings have to be opened up to breeze and oriented to receive air movement. Failure to fulfil this would produce indoor conditions always warmer than a shaded external space which is open to air movement.

Moore (1993) pointed out that in this climate, where the need for shelter from sun and rain predominates, the roof becomes the dominant structural and formal element: steeply sloping to shed heavy rains, with a maximum of insulation and large overhangs to protect buildings against sun and blowing rain.

In coastal regions, the presence of the large area of water greatly reduces both daily and annual temperature variation. Under such near-constant temperature conditions, the stabilising thermal effect of massive masonry construction is of little advantage; walls are usually minimised to provide free airflow (Moore, 1993).

1.3.2.2.1 Site Layout

In hot and humid climates, emphasis is given to cross ventilation as the high humidity of air creates discomfort for human beings. Cross ventilation of streets and buildings is desirable in order to reduce discomfort from excessive humidity. The structure of the settlements becomes scattered and loose (Figure 1.18) in order to channel winds through the streets and inside buildings.

Figure 1.18: Village in A Hot-Humid Zone (Olgyay, 1992)

Figure 1.19: House on the River in Thailand (CLH, 2001)

Buildings tend to have open elongated plan shapes, and the plan should, if possible, avoid double banking of rooms and be organized to aid cross-ventilation. Such rooms may be accessible from open verandas or galleries which also provide shading. Although groups of buildings also tend to be spread out, spacing of buildings should optimise access to breezes. The orientation of Buildings should respond to available cooling winds as well as to sun.

From the point of view of solar heat gain, the best arrangement would be to orientate buildings with the long axis in an east-west direction. This may often conflict with the orientation requirements for wind. With low-rise buildings, where the walls would not get much radiation, orientation towards the wind is more advisable. With high-rise buildings, the opposite is true, and avoidance of sun should be the decisive factor. The same principles apply to the design of external spaces as to the design of buildings. Shading and free passage for air movement are the two basic requirements. Open spaces left under buildings elevated on stilts can also be utilized as shaded out-door spaces. Trees and planting can be relied on for shading, as plants carry full foliage all year round (Figure 1.19). Pergolas and light framing which are covered by climbing plants can cheaply and effectively provide shade to an open space.

The density of development in warm-humid regions is always far less than in hot-dry climates to allow free movement of air through buildings and spaces between buildings. The low density of development also provides privacy by distance, as walls and screens cannot be used for this purpose (they would prevent air movement).

1.3.2.2.2 Urban Form

In the warm-humid climate, openness and shading are the dominant characteristics of the buildings. Buildings designed for passive cooling would be as open as possible, to ensure the maximum possible cross-ventilation; consequently these would be totally unsuitable for air-conditioning. If the building is to be air-conditioned, a completely different design approach must be adopted. In this case the building would be closed, sealed and well insulated (HKU, 2001).

As there is not a large diurnal temperature variation, the structure of buildings is usually lightweight. Buildings have many large openings, with large overhangs and covered verandas. Door and window openings are as large as possible to allow a free passage of air. The ceilings are high to allow space for high windows for the exhaustion of hot air.

Figure 1.20: House on the River in Thailand (CLH, 2001)

Figure 1.21: Traditional Village House of Malaya (Ford Foundation, 2001)

Shading of the vertical surfaces, of both openings and solid walls, will be beneficial. This task will be much easier if the building height is kept down. As the openings are far larger than in hot-dry climates, the shading devices will be much larger. Very often the roof will extend far beyond the line of walls, with broad overhanging eaves providing the necessary shading for both openings and wall surfaces (Figures 1.20 and 1.21). The whole building should be lightweight to allow rapid cooling at night.

1.3.3 The Cold Zone

By definition, cold climates needs an additional heat input; therefore the best strategy is to conserve heat.

1.3.3.1 Traditional Shelters

The indigenous dwellings of this climate region are characterised by minimum surface area, minimum openings and maximum insulation. The tribes entering the cold zone encountered extreme cold and relatively scarce fuel. Under these circumstances, the conservation of heat became essential, so their shelters were compact, with a minimum of surface exposure. Olgyay (1992) mentioned that the Eskimo igloo is a well-known solution to the problem of survival in an extremely cold climate. The Eskimo igloo is a model of sheltering efficiency (Figure 1.22). Its excellent performance is the function of both form and material. The dome shape offers the minimum surface area for heat loss. The vaulted construction is structurally stable and takes advantage of the tremendous compressive strength of compacted snow blocks.

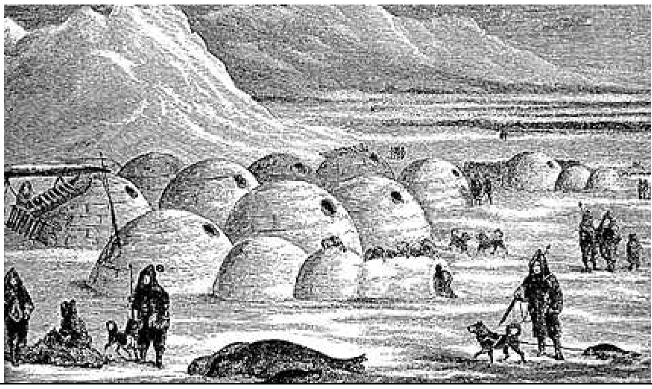


Figure 1.22: Igloo - The Traditional Arctic Snow Dome (BLWD, 2001)

The low hemispherical shelters benefit from the insulation value of the snow that surrounds them, while providing an aerodynamic shape to deflect the arctic winds. Ventilation is minimal, consisting of a small opening near the top of the dome (Moore, 1993). The tunnel exits of igloos are usually oriented away from the prevailing winds to reduce the leak of warmed air from the interior.

1.3.3.2 Design criteria

The severity of this climate suggests that the cold temperature and wind conditions alone dictate the form of buildings, and their organisation, as well as wall and window construction. As a result of the severity of winter conditions, designing buildings for all other conditions (sun, summer breezes and humidity) is subordinated to the demands of the cold (Figure 1.23).

Figure 1.23: Danish Vernacular House (The Great Buildings Collection, 2001)

1.3.3.2.1 Site Layout

In cool zones, multiple dwellings sharing walls, and apartment buildings could be reasonable because they improve the isolation of each dwelling from the external environment (Figure 1.24). In cool zones, the low winter temperature overrules the sun's effort to elongate the structure in the east-west direction and presses it into a nearly square shape (Figure 1.25). Closed compact forms are preferable, such as "point houses" of squarish character, or bilateral (back to back) building plans on the north-south axis, because of their relatively dense cubature. Elongated unilateral (through) buildings are not desirable.

Figure 1.24: House at the Meskwaki Indian Settlement in Tama County, Iowa (Home Energy, 1999)

Figure 1.25: House at the Upper Peninsula of Michigan (Enertia, 2001)

1.3.3.2.2 Urban Form

Construction should be airtight and compatible with the requirements for minimum ventilation. Reduction of the surface/volume ratios is desirable. The best example is the traditional igloo, but contemporary buildings might be compact and cubic in nature. A good strategy is to insulate the building envelope to high standards.

Figure 1.26: The Sullivan Residence (Brown, 2001)

Figure 1.27: High Performance Housing for Cold Climates (NAHN, 2001)

Windows should be small, and double or even triple glazed, sometimes with evacuated or other specialized glazing. Where good winter sun is available, windows should face the equator, with insulated shutters for control of conducted heat losses at night. At entrances, external wind protection is crucial. Generally entrances and exits from the dwelling should be by way of air-locks (Figures 1.26 and 1.27).

1.3.4 The Temperate Area

Temperate climates are those without extremes of temperature and precipitation (rain and snow). This climate has mild to warm summers and cool winters. The need for winter home heating is greater than the need for summer cooling. It is a relatively comfortable climate, especially near the coast, where summer seasons are cooler and winter seasons are warmer than further inland. Regions with a temperate climate are usually characterized by having roughly equally long winters as summers.

1.3.4.1 Traditional Shelters

Moore (1993) clarifies the main characteristic of buildings in this climate. As a result of the wide range of seasonal temperatures that characterise this temperate region, indigenous building envelopes (like clothing and plants) are quite sophisticated in their ability to open and close, in order to adapt to the changeable conditions. The envelopes are changeable in that they make use of a variety of components that can be switched from a closed to an open configuration, rejecting or admitting outside conditions.

1.3.4.2 Design criteria

Olgyay (1992) referred to temperate climates as “a naturally favourable climate, that made fewer thermal demands on its inhabitants, and there is a corresponding diversity and freedom in the structure of these people”. Winter requirements are similar to cold climates, but because the under-heated period is not as severe, insulation standards are not strict. The use of deciduous vegetation for automatic shading discrimination between winter and summer is recommended. Ventilation can deal successfully with most summer overheating by removing the excess amount of heat. But if shading is adequate, such overheating should rarely occur (Figures 1.28 and 1.29).

Figure 1.28: Bairnsdale - Southeastern Victoria (AGO, 2001)

Figure 1.29: House in the Yarra Valley, Victoria (AGO, 2001)

1.3.4.2.1 Site Layout

In temperate regions, the temperature range allows more flexible plans to be developed. The thermal stresses, even on buildings extending in a north-south direction, cause fewer unpleasant consequences than in the other zones. Therefore, this region can afford cross-shaped or freeform buildings (Figures 1.30 and 1.31); however, an east-west elongation is certainly preferable (Olgyay, 1992).

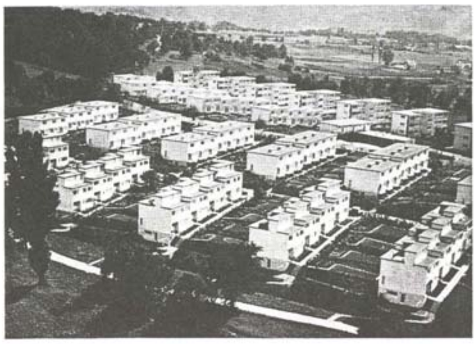


Figure 1.30: Housing in a Temperate Zone (Olgyay, 1992)

Figure 1.31: House on a Corner Site at Landcom's Melaleuca Estate at Metford (AGO, 2001)

In a temperate climate, wind direction usually changes with the season. In this case, it may be possible to choose a street layout which will block the winter wind, yet permit cooling summer breezes through the settlement (CBM, 2001). In cooler parts of the temperate zone, or on exposed sites, it is desirable to utilize wind protection (tree shelter belts, closely spaced buildings of constant height, main streets perpendicular to the prevailing wind).

The sun in temperate climates is undesirable in summer but it can cause any open space and parks to be a very pleasant and enjoyable place to stay in winter. Therefore, permanent shading, even if needed in summer, compromises winter sun. A dynamic solution, like shading open spaces and sidewalks in summer by deciduous trees that supply winter insolation, is preferred. The seasonal responses of deciduous foliage coincide with the solar needs of buildings. In the autumn, trees enter a state of dormancy and their leaves dry out and drop off to minimise surface area exposure during the coldest months. The leafless winter form allows warming sunlight to pass and strike a building just when solar heating becomes beneficial. During spring, the foliage fills in at almost exactly the time when protection from solar overheating is needed.

1.3.4.2.2 Urban Form

In the Temperate Zone there is the least stress from any specific direction. The least penalty is received from this climate, allowing considerable freedom in form. However, elongated form is desirable, especially shapes on the east-west axis (Olgyay, 1992). As night temperatures are often below what is comfortable, even in summer, thermal mass is preferable. The thermal mass is also useful for passive solar design for winter.

Solar heat input in winter is preferable, so it is recommended to face windows to the equator. Passive systems that provide heat in winter can produce overheating in summer unless measures are taken to block the summer sun by installing some structural sun control. The most effective tool is a combination of roof overhangs (Figure 1.32), external shutters or shades, and foliage to prevent the summer sun from entering the home (Figure 1.33). Unless these measures are applied, the system will continue to heat the home in summer, thus increasing air conditioning loads and undermining the net energy benefit of the passive system.

Figure 1.32: Mount Vernon, Virginia Home and Estate of George Washington (Architecture Week, 2001)

Figure 1.33: House in the Hills above Adelaide (AGO, 2001)

1.4 Conclusions

There is a clear link between zones of the climate map and the area in which certain types of buildings commonly occur. For example, flat roofs usually appear in the hot zones, while vaulted roofs are found in dry areas. Inclined roofs are found in temperate climates with consistently dry summers, while buildings with higher roofs are used in the wet-temperate and cooler territories (Olgyay, 1992). It is important to take into account the urban history of the region in order to identify climatic necessity in urban design and the planning of cities. The ancient treatise clearly illustrates a climate conscious approach towards the design and planning of the period. There has been a rich architectural tradition that has reflected an awareness of the local climate. An awareness of climate was integrated with innate human skills to provide comfort and protection. These people have a great ability to adapt their dwellings to their particular environmental conditions. Olgyay (1992) described traditional shelters as building expressions of true regional traits.

Moore (1993) affirmed that contemporary architecture would be greatly enriched, both aesthetically and functionally, by a careful analysis of the climatic responsive designs of early civilisations and a more skilful application of these fundamental principles (although not necessarily the actual materials or methods) to contemporary buildings. It is interesting to note that, while the environment of the region was one of the main factors that supported the formation and development of the early urban centres, it was often the cause of their downfall. It was ecological changes in the subcontinent that brought the decline of many civilisations; flooding of the rivers, climatic changes from humid to dry, hydrological changes in the soil etc.

CHAPTER 2

BASIC URBAN DESIGN PRINCIPLES

2. Basic Urban Design Principles
2.1 Introduction

Buildings provide shelter and safe places for human beings, also helping to determine our quality of life. As Winston Churchill said, "We shape our dwellings and afterwards our dwellings shape our lives". The same is true of streets, villages, towns and cities where we live. The built environment is not just a group of buildings; it is also the physical result of various economic, social and environmental processes, which are associated with the needs of society. The built environment is influenced by social aspects related to culture, security, identity, accessibility and basic needs. The economic aspects linked to property and labour markets are also important. In addition, environmental influences related to the utilization of land, energy and materials play a major role in the formation and development of the built environment.

Santamouris (2001a) indicated that development of the urban environment has serious effects on the quality of the global environment. Major concerns are the quality of air, increase in temperature, acoustic quality and traffic congestion. Buildings are related to global changes in the increase of urban temperature, the rate of energy consumption, pollution and the production of waste, conversion of agricultural to developed land, loss of biodiversity, water shortages, etc.

2.2 Climatic Aspects of Human Settlements

It is well known that the forces of nature have a direct effect on the formation of objects. It is also a recognised fact that only species which are in harmony with their environment and adapted to all internal and external forces to which they are exposed are fit to survive. Olgyay (1992) maintained that "The desirable procedure would be to work with, not against, the forces of nature and to make use of their potentialities to create better living conditions". He also called the structure, which reduces unpleasant stresses, and at the same time utilises all natural resources favourable to human comfort, "climate balanced". The approach to such structures should be comprehensive, based on local experience, technologically advanced, and adapted to the local ecosystem without disturbing its balance. The given physical characteristics, which are unique to the site (such as soil, landform, resources, the vastness of the space, etc.), must influence this approach (Golany, 1983).

Most of the early urban civilisations of the world emerged in the arid or semi-arid zones, primarily in the Fertile Crescent of the Middle East and in the Nile Region (Golany, 1983). This early urban planning experience highlighted some bioclimatic aspects of urban design, such as site selection consideration, adoption of the compact urban form, and development of the Special Street and alley pattern meeting the needs of living in a stressed climate. No one can deny the significance of other factors such as defence needs, social cohesiveness, etc. and it is difficult to isolate the impact of one factor or another on the nature of this early development and planning. However, it is clear that climate consideration stands in the forefront. Climate, at least as a social and economic factor, is always present and cannot be ignored. Kriken stated (Golany, 1983) that there are mainly three techniques for promoting the liveability and comfort of human settlements. They are the use of shadow and breeze, water elements, and the minimisation of the impact of solar radiation. In traditional desert settlements, all the above techniques are used.

2.3 Human Comfort

Comfort within buildings is mainly controlled by four factors: air temperature, mean radiant temperature, humidity and airflow. These are mainly the parameters which affect the heat transfer processes from the body to the environment (ESRU, 2003). In addition, there are other factors which affect comfort, such as clothing, activity level, etc. Fanger (1970) provides a sufficiently broad discussion of this topic in his book, and he defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment". He points out that, because of the biological variations of people, the aim is to create optimal thermal conditions, which will be found comfortable by the highest possible percentage of people. Therefore, comfort zones, are defined as "the zone in which 80 percent of the population will experience the sensation of thermal comfort" (Fairey, 1994). Comfort is mainly influenced by temperature and humidity. The psychrometric chart graphically represents the interrelation of air temperature and moisture content (Figure 2.1).

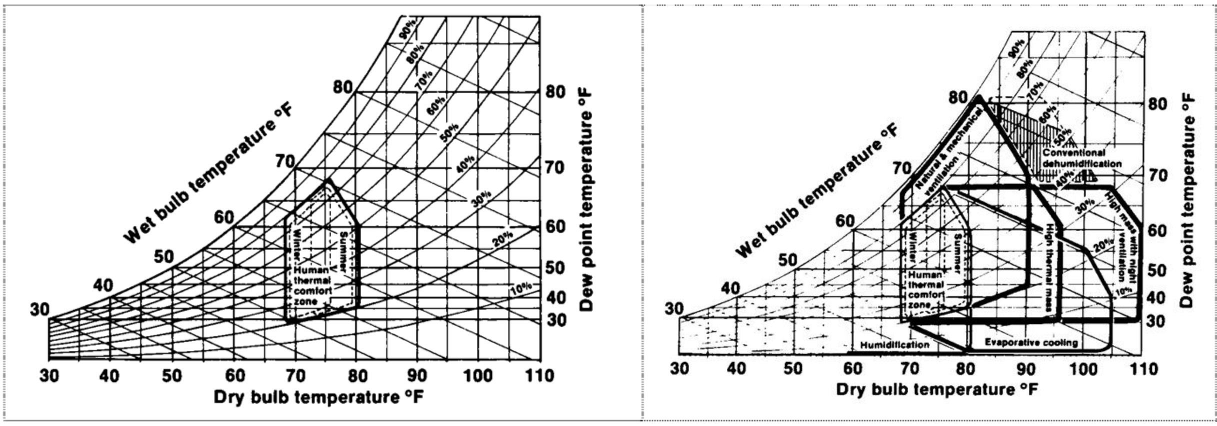


Figure 2.1: Psychrometric Charts and the comfort Zone (Fairey, 1994)

Psychrometric charts relate temperature on the horizontal scale to moisture on the vertical scale. “If the temperature of a given volume of air is decreased to the point at which it can hold no more moisture it becomes saturated” (Fairey, 1994). The corresponding temperature is known as the dew point. Thus, air is at 100 percent relative humidity if it is cooled to its dew point. Therefore, relative humidity can be described as the moisture content of a given atmosphere as a percentage of the saturation humidity at the same temperature (HKU, 2001). In other words, it is “the moisture content of the air relative to the maximum amount of moisture which air at a given dry bulb temperature can hold when saturated” (Fairey, 1994). The saturation point is represented in the psychrometric chart by the outer curved boundary. The air temperature represented by the horizontal axis of the psychrometric chart is called the dry bulb temperature and it represents the recorded temperatures in the common thermometer. The moisture axis represents the amount of the relative amount of moisture contained by air.

Sensible heat is the heat content causing an increase in dry-bulb temperature, while Latent heat is the heat content due to the presence of water vapour in the atmosphere (HKU, 2001). The total energy content of the air is the sum of both the temperature content of the air (sensible energy) and the vaporized moisture content of the air (latent energy). The sum of the latent energy and the sensible energy is known as the air enthalpy. As the lines of constant air enthalpy follow the line of constant wet bulb temperature, wet bulb temperature can provide a relatively accurate measurement of the heat content of the air. The higher the wet bulb temperature, the greater the energy content of the air (Fairey, 1994).

Since humans are warm-blooded mammals, deep body temperatures must remain relatively constant at 37 °C to prevent any medical difficulties. For instance, if the surroundings are very cold the body shivers to produce more body heat to keep deep body temperatures at tolerable levels. Likewise, the body can dissipate heat when the environment is overheated through perspiration. The human body exhibits all normal heat transfer mechanisms (conduction, convection and radiation) in addition to the ability to perspire and cool itself by evaporative heat loss. "If the air has a high relative humidity, the potential for evaporation to take place is greatly reduced because the air cannot easily absorb more moisture" (Fairey, 1994). Ventilation can greatly increase the tolerance for higher temperature and humidity levels, as it increases air motion across the skin, which provides cooling through both convective energy transfer and latent energy transfer (evaporation of perspiration through the skin).

Another variable affecting comfort is mean radiant temperature of a building environment. Fairey (1994) defined MRT as "the average of the surface temperature of the surroundings with which the body can exchange heat by radiant transfer". Radiant heat transfer to and from the body can be noticeable when sitting near a fireplace (high MRT) or large cold window area (low MRT). The comfort zones can be presented graphically as an overlay on the psychrometric chart which shows the relationship between temperature and humidity. Usually, there are two overlapped zones which represents winter and summer periods (Figure 1). Their difference is mainly attributed to the variation in clothing levels between winter and summer (Fairey, 1994).

Only a few comfort charts consider the additional comfort variables of mean radiant temperature (MRT) and air motion. The usual comfort chart (Figure 2.1) assumes that the MRT is equal to air temperature and there is no substantial air motion. However, Fairey (1994) pointed out that if MRT is increased, the net radiant exchange from the body to its surroundings will decrease, and if MRT is decreased, this net radiant exchange will increase. As regards air motion, research conducted by Fanger (1970) has revealed that comfort can be maintained at 27.78 °C and 100 percent relative humidity as long as air velocities of 90.90 m per minute across the skin are maintained (Fairey, 1994). One of the expanded versions of the comfort zone has been produced by Givoni (Figure 2.1). The various zones in the expanded chart show building comfort-producing potentials for selected building design techniques, which illustrate the effectiveness of passive building design in promoting thermal comfort.

As can be seen from the above, human thermal comfort is a phenomenon which occurs when the human body's metabolic rate stabilizes. This happens at a certain range or zone of air temperature which varies according to the influence of the previous mentioned contributing factors. At the state of thermal comfort there is no perceived discomfort due to neither heat nor cold. When temperatures rise above or below this comfort zone the body makes an effort to compensate for the change as a means of maintaining its deep body temperature at about 37 °C.

2.4 The Influence of Urban Forms on Climate

It is an established fact that the process of urbanisation produces radical changes in the environment of the region, involving radiative, thermal, moisture and aerodynamic characteristics (Deosthali, 1999). An increasing awareness that urban form has a great influence on climate has emerged. " It is widely recognised that city structure and its spatial organisation affects its environmental quality and its environmental performance" (Alberti, 1994). Different layouts result in differing microclimates, with greater or lesser comfort. Urban building forms might be modelled for solar access or shade, for shelter or exposure to winds depending on requirements. Mascaro et al., (1998) stated that each built site interacts with the physical environment and produces particular microclimate conditions. To succeed in integrating renewable energies in established urban structures, the actual behaviour and the microclimate performance of the urban forms have to be precisely identified. Geometry is a variable that may be controlled for the preservation of bioclimatic conditions, besides others functional, socioeconomic and symbolic aspects of the urban form.

The urban layout affects the climate of the area and can even modify it to improve the thermal comfort conditions both outside and inside buildings, even reducing their energy demands for heating and cooling. As design requirements differ from one climate to another, regional architecture demonstrates variation from one region to another to provide a suitable response of buildings to the existing climate conditions. Solar and wind orientation of the urban structure and the height and spacing relations between buildings are the parameters that define the geometry of an urban place. The urban design scale should take into account the varied urban sites, since the local situation of topography, solar and wind orientations are the base for guidelines to the best height and gap relations between buildings (Assis et al., 1999).

The great variation of urban settlements produces different kinds of microclimates inside the city. The issue that matters most in terms of climatic design and urban geometry is the "View Factor", (i.e. the proportion of the total spherical field of view from a subject taken up by surfaces). It seems clear that street geometry as an urban design tool is more important in improving urban climate than other factors: at least in the small to medium scale. Solar radiation, temperature and wind conditions can vary significantly according to urban form and layout density.

In winter, most urban microclimates are more moderate than those found in rural areas. They are characterised by slightly higher temperatures and usually weaker winds. During the day, wide streets, squares and non-planted areas are the warmest parts of the town. At night, the narrow streets have higher temperatures than the rest of the city. Urban warming affects the city's energy use, reducing the demand for winter space-heating, but increasing the energy needed for cooling.

Usually winds in towns are moderate because of the number and range of obstacles they face. However, some types of urban configurations such as long straight avenues or multi-storey buildings can cause significant air circulation. High buildings rising above low-rise building can create strong turbulent wind conditions on the ground as the air is brought down from high levels (HKU, 2001). In the climatically optimum city, thermal comfort can be improved and the energy needed for indoor temperature control can be reduced (CBM, 2001).

2.4.1 Urban Microclimates

It is well known that urban built form has an influence on the urban microclimate which, in turn, will affect the environment performance of buildings. Schiller et al., (1996) stated, " the built environment produces modifications in the urban climate, while the modified urban climate in turn affects buildings and spaces around them". Temperature distribution in urban areas is greatly affected by the urban radiation balance. Incidents of solar radiation on urban surfaces is absorbed and then transferred to sensible heat. The intensity of the emitted long wave radiation from walls, roofs and the ground depends on the view factor of the surface regarding the sky. The net balance between the solar gains and the heat loss determines the thermal balance of urban areas. Higher temperatures are presented in urban areas because the heat loss is slower than in the surrounding rural areas (Santamouris, 2001b).

Urban areas have particular climatic conditions with a higher temperature than exposed countryside, slight winds and an amount of sunshine that varies according to the degree of pollution, the urban density and the orientation of the streets. The quantity of solar radiation has a dominant effect on the temperature microclimate of the site, as well as the overall climate of the region. In northern latitudes, south-facing slopes receive sunlight more perpendicular to the ground surface than does level terrain. Therefore, south-facing slopes experience the warming effects of the sun that duplicate seasonal progressions similar to a comparable level site several hundred miles to the south. Conversely, because sunlight strikes north slopes at a more oblique angle, these locations are similar in climate to much more northerly locations, with shorter growth seasons and more prolonged snow cover.

Air movement has a significant effect on thermal comfort, both during cool periods (accelerating bodily heat loss by convection) and during warm periods (increasing perspiration evaporation, which becomes the primary means of maintaining comfort at a higher temperature). In general, strong winter winds suggest strategies which reduce building infiltration heat loss, tighter construction and shielding (by adjacent plants, landforms or adjacent buildings) from predominant winter winds. In summer, cooling breezes are important in encouraging ventilation through buildings by utilising the design of landscape. Small differences in terrain can create remarkably large modifications of the wind microclimate. An understanding of the basic principles behind these localised effects is essential in designing landscapes that effectively defend against winter wind or utilise summer breezes.

Large water bodies are more stable in temperature than adjacent land surfaces (as a result of the higher specific heat of water). During the day, the sun heats up the land surface quickly to a temperature higher than the adjacent water. The air over the land is warmed in turn and begins to rise. Cooler air is drawn in from over the water to replace it, resulting in a daytime onshore breeze.

2.4.2 Urban Heat Island

It becomes very clear that urban geometry and thermal properties of built-up surfaces have more influence on the magnitude and configuration of the urban heat island than wind behaviour or population density. Papadopoulos (2001) pointed out that "The urban environment, characterised by a dense and often continuous development of buildings, as well as by the use of materials with high thermal storage properties, leads, amongst other reasons, to high thermal accumulation". Although surface characteristics play a major role in creating the urban heat islands, an increasing number of authors are beginning to suggest that the geometry of urban canyons, namely, the street to building height and width relationships are important, if not the primary contributors to the problem.

The climate of cities shows considerable difference from that of the surrounding countryside, as large urban areas are warmer than the surrounding suburban and rural areas (Figure 2.2). This temperature difference between the city and its surroundings is known as the "urban heat island". At night, cities are usually warmer than their rural surroundings because of heat stored in bricks and concrete trapped between close-packed buildings. In the cooling season, the city still tends to be hotter than the countryside because of the relative lack of ventilation and the large proportion of hard surfaces of high thermal mass which retain heat. In cities, plants are replaced with surfaces such as asphalt, brick and concrete. These surfaces have a low reflective capacity so they absorb and store solar energy instead of reflecting it. It is evident that urban areas without a high climatic quality use more energy for air conditioning in summer. In addition, discomfort and inconvenience to the urban population due to high temperatures is very common (Bitan, 1992).

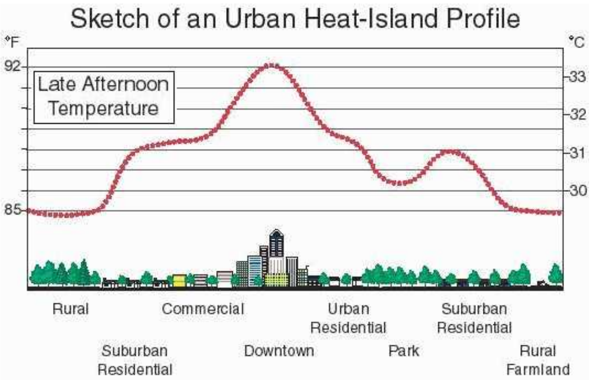


Figure 2.2: Sketch of an Urban Heat-Island Profile (EETD, 2001)

The phenomenon of the urban heat island is due to many factors. One of the most important factors is the geometry of the city streets, which means long-wave radiation is exchanged between buildings rather than being reradiated to the sky. Additionally, air pollution in cities creates a layer that blocks the night heat radiation to the sky dome, contributing to the enhancement of the "heat island" phenomenon (Santamouris et al., 1996). As a result, the urban heat island will increase the cooling requirements of buildings in summer and modify heating demand in winter.

Also, the thermal properties of materials increase the storage of sensible heat in the fabric in cities. As compared with rural areas, urban districts have a high absorption and fast transmission of heat. Urban evapotranspiration is also sharply reduced because of the reduced plant cover. The reduction of evaporating surfaces in the city means that more energy is put into sensible heat and less into latent heat. Also, the anthropogenic heat released from animal metabolism and heat released by vehicles increase the intensity of the urban heat island.

Studies of the urban heat island refer usually to the "urban heat-island intensity", which is the maximum temperature difference between the city and the surrounding area (Santamouris, 2001a). Data compiled from various sources show that the intensity of the heat island can be up to 10^0 C or more. The bigger the city, the more intense the effect (Littlefair, 2000).

The difference in climate between urban areas and countryside is greatly affected by the way through which the received solar radiation is treated. Countryside is generally characterised by large amounts of green. In a rural landscape, much of the solar energy that strikes vegetation is used by the plants for metabolic processes. A large proportion of the solar radiation falling on plants is used for evapotranspiration, which lowers the temperature of the surrounding air and releases moisture. In addition, solar radiation absorbed by the earth is partly used for evaporation of its moisture. On the other hand, cities are characterised by reduced green areas and an accumulation of artificial materials which have high absorptive properties. The absorbed heat from the material increases its temperature which is partly convected to the adjacent air and partly radiated to the surroundings.

In colder climates, the heat island effect can be beneficial, reducing heating demands. But in warmer climates the heat island effects can significantly worsen the outdoor comfort and energy consumption of buildings. During hot months a heat island creates considerable discomfort and stress, and also increases air-conditioning loads.

2.5 The Influence of the Socio-Economic Conditions on Urban Form

The urban form is a result of a complex interaction of many pressures and influences: economic, social, environmental, political, aesthetic, transportation systems, municipal ordinance, etc. Moudon (1997) described the city as " the accumulation and the integration of many individual and small group actions, themselves governed by cultural traditions and shaped by social and economic forces over time". Density, land-use and road networks are the most important issues in defining the pattern of urban development and their use of energy.

Developing new subdivisions is a level where careful site planning can affect the overall energy performance of a community. The two most important factors are density and district integration. Density is the use of units per acre for overall development instead of using rigid lot size requirements to control density; this permits flexible clustering of housing units. District integration combines housing with commercial and recreational uses and allows land uses to be more accessible to each other. Allowing cluster housing, mixing single and multifamily units, and higher density can reduce the energy needed in each housing unit.

2.5.1 Compactness

Kriken (Golany, 1983) defined compactness as "The technique of minimising the amount of building surface exposed to the direct radiation of the sun", while Golany (1983) referred to compactness as "A city form that is concentrated and firmly unified in its buildings, with consolidated land uses in a close, tight relationship with each other and within themselves, too". Compactness can be specified in many ways, but it is most clearly evidenced by the ratio of the exposed building surface to the enclosed living volume. A one-storey, single-family house, totally detached from its surroundings, demonstrates the largest amount of exposed wall and roof area to usable floor area. The ratio of exposed surface to usable area continues to drop, as one combines dwelling units into multi-family residential building blocks. In theory, buildings with higher surface area to volume ratio should require more energy for space heating per unit of floor area (Owens, 1980).

Compact cities were developed throughout history for many reasons: social cohesiveness, defence, economic efficiency, or adapting to a stressed climate. Hui (2001) thinks that economic and social imperatives often dictate that cities must become more concentrated to accommodate the people, to reduce the cost of public services, and to achieve social cohesiveness. On the other hand, Golany (1983) believed that the climatic aspect was a dominant motive in the arid-zone city. Gadi (2000) referred to the compactness of the buildings' layout, narrow interwoven streets and covered pathways as examples of the various solutions adopted in hot dry climates to provide shading against intense heat in summer, as well as sheltering the buildings from the cold wind in winter. The compact form alleviates the strong, hot day or cold night winds, reduces the harsh effect of dusty storms, reduces direct radiation, and minimises heat gain during the day and heat loss at night. Therefore, the compact city consumes less energy for cooling or heating.

Santamouris et al. (1996) pointed out that hot-arid climates are characterised by high-density settlements with narrow streets, arcades and small-enclosed courtyards, to minimise buildings' solar exposure and to provide outdoor shaded areas. Compact settlements can also climatically moderate the outdoor environment with adequate orientation of the streets, a self-shadowing configuration, and the reduction of vehicle transportation within the residential area. In hot and wet climates, wide streets and open spaces between buildings are found in order to ensure adequate ventilation. The same layout can be found in cold climates in order to allow maximum solar exposure of buildings and of open spaces during the winter period.

"Density is one of the main criteria for keeping the overall energy consumption of buildings and traffic at the lowest level possible" (Herzog et al., 1996). The compact city allows a noticeable shortening of the entire infrastructure network and transportation system and therefore reduces energy consumption and construction cost. Also, there is quick and easy access to facilities within the compact neighbourhood. This enables residences to approach daily services, such as education, employment, recreation, shopping, social and other services easily. The close and proximate living will also encourage social contact among different age groups, especially among children and elderly people. In addition, the compact design form destroys less of the environs than does the conventional city development (Golany, 1983).

Urban density is one of the main factors that affects the microclimate of an area and determines the urban ventilation conditions and urban air temperature. Yannas (2001) reported that "The built density and energy intensity of cities foster changes in urban microclimates which have far reaching implications for urban design, as well as for the environmental sustainability of cities". The heat island is more intense in the city centre, where there is a dense urban structure and concentrated activities. Studies have shown that the phenomenon of the "heat island" is mainly affected by urban density rather than by the size of the urban area (Santamouris et al., 1996).

The higher the density of buildings in a given area, the poorer its ventilation conditions. However, the influence of urban density on ventilation conditions depends on wind direction and the spatial arrangement of buildings. However, it is also possible that a high-density urban area, consisting of a mixture of high and low buildings, could have better ventilation conditions than an area with lower density but with buildings of the same height (Hui, 2001). Givoni (Santamouris et al., 1996) proposed a bigger separation between buildings in the north and south directions than east and west, in order to ensure high solar collection during winter and solar protection of the west and east sides during the summer. Thus, higher urban density could be achieved by a row of terrace houses along the east-west axis with adequate openings in the north- and south-oriented walls to provide ventilation.

While higher densities will improve the potential for a total energy system, a crowded and stressful urban environment may have unhealthy effects on occupants, such as air pollution and noise problems (Hui, 2001). In addition, conflicting considerations may apply to the use of energy from renewable sources. Roth (1977) has pointed out that extensive exploitation of solar energy for hot water and space heating would require large collecting surfaces and therefore, relatively low densities. Boothroyd (1976) also indicated that the need to provide accessible sunlight for solar heating systems might counter any move towards higher densities. Hence, the use of renewable energy sources may impose some constraints on urban form and certain energy related developments might need specific spatial requirements (Owens, 1980). However, very high densities seem to be neither necessary nor desirable from other points of view, such as the social aspects. Nevertheless, a suitable extent of density, which might be energy efficient, maintain privacy, and facilitate the adoption of certain energy technologies, can be found. Furthermore, Kausch (1998) believes that low energy building design is compatible with a wide range of architectural styles. Another conflict can arise in city centres where the required spacing for utilising passive solar principles is not practicable. In this case, Littlefair (2001b) suggested that passive solar techniques may be limited to the upper storeys and to roof space collectors.

2.5.2 Land Use

Some land-use patterns can be more energy-efficient than others. Owens (1980) stated that certain threshold densities should be achieved in the interests of energy efficiency. This will result in lower physical separation of activities. The concept of land use proximity is linked directly to the concept of compactness; both are desirable ways of achieving the same goal. Land use can be proposed as an integrated pattern for the residential area where shopping, offices, clean manufacturing, educational and cultural activities, social services and restaurants can be joined within residential areas. These integrated land uses support proximity, social interaction and convenience. In addition, they conserve land and intensify its use by all age groups and they reduce the inhabitants' dependence on transportation. Separate placement is required in the case of disruptive land uses, such as major transportation routes and facilities, industrial parks, major shopping centres, etc. (Golany, 1983). To investigate the energy requirements associated with alternative land use patterns (with a view to identifying the characteristics of efficient and inefficient forms), all possible arrangements of land use in a given situation can be evaluated (Owens, 1980).

2.5.3 The City Network

Shashua-Bar et al. (2002) asserted that canyon street morphology plays an important role in affecting the urban climate. Golany (1983) referred to the road and alley networks within a city as channels for air movement and heat exchange, and explained the significance role which they play in establishing the city climate. Narrow and winding streets produce minimal heat exchange, and therefore they are normally shadowed and cooled in the daytime and are warm at night. They also reduce the effect of stormy or dusty winds. Streets in parallel design will encourage air movement or dusty winds when surfaces are not paved. A grid pattern of streets, usually designed east-west and north-south, causes shadowing on one side of the street only and leaves the other radiated all day;

or it will cause shadow or heat in each half of the day. While, northeast to southwest and southeast to northwest directions for the grid can establish interchange of shadows and radiation along the city networks (Golany, 1983).

The primary routes of the city network are usually located around the edge of any land use, especially in residential areas. Pedestrian paths are within a neighbourhood with vehicular traffic largely limited to the periphery. This hierarchical system for movement within the city limits and diverts unnecessary traffic. The city's network should be designed in relation with the daily and seasonal sun cycle. In the arid city, shadowing is a desirable design concept to protect pedestrian paths from the stressed climate. Alleys should be shadowed and cool throughout the day. This is achieved by considering their orientation and direction, by landscape elements, and by adjusting the building heights. Narrow alleys will keep their space cool in the day and warm at night (Golany, 1983).

To reduce environmental impacts, transportation must be addressed. Even the most energy-efficient passive solar house will carry a great environmental burden if its occupants have to get into a car each morning and travel 20 miles to work. Markovitz (1971) pointed out that the interspersion of land uses does have a significant effect on travel demands. Clustering commercial and industrial zones results in a reduction in trips. He also reported that the most efficient urban form (that is the one with the lowest total travel time) would couple dispersed employment and commercial opportunities with residential density declining with distance from the centre (Owens, 1980).

2.6 The Built Environment and Landscape

The microclimate of an urban area can be modified with appropriate landscaping techniques by a combined use of vegetation and water surfaces. The main benefits resulting from appropriate modifications of climatic conditions are: air cooling, sheltering from wind to reduce convective heat losses in winter, the filtration of air pollution, reduction in noise levels and channelling of cooling summer breezes (Figure 2.3). Landscaping through vegetation and water surfaces around buildings can reduce the solar radiation and modify the air temperature outdoors, and indoors and effectively minimise the cooling load of buildings.

Hutchison et al. (Sattler, 1994) also asserted that vegetation can modify the climate and thus energy consumption in three different scales (macro, meso and microscales). On a mesoscale climate, the best-known effect of vegetation is that of its interaction with the urban heat island. Hutchison states that "of the three scales of climate, the microscale features are easiest to modify and the interactions of vegetation with microscale processes are fairly well understood".

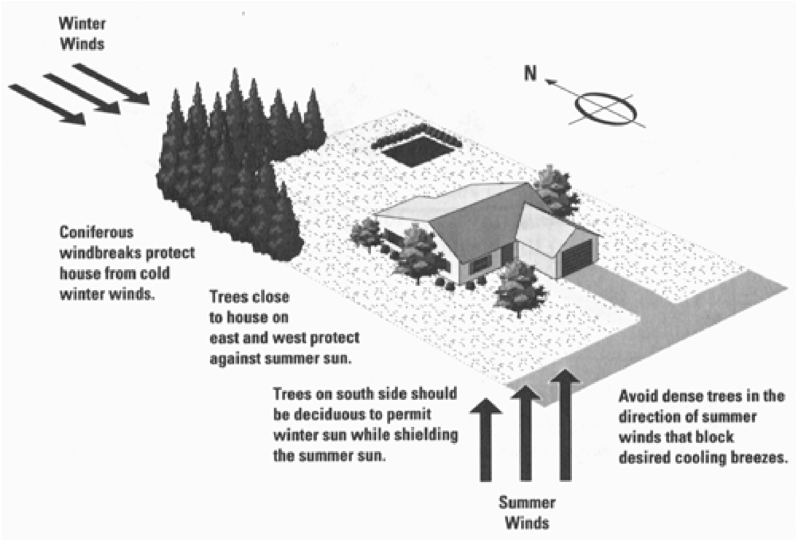


Figure 2.3: Landscaping can Modify the Microclimate of an Urban Area (EETD, 2001)

Design approaches at this stage aim to improve the microclimate around the building and its thermal performance by reducing heat gains and by providing natural cooling of the building. Measures are taken in the space surrounding buildings (private gardens, courtyards, atria), in the design (orientation, shape, openings, internal layout, functional elements) and in the construction (material, colour) of each individual building. Successful design for the environment surrounding the building can result in minimising the operating hours of the air conditioning in mechanically ventilated buildings, or reducing the hours of thermal discomfort in naturally ventilated buildings (Santamouris et al., 1996).

2.6.1 Open Space Design

Mertens (1999) has pointed out that open spaces have an important impact on the climatic and health-oriented aspects inside cities. Santamouris et al. (1996) postulated that landscaping could be applied to public spaces in the form of large public parks, small neighbourhood parks, playgrounds, trees along streets, or by providing space for landscaping around buildings. The consideration of the location of open space, its pattern of distribution within the city, its size and its positioning in relation with the neighbouring land uses is very important, in terms of the type of microclimate which it can generate.

The liveability of open spaces is significantly affected by environmental factors, including solar radiation, ambient temperature, humidity, wind velocity and radiant energy from the sun (Kim, 1989). All these factors directly affect the potential for thermal comfort in open spaces. In hot-dry climates, as in most warm climates, many of the daily activities take place in the outdoor open space. It is therefore necessary to treat the external spaces just as carefully as the building itself (Koenigsberger, 1974). Golany (1983) believes that open space design in the arid zone is more essential to human comfort than in non-arid zones.

Adjacent buildings, pavements and dry ground heat up quickly, causing painful glare and reflecting radiation towards the building; at night they will reradiate the heat stored during the day. Enclosure of out-door areas by walls which are themselves shaded will help to avoid such undesirable effects and at the same time will support effective protection from the dust and hot winds outside. Open spaces should be small sized and dispersed throughout the city rather than being concentrated as one or few large spaces. A dispersion pattern facilitates access from all land uses. The proximity to residential areas supports its utilization by children and the elderly. In addition, it will have a positive impact on the ambient temperature, establish large amounts of shadow, and reduce the stress of urban areas.

Also, in tropical climates, many of the activities normally associated with indoor spaces in moderate climates (sleeping, eating, playing, working, etc.) can be performed out-of-doors. The shelter of the building is mainly sought when the need for privacy or unfavourable weather conditions demand it, and for the safe keeping of personal belongings. As the area adjoining the building becomes an extension of the indoor space, it has to be treated by the designer with equal care. While natural conditioning is preferable to mechanical control for indoor spaces, this is the only method of control possible for the out-door space.

Assis et al. (1999) affirm that for better utilisation of the cooling potential of vegetation in tropical climates, green areas should be regularly inserted into the urban structure. In warm-humid climates, the same principles apply to the design of external spaces as to the design of buildings. Shading and free passage for air movement are the two basic requirements. The influence of open green spaces on the ambient conditions extends only a short distance into the surrounding urban area. Thus, it is more effective to have more small green areas spread around an urban area than a few large parks. The size of green areas should be regularly inserted into the urban structure for a better utilization of its cooling potential in tropical climates.

Sakakibara (1996) reported that the urban canyon absorbs more heat in the daytime and releases more at night than the parking lot. The natural cover of terrain tends to moderate extreme temperatures. Green belts are effective in trapping soil particles and particles generated by motor vehicles and industrial pollution. Provision of trees can minimise the discomfort of thermal stress and heat stroke in people in cities. Air and radiant temperature behind trees are significantly lower than temperature on hard surfaces like roads, concrete or opens areas of soil. Not only does the paved area add noticeable heat to the air layer near their surface, but they also radiate and reflect large amounts of heat into the building (Konya, 1980).

Plenty of spaces with trees must be provided along streets, in public parks and in children's playgrounds in order to provide shaded areas. Deciduous trees will provide shade when needed; they will also allow sun penetration in the cool season when they lose their foliage. Other functional landscaping elements like trellises, pergolas, alleys and hedgerows can be used. The tangible effect of vegetation on noise reduction is relatively small as it does not significantly reduce the level of noise reaching the buildings. The actual effect is mostly psychological by visually hiding the source of noise from the affected person. The use of trees and shrubs is effective for noise reduction if they are planted densely in belts.

2.6.2 Vegetation

The contribution of vegetation towards a better urban environment has been recognised by professionals in many different fields for quite a long time. Some good examples of landscaping aiming at practical environmental benefits were found in early Egypt, Babylon, Persia and Ancient China. These examples illustrate the long and rich tradition in human history for integrating architecture and vegetation to improve the environments of human life. Besides providing aesthetically pleasant and attractive recreation areas, vegetation plays an important role in the improvement of man's immediate physical environment (Figure 2.4). Landscaping through vegetation is a very effective strategy for modifying the microclimate. Apart from the decorative function that vegetation affords, it modifies the microclimate and energy use of buildings by lowering air temperature, increasing the relative humidity of the air, functioning as a shading device and channelling wind flow. The psychological effects of the green areas on people's moods, their happiness and calm are also significant.

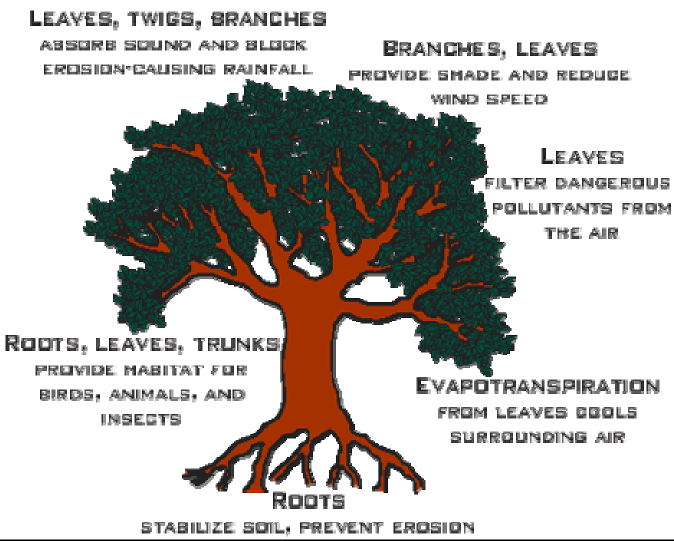


Figure 2.4: Planting Trees is a Good Strategy for Improving the Quality of Life in Urban Areas (EETD, 2001)

Mascaro et al. (1998) pointed out that vegetation contributes to the control of solar radiation, temperature and humidity. Planting trees is a good strategy, both for saving money through energy efficiency, and for improving the quality of life in urban areas (Figure 2.5). Data collected over the last century clearly demonstrate an increase in the temperatures within cities since buildings and pavements began replacing agricultural land. Rosenfeld et al. (1995) cite vegetation evapotranspiration and tree shading as an important control measure in heat-island mitigation.

Figure 2.5: Vegetation Enhances Human Thermal Comfort (Hargreaves Associates, 2001)

Reducing city cooling loads can provide significant environmental and economic benefits for the whole community. The utilization of trees and "high-albedo surfaces" are often mentioned as one of the methods for reducing cooling loads. High-albedo surfaces are more reflective of the sun's energy (usually light-coloured surfaces) and can therefore reduce the cooling load of buildings. One of the simplest and cheapest strategies for countering the urban heat island effect is to increase the number of trees and other plants. Vegetation cools directly by shading and indirectly through evapotranspiration (the process by which plants release water vapour). Plants can be effectively used to reduce solar access, to provide shade during summer and to improve ventilation conditions in buildings. Properly selected and sited vegetation can provide shade for both buildings and people and can offer protection from the convective cooling of the wind. Sattler (1985) described the recommended energy-conserving landscape designs, as those “that provide shade from the summer sun, channel cooling breezes toward windows, allow winter sun to reach the structure and, particularly, to penetrate southerly windows and provide protection from winter winds”.

In addition, vegetation can improve the quality of daylight entering the building by softening and diffusing it and reducing the glare from the bright sky. In addition, plants can control air pollution, filter dust and reduce the level of nuisance. It can extend the living area outdoors under more pleasant thermal conditions. Large green urban areas can positively contribute to the social life of an area by housing recreation places, cafes, open cinemas or open theatres. Vegetation enhances human thermal comfort and adds to the psychological well-being of urban dwellers. In addition, urban vegetation improves the surface water flow by the quantitative and qualitative regulation of runoff and enriches the urban bio-diversity.

Figure 2.6: Vegetation Can Improve the Microclimate and the Energy Use of Buildings (Acres Wild, 2001)

In hot dry climates, trees with dense canopy that provide thick shade are desirable as they reduce direct and diffuse radiance (Figure 2.6). Akbari et al. (2001) suggested that the planting of urban trees is inexpensive measure that can reduce summertime temperature. Trees and bushes can be also located in such a way to improve ventilation conditions inside the building (Figure 2.7) by directing more of the cooling breezes into the building (Santamouris et al., 1996). In areas where water is not so scarce, vegetation is a very attractive cooling approach. In humid climates, the beneficial cooling effect may be reduced by the undesirable, increased relative humidity of air. The vegetation in this case should be arranged to encourage air movement.

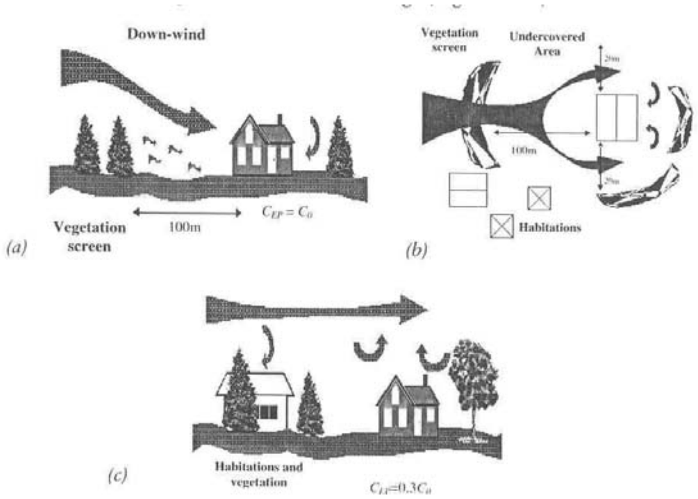


Figure 2.7: The Influence of Vegetation on the Surrounding Environment (Santamouris et al., 1996)

Although trees absorb most of the solar radiation falling on their leaves (up to 90 %), they reradiate back a small portion of it. The absorbed solar radiation is mainly consumed for evaporating water from the leaves. This process cools down the leaves and consequently, the immediate air, releasing vapour and increasing air humidity. The remaining small portion of the absorbed solar radiation is used for photosynthesis. Leaves with open pores release about 50 to 70% of the amount of vapour that would be released from the same water area under the same climatic conditions (Santamouris et al., 1996).

Santamouris et al. (1996) also mentioned that the cooling effect of plants, due to the combined effect of evapotranspiration and the shade they offer, can result, in heavily landscaped areas, in an ambient temperature drop in the immediate surroundings of 5.5 to 8.5 ^{0} C in hot dry climates. Evapotranspiring surfaces in urban areas, like water, parks, trees, lawns, etc., have the effect of lowering the temperatures of the surrounding, much drier, non-vegetated areas. This so called “oasis effect” results from the movement of hot, dry air sinking over the cooling vegetation and advecting into the neighbourhood along the streets from the down-wind park/urban boundary. Oke (1992) suggests that 20-30% of cities’ area should be vegetated to benefit from the oasis effect and to offset the development of the urban heat island (Sattler, 1985).

Robinette (1972) states that plants, particularly if in full foliage, are obstructions to wind. Hence, there is a major reduction in wind velocity up to five times the height of the obstruction. There is some reduction in velocity as far out as 10 times the tree height for single trees. Dense rows of trees are even more effective in providing shelter. For example, wind velocity may be reduced by 50 percent for a distance downwind from 10 to 20 times the height of such dense shelterbelts. Wind is also affected on the windward side of the obstruction, but only one-third as far as to leeward (Moore, 1993). The interest in wind protection lies, not only in outdoor comfort conditions, but also in its effects on house heating. Windbreaks or shelterbelts can be used for the reduction of domestic heating requirements. The type of windbreak affects the airflow pattern and the area of protection. In general, more belts with greater density and thickness will produce larger effects in wind protection. Sattler (1985) reported that DeWalle and Heisler found that a windbreak composed of a single row of white pine trees reduced air infiltration rates by up to 54% and space heating requirements by up to 18% during winter.

The choice of trees should be very carefully based on the shape and character of the plant (tree or bush), both during the winter and summer periods, and on the shadow shape they provide. Deciduous trees are very useful as they drop their foliage during autumn and permit solar access during winter (Figure 2.8). Therefore, they are leafless when solar gains are most valuable, while they can prove some shade in summer (Littlefair, 2000). The most appropriate plants for effective landscape are native plants as they are accustomed to the local climatic conditions.

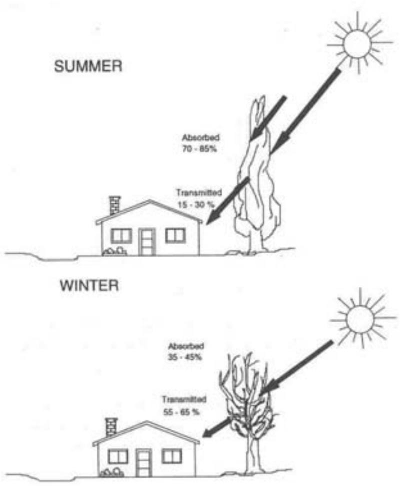


Figure 2.8: Shadow Shape during Winter and Summer (Santamouris et al., 1996)

Tree locations are important; the position of plants around the building should be carefully chosen in order to provide shade at the most critical hours of the day. Shading of windows is the most beneficial. Horizontal overhangs, like pergolas, are preferable at the south side, as the sun is in its high position at this orientation. Trees on east-south-east and west-south-west sides offer the best performance as the sun is at low altitudes in the morning and late in the afternoon, and low sunrays cast long shadows. Vertical trellises, covered by vines or other creeping plants, are effective on east and west facades. Climbing plants on the walls are also effective in reducing the solar heat penetrating through the building's envelope.

As the roof is a part of the building that absorbs the highest amount of solar radiation during summer, grass planting provides a remarkable reduction in the roof's surface temperature and consequently in air temperature of the space below it. The development of a roof garden can also reduce the roof's temperature. In addition, the roof garden provides an amenity space by extending activities at a higher level, where air speed is higher than at the ground. Vegetation used on the roof could range from a simple horizontal vine-covered trellis, to trees and bushes planted in lightweight soils, or even the creation of fountains, pools, etc. Grass and other plants covering the ground around a building are also effective in controlling its air temperature and in ensuring that its load will be smaller than a building surrounded by asphalt or concrete surfaces (Santamouris et al., 1996). In the case of buildings with solar collectors on the roof, precautions should be taken to control trees height positioned at the south side in order not to obstruct solar access to the collector.

2.6.3 Water surfaces

Water surfaces modify the microclimate of the surrounding area by reducing the ambient air temperature either through evaporation (latent heat) or by the contact of the hot air with the water surface, which is cooler, owing to its high thermal mass. Evaporative cooling can increase human comfort. Fountains, ponds, streams and waterfalls may be used as cooling sources in order to lower the temperature of outdoor spaces (Figure 2.9) and of the air entering into buildings. The psychological cooling effect offered to people is also significant (Golany, 1983). The distribution of wet surfaces around gardens is particularly effective in hot dry climates. Although water surfaces are very useful in dry climates, their existence may be limited by the scarcity of water.

Figure 2.9: Water Surfaces Can Increase Human Comfort (Acres Wild, 2001)

As water surfaces increase air humidity, they can be problematic in very humid climates and thus air circulation should be promoted. They can also be used in humid climates, but they will be more effective if they are positioned downwind in order to avoid human discomfort from the extra humidity in the air (Santamouris et al., 1996). In addition, preventive measures to control Legionnaires' disease have to be considered as the disease is caused by a bacterium found primarily in warm water environments. Also, the air conditioning systems for large buildings often include cooling towers, which contain a pool of warm water in which the disease can flourish. Such water surfaces have to be maintained and disinfections procedures can be implemented to minimize the growth of legionellae.

2.7 Conclusion

It has become very well recognised that the intrusion of the form of the urban pattern will influence the microclimate of the site and, to certain extent, the immediate macroclimate of the region. Heat gain and loss within a settlement result from the overall form and configuration, street patterns and orientation, building material and its colour, overall exposure to radiation, and density of vegetation. Urban areas are increasing in size rapidly and it is estimated that in the future most of the world’s population will be living in urban areas. Increasing urbanisation and industrialisation has caused the urban environment to deteriorate. The concentrated activities of the population in urban areas and the rapid increase of motor traffic are the main contributors to air pollution and the deteriorating environmental and climatic quality. The relationship between urban areas and nature should be developed to achieve a symbiosis between the two. Alterations and other measures carried out in public spaces or existing buildings, or caused by new construction, must consider the climatic aspects of the development.

CHAPTER 3

PASSIVE SOLAR URBAN DESIGN CHARACTERISTICS

3. Passive Solar Urban Design Characteristics
3.1 Introduction

Urban areas are growing in size very rapidly and it is expected that in the future most of the world's population will be living in cities. Industrialisation and the concentrated activities of the population in the cities are the main influences on the environment and the quality of climate deterioration. Urbanisation in the region is the prime cause for the increase in energy consumption, particularly in those areas where increasing income has resulted in greater demand for transportation and home appliances. Passive Solar Urban Design can have a significant impact on the pattern of energy consumption. Such a reduction will certainly lead to a healthier environment and alleviate pollution problems.

Energy-conscious urban design respects the environment and applies various methods and techniques to reduce the amount of energy consumed in buildings, especially for heating, cooling, lighting and hot-water use. An energy-conscious urban form will help direct individual buildings and sites to be properly oriented and shaded or exposed, as needed. Until now, the main efforts of energy-conscious design have been focused on single buildings and little attention had been devoted to this aspect of urban design. The aspects affecting energy requirements of urban space rank in scale from the regional to the neighbourhood and include the layout of the settlement, the location of main traffic routes, the distribution of residential and commercial areas, and landscape design.

Santamouris et al. (1996) pointed out that design concepts should aim to provide protected spaces for outdoor activities and to contribute to cooling load reduction and to a lesser dependence of buildings on air conditioning. There is a fundamental relationship between the urban microclimate and the energy consumed there for heating and cooling purposes. Urban areas create their own climate. New buildings must take account of the climatic conditions and subdivisions can be designed so as to create the best possible urban microclimate. In public spaces, steps should be taken to improve the urban climate, temperature control and wind protection. The overall design strategy should be a compromise of measures for both summer and winter thermal requirements.

3.2 Bioclimatic Urban Design Strategies

It is acknowledged that buildings not only satisfy the basic need for shelter, but also satisfy other needs required for the sustainability of housing environments (Oktay, 2002). The various existing or emerging patterns of building development will enter into a reciprocal relationship with climatic data. Therefore, the form of the urban structures must take account of the environmental and bioclimatic factors, such as topography, temperature, airflow pattern and orientation. Along with the architectural character of the area and the functions it has been designed to provide, the climate zone in which the settlement is located is one of the predominant factors that will govern the overall planning process (Santamouris et al., 1996). In terms of their energy balance, settlements should be regarded as self-contained systems with an optimal utilisation of environmentally sustainable forms of energy to meet various needs. It should be possible to meet comfort requirements largely through the design of the development by incorporating principles of passive solar urban design.

Buildings and urban open spaces should be designed in such a way that a minimum of energy is needed to serve them in terms of providing hot water, heating, cooling, ventilation and lighting. To cover the remaining needs, solutions should be chosen that support the use of environmentally compatible forms of energy. A reasonable density in new urban areas, coupled with a design plan to infill developments, can help to reduce expenditure for infrastructure and transport. Mixed development should be allowed in all sections of the city to reduce the need for travel.

3.3 Site Selection

The design of urban areas should start from a decision taken concerning the selection of the location. The specific local situation, the existing vegetation and building fabric, as well as climatic and topographical factors, all have to be analysed and evaluated as the basis for any urban design project. The natural resources available in a given location, especially solar insolation and air flow pattern, should be harnessed for the amelioration of thermal comfort in buildings and should be reflected in the design of their layout and form.

Elevation differences, the character of land cover, and water surfaces produce variations in the local climate. The selection of the site is very important for the thermal comfort of the settlement. Correct site selection for new large housing developments can prevent environmental problems and improve the microclimate of the development. Favourable locations should be considered. Olgyay (1992) mentioned that windbreak and some surrounding surfaces, which can induce an advantageous reaction to temperature and radiation impacts, may improve less favourable sites.

Sites affected by natural hazards, such as floods, should be avoided. In addition, the location of a site should be carefully chosen in relation to pollution sources (heavy industry, etc.) and the direction of prevailing winds. The direction of prevailing winds is a very important parameter in the site selection process, as wind can transfer pollution particles from sources to other sites lying in their path.

3.3.1 Effects of Topography

The shape, orientation, exposure, and elevation of hills or valleys located at or near the site must be investigated, as they can have an effect on temperature, the distribution of solar radiation, wind and precipitation, etc. (Konya, 1980). Air temperature decreases with altitude, at a rate of 0.65^0 C for every 100m. This effect is important in tropical lands where temperatures become more favourable at higher altitudes. Also, the amount of radiation that hillsides can receive depends on the inclination and direction of the slope.

Average radiation conditions are important in the evaluation of sites. Advantageous locations can be inclined surfaces, which receive larger amounts of radiation during underheated periods, and less at overheated times than horizontal sites. These categories can also be expressed as radiation time factors, since the same radiation intensities received on southern slopes will be received on level sites a few weeks later. In other words, a sloping site, which receives more winter radiation than a level site, will be a few weeks ahead in terms of the arrival of spring. For site selection purposes only, small-slope inclinations are of importance. Slopes steeper than 20^0 are not usually considered since they are generally regarded as unsuitable for ordinary building purposes.

A hill can modify both wind and precipitation. Wind flow is diverted by a hill in both its horizontal and vertical stream patterns, causing higher speeds near the hilltop on the windward side and less turbulent wind conditions on the lee slope. Therefore, from a ventilation aspect, windward slopes are preferable to leeward slopes. A down-valley location would expose the building to colder winds. Precipitation on the windward side is carried over a hill by the wind and falls on the lee side, where weak air movement prevails. However, high mountains cause exactly reversed precipitation distributions. When air is forced to ascend on the windward side, this produces the adiabatic process of condensation and precipitation (Olgyay, 1992). If a valley is surrounded by mountains, it is possible to experience poor ventilation conditions which, under temperature inversion conditions at night, can trap the air pollution produced in this area.

In mountain and hill sites, the best location is generally at the middle of a slope along the contour lines. In this position, temperate slope winds can drive cross ventilation through the shortest section of the building. A ridge location would expose the building to much higher wind velocities and sites near the crest of a hill, or at high elevations on the windward side near a ridge, are exposed to high air currents. Lower hillside locations tend to be cooler than slopes, as the cold air flows toward the lowest point. During night, cold breezes slide down the slope of the valley. Thus, valley slopes can experience down-slope air currents during windless nights. The valley floor also benefits from these air currents, especially under hot conditions with no local night winds. As far as cooling needs are concerned, sites with low summer insolation and good ventilation conditions should be considered. North and east facing slopes get less direct solar radiation than the west and south slopes. During summer, a north slope is the coldest and shadiest, while a west slope is the warmest.

In various climate regions, different topographic exposures will be desirable according to the specific bioclimatic needs of the area. In a cold climate, where heat conservation is the main target, protected sites are preferable. Sites about half-away up a slope, located in wind shadow areas and well exposed to winter insolation, offer advantageous positions. Orientation somewhat east of south secures balanced heat distribution. Accordingly, sites located in a SSE direction would offer the best location for desirable cool-zone habitation.

In temperate zones, location requirements are not so strict as in cold zones; however, thermal requirements for both over and underheated periods must be correlated. Desirable site exposure tends to move farther east of south. The cool-air flow effect is less important, allowing the utilisation of the lower portions of the slope. The upper topographical locations of a warm slope can be also advantageous if adequate breeze utilisation in warm periods can be provided. However, this need should not conflict with winter wind protection and prevailing seasonal wind direction should be carefully considered.

In hot-arid zones, the desirability of heat loss overrules the demands of cool periods and the main emphasis is on the reduction of heat gains. Lower hillside locations, benefiting from cool airflow, are preferable if measures are taken to avoid the flow during underheated periods. Wind effects have relatively small importance. The large daily temperature range makes easterly exposures desirable for daily heat balance. As afternoon shade is required during the majority of the year, sites with ESE exposure are preferred in hot-arid zones. In areas with mild winters, east- and north-facing slopes can be used. West slopes should be avoided in all cases.

In hot and humid climates, ventilation is desirable and locations on the high parts of windward slopes are preferable. Olgyay (1992) indicated that west sites should be avoided, as they are associated with high ambient temperatures and exposure to high solar radiation. Santamouris et al. (1996) also stated that east slopes are not desirable as during summer, east and west slopes collect more solar radiation than any other orientation, owing to their inclined position. Because of their lower exposure to solar radiation, northern and southern oriented slopes are beneficial. However, the ventilation aspect should have priority in this climatic type, as shading might be provided by other means.

3.3.2 Proximity to Water

The proximity of a site to bodies of water affects its air temperature and can moderate extreme temperature variations. Sites with a proximity to the sea or a lake experience lower air temperatures, especially during daytime, and smaller diurnal air temperature differences during summer, than sites on the mainland. Water, having a higher specific heat than land, is normally warmer in winter and cooler in summer, and usually cooler during the day and warmer at night, than the terrain. The stabilising influence of large bodies of water on temperature variation is considerable. Land on the lee side of water will be warmer in winter and cooler in summer. Accordingly, the proximity of bodies of water moderates extreme temperature variations; in winter it raises minimum temperatures, and in summer lowers heat peaks.

In addition, places with a proximity to the sea benefit from daytime sea breezes and nighttime land winds. Humidity in sites may also be affected, depending on the general temperature pattern. The larger the body of water, the greater its impact on the microclimate (Konya, 1980). Sea breezes, which are associated with high humidity, can be a major problem in humid climates. However, in most cases, this problem is balanced by the desirable effect of the increased wind speed on human thermal comfort.

3.3.3 Land Cover

The land cover characteristics of a site can have a pronounced impact on temperature. The natural cover of the terrain tends to moderate extreme temperatures and stabilises its conditions. Grass retains less heat and should be used as much as possible as opposed to bare ground or paving. Plant and grassy covers reduce temperatures by the absorption of insolation and heat dissipation through evaporative cooling. The effects of grass on the microenvironment of a desert settlement can decrease the maximum temperature by more than 6 ^{0}C (Allard, 1998). Conversely, synthetic surfaces and man-made surfaces tend to elevate temperatures, as the materials used are usually both thermally absorptive and conductive. For example, asphalt-paving temperatures typically elevate 14 °C over air temperatures and cities are usually warmer than the surrounding suburbs: 4.4 °C during summer days and 6 °C at night (Moore, 1993).

3.4 Site Design

These aspects should be taken into consideration in both site selection and site design. The location, layout, the general form and orientation of buildings, as well as the landscaping of the site, are the principal aspects to be considered when selecting and designing the site for a building project suitable for passive solar design. Also, the best exploitation of the airflow pattern due to topography and the surrounding buildings should be taken into account, in order to increase the potential ventilation rate. In addition, the best compromise between summer and winter comfort conditions has to be considered.

3.4.1 The Microclimate of The Site

Meir (1990) stated, “Considerable microclimate differences may exist within a small site, as a result of site planning and house design”. The intrusion of the urban form itself and the form it takes in a region of a given climate character will influence the microclimate of the site and, to certain extent, the immediate macroclimate of the region. Heat gain and loss within the city result from the city’s overall form and configuration, its street patterns and orientation, building material, morphology, overall exposure to radiation and the density of its vegetation. The major factors determining the character of the microclimate of spaces between buildings are the proportions of the space (H/W ratio) and orientation. H/W ratio varies according to climatic and cultural, as well as aesthetic needs. The medieval walled cities of Italy generally had H/W =2. Leonardo da Vinci believed in the ratio of 1 as the ideal proportion or “Golden Proportion”, whilst the Baroque era reversed the medieval proportion to 0.5. Modern designs are normally based on sunlight and privacy.

Site design can significantly improve the microclimate. Design guidelines should be considered according to the desirability in living conditions, based on a microclimatic survey. Sites can be further improved by layout, windbreaks and shade-tree arrangements (Olgyay, 1992). The site can be usually warmer when utilising all of the maximum solar exposures on a particular site. In this case, windbreaks and cold airflow diverters can be provided either with vegetation, walls, fences, or the building itself. Also, paved areas and terraces on the south side of the building can be utilised. Additionally, shade or shading devices from the south and west sides of the structure can be removed when they block sunlight during the cooler months.

On the other hand, the site can be made cooler by the extensive use of shade-trees as an overhead canopy and the utilization of vines, either on an overhead trellis or canopy, or on the south- and west-facing walls. Also, applying overhangs, trellises, arbours or canopies where possible makes the area cooler during daytime and yet warmer at night, as these limit the release of radiation to the cool night sky. In addition, the use of ground cover on earth surfaces rather than pavement; the use of sprinklers, fountains and pools; and locating the activities downwind of these elements can provide for evaporative cooling. Moreover, the removal of windbreaks, which limit airflow of prevailing breezes during the warmer months, can also contribute to the cooling requirements of the site.

If the standing water is allowed to remain on the site and drainage is limited to the minimum, the humidity of the site can be increased. Also, the increase of overhead planting can slow evaporation and add moisture through transpiration from plants. Additionally, the use of ground cover on all surfaces where possible, rather than paving, and adding fountains, pools, sprinklers and waterfalls can increase moisture in air (Robinette, 1972).

3.4.2 Urban Canyon Layout

The configuration of an urban area has an impact on its internal climate. Oke (1981) has demonstrated that urban geometry and the thermal properties of a building's form have more influence on the magnitude of the urban heat island than wind behaviour or population density. A variety of factors contribute to the settlement's configuration, such as the horizontal skyline and its vertical cross section; the relative height of buildings in relation to each other; open or undeveloped spaces within the city and their relation to the adjacent structures, etc. Urban morphology has a varying effect on gaining solar radiation through urban canyons. This is a function of building shape, plan arrangement, plan area density, orientation, the latitude of the site and other details of the building facades. Street geometry, and its distribution within the city, plays a fundamental role in generating the pattern of street surface temperature. The city configuration can support pollution, ventilation, wind velocity, inversion and thermal load, as well as influencing the condition of vegetation and determining the solar radiation within the city. Dense configuration in any built-up area gains temperature slowly in the morning and loses it very slowly in the evening.

Unvarying city morphology allows greater radiation absorption through roofs simply because higher buildings do not block it. Tall buildings, scattered within the urban structure of the city, will divert winds and can create turbulence. Air above the city has free movement compared with air within the city itself. A high-rise building standing alone among many lower buildings can cause air diversion downward and can promote ventilation of nearby streets. Site layout has an enormous impact on the viability of passive solar heating in buildings, as tall obstructions can block low winter sun. The cooling process within the central part of the city moves more slowly than in other sections because of the density of the structures and the increased human and motor vehicle activities. The heated air created in the central part of the city will be rising and will cause air to move in from the peripheral streets. Large open space covered by asphalt generates an upward movement of heated air and causes air turbulence.

3.4.3 Air Flow Patterns

The effectiveness of natural ventilation and its ability to ensure indoor air quality and passive cooling in buildings depends greatly on the design process. The height of buildings is the most important factor in determining the wind pattern over a built-up urban area and this, in association with the distance separating buildings, characterises urban ventilation conditions. These parameters also affect the solar exposure of buildings. Buildings can modify the existing wind pattern, as they present greater roughness to wind flow than an open area (Figure 3.1). The airflow around and over buildings reaches a lower average air speed but has higher turbulence due to friction on them. The variation of wind speeds inside an urban area depends on wind direction and speed, the urban layout, and the height of buildings.

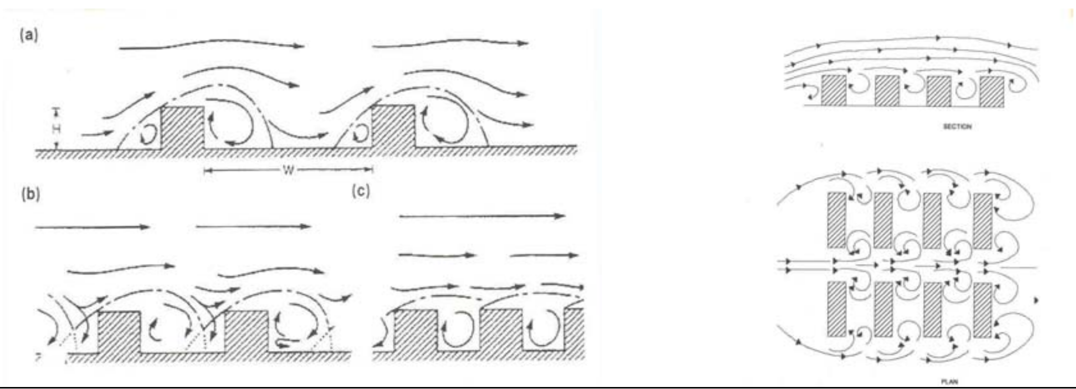


Figure 3.1: Air Flow Patterns Associated within Building Arrays of Different Configurations (Santamouris et al., 1996)

As the wind blows against the building, it is diverted from its original direction and zones of positive and negative pressure are created around the building. The pressure on the façade facing the wind (windward side) exceeds the atmospheric pressure on the facade (pressure zone) and the pressure on the leeward sides is reduced (suction zone). This pressure difference drives airflow around and through the building, as the air flows from regions of higher pressure to those of lower pressure. In the case of buildings perpendicular to the prevailing winds, the front façade is subjected to positive pressure and all other sides are under negative pressure. Long rows of high, long buildings of the same height, which are perpendicular to the prevailing wind direction, block the wind in the first row and divert it upwards, creating weak ventilation conditions both along the streets and inside the buildings in the row behind.

Individual tall buildings, rising higher than the neighbouring ones, disturb the wind pattern of the area and create strong wind currents. The height of such tall buildings mainly determines the flow diverted on the sides of the building, while its width affects the flow pattern behind it. An increase in the width of the windward surface results in the diversion of a larger air volume around the building. The highest wind speed is experienced in front of the windward façade and the lowest speed behind and between tall buildings. The shape of the windward wall can modify the flow pattern, as a convex wall disperses the flow around the building and a concave wall concentrates the flow along this wall and therefore increases the turbulence. A row of buildings of different heights with their facades oblique to the wind direction, improves ventilation conditions both on an urban scale and inside the buildings (Santamouris et al., 1996). Also, an optimum street layout, which can provide good ventilation conditions to pedestrians in the streets and to buildings along the street, is one with wide main avenues oriented at an oblique angle to the prevailing winds. In this way, wind can blow through the urban structure. In addition, buildings along such avenues are exposed to differential air pressure between the front and back facades, providing, in this way, potential for natural ventilation.

In very dense urban areas, spaces with higher ventilation requirements should be put on the highest floors, where wind flow is stronger and less turbulent, rather than near the ground. Narrow passageways, corners of buildings too close together, and arcades that go from one side of the building to the other, should be avoided in order not to expose pedestrians to gusty acceleration of airflow due to the Venturi effect. When the density and configuration of the surrounding buildings do not allow for suitable wind exposure, the building should be designed to be high enough to prevail over the wind sheltering obstructions, subject to considerations related to other requirements and building regulations (Allard, 1998). Santamouris et al. (1996) stated that if the buildings are of variable heights, even a highly dense urban area may have better ventilation conditions than an area of lower urban density with buildings of the same height.

3.4.4 Orientation (Buildings/Street layout)

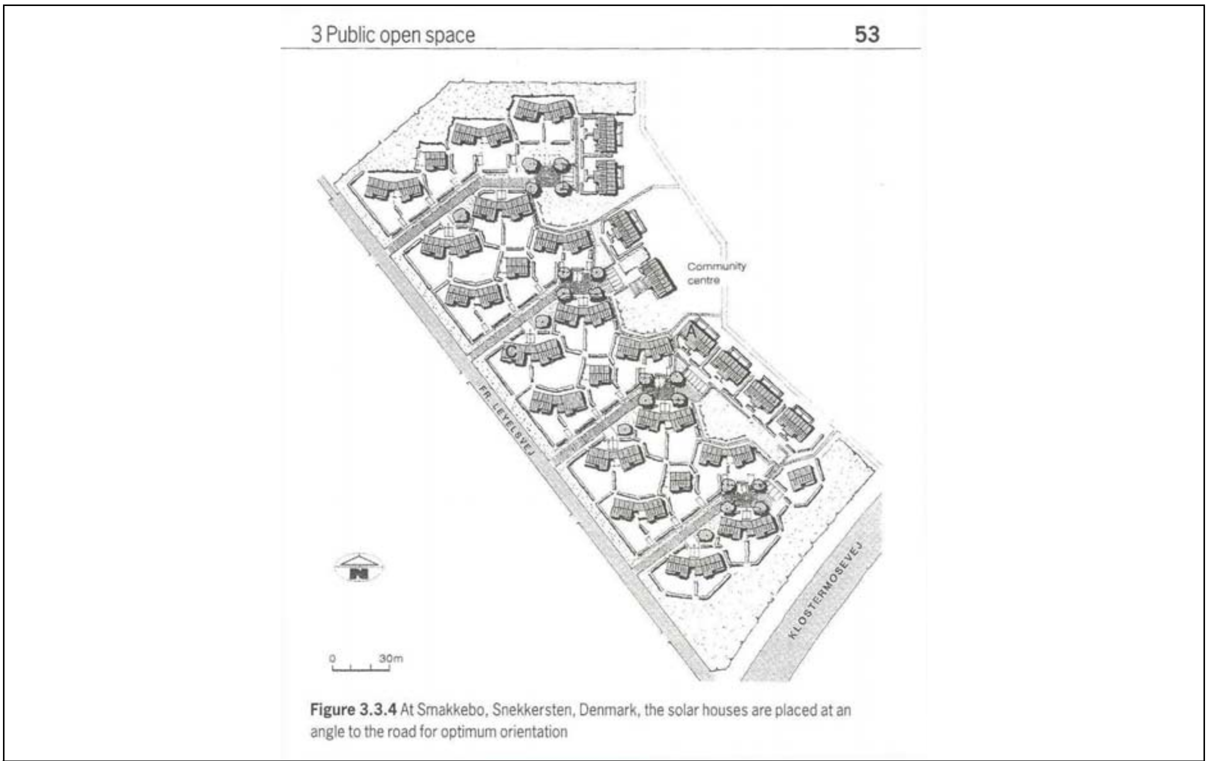


Figure 3.2: Solar Houses are Placed at An Angle to the Road for Optimum Orientation (Littlefair, 2000)

The orientation and width of streets affect urban ventilation conditions, as well as the solar exposure of buildings. They are of greater importance in dense urban areas. At the urban scale, it is easier to control site orientation than building orientation without influencing too much the individual design choices. If design guidelines are to be effective in terms of reducing the cooling needs, they must ensure that buildings and not just sites are oriented properly (Figure 3.2). Then a south-facing slope is preferable to a north-facing one. Also, taller buildings have to be located to the north of the site with the low-rise buildings to the south, but care must be taken not to overshadow the neighbouring property. Additionally, the low-density housing (semi-detached and detached) can be located at the southern end of a site, with the terraced housing to the north. Opening courtyards to the southern half of the sky can be beneficial (Littlefair, 2000).

The location of a building should be at a distance from other buildings that is greater than the depth of their wake so that they will not shelter it from summer wind. The building should be also positioned with its longitudinal axis perpendicular to the prevalent summer wind direction in order to catch the streamline flow. If the prevailing winter wind direction is different from the summer one, as is usually the case, it is possible to optimise the location of the building in order to obtain a good summer wind exposure while protecting the building from the cold winter winds. In the vicinity of the sea, a lake or a larger river, a building should be positioned close to the shore, with the longitudinal axis parallel to the line of the coast or the bank in order to make use of day water and night land breezes.

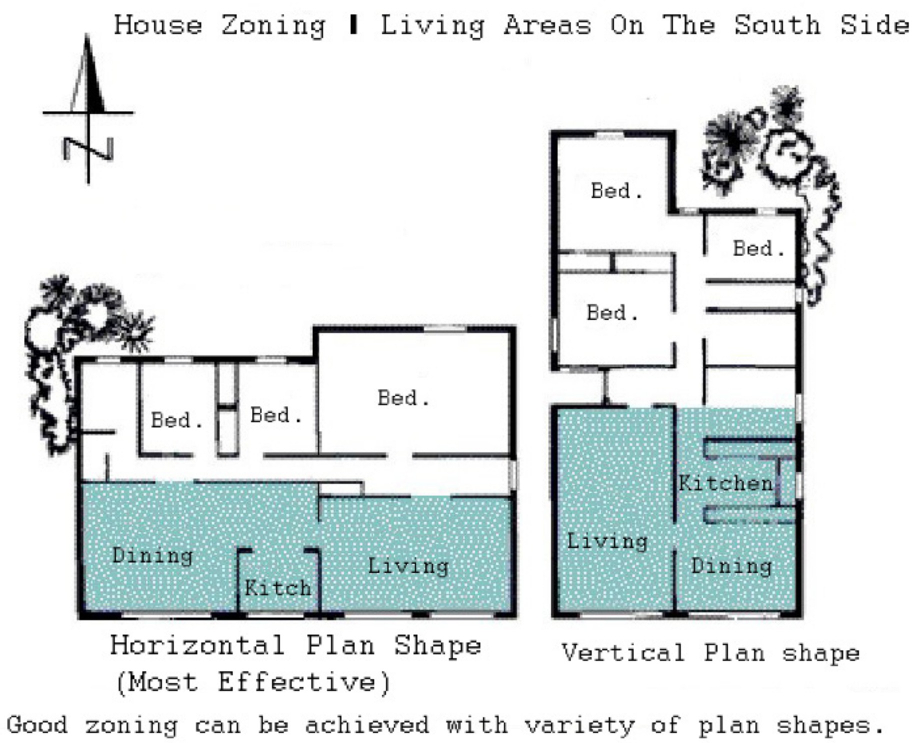


Figure 3.3: Principal South-Facing Facades of Buildings Offer Better Living Conditions (Murdoch University, 2001)

In the northern hemisphere, most of the windows face the south (Figure 3.3) (in the southern hemisphere most windows face north). This can be generalised by referring to equator-facing glazing. Generally, the building plan with a long east-west axis and optimised equator-facing walls will provide the best passive solar performance. The plan of new developments should be arranged to have a predominance of north- or South-facing blocks. Hence, streets in the subdivision can be oriented to run east-west, so that the lots in the subdivision will be able to use a north-south orientation to allow maximum solar access. The orientation of the urban area with respect to solar radiation determines the degree of heat gain and heat loss and light, especially when there are sloping locations

(Golany, 1983). The maximum use of south- and east-facing slopes will permit the utilization of natural solar exposure.

In climates where shading is of major importance, narrow streets ensure the shading of buildings during summer and the reduction of solar exposure of buildings along the streets. Appropriate street orientation relative to building forms can also promote the shading of streets, as well as promoting air movement through the channelling effect (the Venturi effect) and turbulent airflow (Salleh, 1994). Santamouris et al. (1996) indicated that in southern latitudes, effective shading of south-facing buildings can be provided with a street width of around a fifth of the height of the building on the opposite side of the street. On the other hand, for west-facing buildings, the separation distance can increase to about 1.5 to 2 times the height of the building that provides the shade.

3.4.5 External Shading

Shading is important in the reduction of over heating and the reduction of glare from window. The interface of solar radiation by building is the source of maximum heat gain inside the building space. The natural way to cool a building is to minimise the incidents of solar heat. Shading is essential for daytime use of outdoor living spaces. Also, the treatment of the exposed surfaces is important. If an elevation is properly protected or equipped with shading devices, radiation in the overheated period can be less than in the underheated period (Olgyay, 1992). Vertical elements, walls and the building itself provide shade only in the morning and late afternoon hours. Horizontal elements, such as loggias, verandas, awnings and louvers may be used more effectively (Figure 3.4).

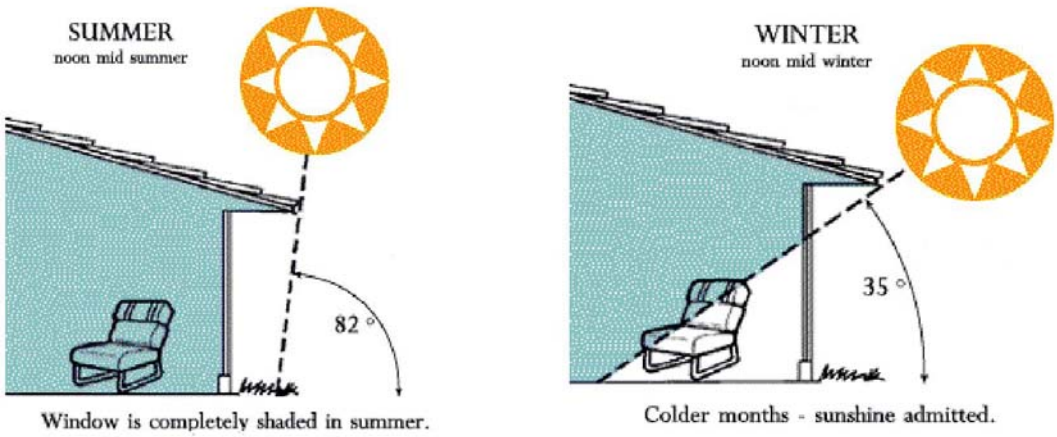


Figure 3.4: The Efficiency of Horizontal Shading Devices (Murdoch University, 2001)

Planting offers the most pleasant shade, as it reduces the contrast between bright light and solid shadow with its soft half-lights. Pergolas can be equipped with innovative technology to enhance their function, namely by having planter boxes carrying “aerial plants” forming the shade, while also being provided with micronizers that produce water mists for evaporative cooling (Salleh, 1994). Shading of spaces against direct solar radiation is critical in hot environments. Appropriate combinations of building height and street width can create shading of street spaces from direct solar radiation. Narrow streets increase shading and keep direct sunlight out for most of the day. In addition, narrow streets tend to assist better air movement due to channelling, as well as “Venturi effects” and turbulence. A narrow alley of north-south orientation would obviously receive less direct sun except during the short period at noon. It would thus be rather cool. Tensile structures are the most familiar forms of shade for large expanses of outdoor areas.

In arid zones, facade protection from direct solar radiation produces an important reduction of the absorbed solar energy. Then a shaded facade will have only to withstand diffuse and reflected radiation. Diffuse radiation is not significant, due to the local sky conditions, and reflected radiation, depending on the surrounding environment, can be reduced with the careful use of vegetation, water, colour and surface texture (Belakehal et al., 2000). The typical building form is usually composed of an outer wall surrounding the building, which has an interior atrium and an external garden. The internal and external spaces have different kinds of shadow and ensure comfort at different times of the day. The interior atrium acts as a source of light for rooms that surround it. In addition, it provides indirect exposure during the hottest hours of the day when the family rests inside. The atrium also acts as a vertical passage and carries a constant flow of warm air upward, while cool air enters to create comfortable adjoining living areas. During summer, the external garden is a comfortable place only in the morning and evening. At that time the temperature is low enough to allow activity outside where the trees provide shadow and where lower shrubs can channel cool breeze (Golany, 1983). Also, it can be advantageous to shade the floor of the yard during the day, but leaving it exposed to the zenith sky at night without restricting outgoing radiation.

3.4.6 Landscaping Requirements

Landscaping has an important role in controlling air movement around buildings so that optimum natural ventilation can be achieved. The type and layout of vegetation to be included in a site should be selected with the airflow pattern taken into account, as well as the aesthetic and environmental considerations. The main roles of vegetation, as far as air movement is concerned, are wind sheltering; wind deflection; funnelling and acceleration of air; and air conditioning. Areas around a building should be designed to reduce undesirable airflow, as in winter, and to create suction zones for outlet openings. Trees and planting can also be used appropriately to redirect wind for safer conditions or useful purposes.

Rows of trees and hedges can be placed to direct air towards or away from the building. Vegetation can create areas of higher wind velocities by deflecting wind or funnelling air through a narrow passage (the Venturi effect). Reducing the spacing between trees used to funnel air can increase airflow up to 25 % above that of the upwind velocity. If a protected area is desired, it is preferable that the landscaping is designed to allow for reduced air velocities without large-scale turbulence. To achieve this, windbreaks should be at least 35% porous. A windbreak is most effective when the building to be sheltered is located within a distance up to 5 times the height of the windbreak.

Vegetation can create natural shelter from winds while providing shade in summer. Similarly, vegetation can be used to cover building surfaces in order to provide cool. This can be in the form of creeper plants for vertical surfaces and roof gardens for horizontal surfaces. Creepers will give the best value, producing larger green areas to look at, offering an overhead cover, and a pleasant dappled shade. Pedestrians should be protected from solar exposure by the provision of trees planted along the streets and special building features like awnings, overhanging roofs, colonnades, etc. Proper planning of road patterns to make possible less paving, shorter sewer and power lines, and less outside lighting can result in less expenditure for embodied energy, as well as lower infrastructure costs.

The trees within the arid urban space can improve the ambient air temperature because vegetation absorbs radiation and converts it to chemical energy through the photosynthetic process. The heat content of the ambient air crossing a vegetation barrier decreases through the effect of shading and transpiration. At the same time, air humidity increases and the process produces an air-cooling effect. Moreover, vegetation reduces noise, removes dust particles, absorbs carbon dioxide and introduces oxygen into the air (Allard, 1998). Evergreen trees, shrubs, cacti, creepers and a few types of grass can be utilized. This is more feasible in enclosed spaces than in open areas. Even potted plants can play a role. This is restricted by the availability of water. Large water bodies within or at the margin of urban areas can offer lower temperatures. Water fountains, cascades and sprays can help to cool the urban air. The smallest pond, basin or fountain adds a sense of wellbeing to the occupants. The physical effect of evaporative cooling is quite significant in enclosed out-door space but the psychological effect is far greater.

Urban areas are known to have a substantially higher temperature than the countryside (the "heat island" effect). Parks can be used to weaken heat island effects, as the cool air from parks is circulated to warmer areas of the city, thus helping to moderate air temperature. One way to reduce the thermal discomfort in urban areas is to minimize radiating surfaces with shading. Trees, arcades, etc. could be used for this purpose. Shade of trees can provide both evapotranspiration as well as shading for ground surfaces. It is also important for ecological balance. Planting of appropriate shade-trees can substantially reduce environmental thermal stress and provide occasional resting-places. Planting with appropriate foliage in open parking areas can pleasantly contrast paved areas and reduce the undesirable effect of open hard surfaces.

Materials used in construction impact the thermal performance of buildings as their proprieties (such as absorption, reflectance, specific heat and conductance) are different. Highly absorptive surfaces must reach a point of thermal saturation before they begin radiate into canyon. Materials with high specific heat have the ability to store heat during the day and then start to radiate it at night for a longer time than other materials with low specific heat. Also, the materials of a building's skin play a decisive part in controlling and utilising solar rays. It is well known that light colours reflect the impact of the sun and dark colours absorb it. Albedo (the reflectivity of urban surfaces) modification can improve the reduction of cooling loads in cities in hot climate. Lighter coloured and drier materials tend to have higher albedo than dark coloured and moist materials. White external finishes can reduce solar radiation impact on building surfaces.

3.5 Energy-Saving Techniques in Urban Form Design

Energy-saving techniques that can be applied in a given building include two main categories. The first category is related to the conservation of energy through the application of thermal insulation in the external building surfaces and interventions in the building's mechanical system. The second category includes design guidelines for passive solar heating and for natural cooling and lighting. The second category of techniques requires some special arrangements, such as a south orientation for the main façade, the avoidance of shading by adjacent buildings, etc. The implementation of energy-saving strategies in all building categories in an urban environment demands careful management.

The current condition of the urban fabric of cities has frequently taken place with chaotic expansion, without taking into account the principles of energy-conscious design on an urban scale. The layout of the road network affects locating buildings on either side of the road, giving them an orientation that, in some cases, is not suitable for the implementation of solar and energy-saving techniques. Also, overshadowing caused by adjacent buildings in densely built urban centres prevents access to direct sunlight in living spaces. Moreover, building regulations in most cases determine the dimensions of the building and thus its geometrical form and its position on the plot. These factors usually have a negative effect on the design and construction of urban buildings of low-energy consumption. Santamouris (2001a) pointed out that, in spite of all the negative aspects of the urban environment, there are still many possibilities for energy-saving intervention related to the site layout and the design of the building.

3.5.1 Goals of Urban Form Design

Since the energy efficiency of a building is affected by a number of different environmental factors, such as air temperature, solar radiation and wind speed, the mapping process must take into account the combined effect of these factors. Passive design covers a range of issues including the provision of daylight and passive cooling. However, site layout has the biggest impact on passive solar heating. Passive solar design has been mainly concerned in the use of rural or suburban sites. To make a major impact in the future, passive solar design has to move into the city, as rural areas are now increasingly scarce. New development may restrict solar gain to existing buildings nearby. The safeguarding of existing buildings, in particular the special requirements of buildings which rely on solar energy, becomes more important.

3.5.2 Criterion of Optimum Form

Volume can be related to the thermal capacity of the form (the ability to store heat) while exposed surface area is related to the rate at which the building gains or loses heat. Thus, the ratio of volume to the exposed surface area is generally used as an indicator of the speed at which the building will heat up during the day and cool down at night. A high volume-to-surface ratio in buildings offers a small exposed surface for controlling both heat losses and gains. Simplifying the building geometry and reducing the surface area of the building can reduce energy consumption (BG, 1995). Although the ratio of volume to surface can provide some indication of the thermal efficiency of the building, it does not consider either the thermal characteristics of the building fabric or the effects of solar gains, which can be determinants of the building's thermal performance (Santamouris et al., 1996). It is widely believed that a square building has the best characteristics of preserving heat in winter and remaining cool in summer. This belief is based on the fact that a square building combines the largest volume with the smallest external surface. A compact building form, such as a cuboid, will result in the minimum surface area and thus the minimum fabric heat loss. However, this form does not necessarily provide optimum solar access to the building.

Passive solar buildings tend to be well insulated and have reduced air leakage rates to preserve the solar heat within the building envelope. Adopting such energy-saving measures allows more architectural freedom in the choice of the building's form. With good insulation levels, variations away from the compact cuboid form only result in a small increase of fabric heat loss. For example, fabric heat loss will only increase by about 1.5 % when moving to a plan: aspect ratio of 1:2. Thus, with such a form the designer will have more possibilities to introduce solar gain without a significant increase in heat loss (Pitts, 1989).

It can be taken as a rule that the optimum shape is the one that loses least heat during winter and receives the least amount of radiation during summer. Olgyay (1992) carried out calculations based on yearly thermal performance and showed that the assumption that the square form is the optimum one is not the case for all climates. An elongated form, somewhere along the east-west direction, can perform better. A square form performs better in old massive traditional structures with small openings where, because of the relatively small window openings, the radiation effect is negligible. With large contemporary openings, this concept becomes invalid and the thermal impacts on the interior of the building should be calculated on a quantitative basis. The model which was suggested by Olgyay consists of the usual insulated construction with 40% glass on the south side and with 20% glass surfaces on all other sides. Other types will behave more or less similarly. As a reference for comparison, a 1000 square foot house with equal sides was computed. Only the heat impacts through the four sides were calculated, as the impact through a horizontal roof remains constant regardless of the form. The results for the house with a square plan was compared with houses of the same construction, characteristics and same square-foot area, but with a different form.

"The optimum shape was defined as the one which has minimum heat gain in summer and minimum heat loss in winter" (Olgyay, 1992). When applying this criterion to define the most desirable form of house in a given environment, it can be observed that the square house is not the optimum form in any location.

At the lower latitudes, an elongated form to minimise east and west exposure is a demanding necessity. This form gradually altered to a ratio of 1: 1 (cylindrical) at the higher latitudes (Figure 3.5). This is a direct response to the varying solar angle in the various latitudes. In general, the optimum form in every case is the one elongated somewhere along the east-west direction. Shapes elongated on the north-south axis work both in winter and summer with less efficiency than the square one. Buildings with relatively small window openings, or in full shade, will show less need for elongation (Olgyay, 1992).

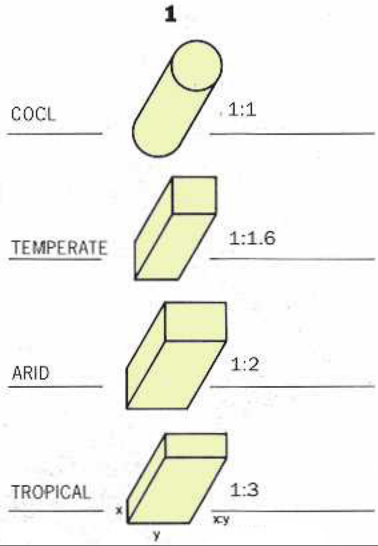


Figure 3.5: The Preferred Length of the Sides of the Building for Each Climatic Zone (HKU, 2001)

On the other hand, the volume effect can alleviate the over-all thermal pressures. While, in houses, the vast majority of cooling load is due to weather factors, in large buildings the influence of the same effects is relatively smaller. In such cases, form and orientation are of secondary importance. In larger buildings, other factors play a more important role in forming the structure, such as the logic of circulation, the overall need for space, and the economy of the structure.

"In the cool zone, the low winter temperature overrules the sun's effort to elongate the structure in the east-west direction, and presses it into a nearly square shape" (Olgyay, 1992). In this zone, elongated unilateral buildings are not advantageous. Closed compact forms, such as "point houses" or bilateral (back to back) buildings, are more desirable because of their relatively dense cubic structure. The environmental pressure favours higher buildings in this region.

In temperate zones there is the least necessity for any specific direction. The smallest penalty is received from this climate, allowing considerable freedom in building form. However, shapes on the east-west axis are preferable. In a temperate region, temperature range permits more flexible plans, such as cross-shaped or freeform buildings; however, an east-west elongation is preferable. In this zone, thermal stresses, even on buildings extending in the north-south direction, produce fewer disadvantages than in the other zones.

The typical structure in a hot arid zone is usually extended on an east-west axis thereby reducing morning and afternoon heat impacts on the two end walls in summer, when avoiding the sun's rays is desirable. Moreover, the structure receives the maximum amount of southern sun in winter when its heat is welcomed (Olgyay, 1992). Buildings are constructed with minimum openings so that the amount of direct sunlight entering the structure can be controlled. In desert regions, indirect lighting is more preferable than direct exposure (Golany, 1983).

Although winter conditions in hot, arid regions would permit more elongated house design, heat stress in summer is so severe that a compromise is required and the traditional solution is a compact, inward-looking building with an interior courtyard. By cutting out part of the form and filling the hole with shade and cooled air (evaporative cooling, trees, pool, fountain effect) a better microclimate is created. Courtyards have been a traditional feature of hot-dry climatic design. Space surrounded on all four sides by tall walls, forming a small courtyard, can effectively block direct sunlight. Thus the courtyard becomes an excellent cooling device that can promote drafts and cross ventilation through adjacent rooms (Salleh, 1994).

In a hot humid region, the sun attacks the east and west sides of the building and forces it into a slender, elongated structure. The temperature is not excessive, and such shape can be used beneficially for wind effects. In this zone, buildings freely elongated in the east-west direction are advantageous. Buildings located on the north-south axis receive a greater penalty than they would in other climatic zones (Olgyay, 1992). In hot humid climates, where ventilation is desired, buildings should maximise the area of exposed surfaces. Free plans can also be applied here, as long as the house is under protective shade.

3.5.3 Solar Orientation

The amount of solar radiation varies depending on the time of day and the season. Muneer (1997) reported that, according to the Bouguer-Lambert law, "the attenuation of light through a medium is proportional to the distance traversed in the medium and the local flux of radiation". In general, more solar radiation is present at midday than during either the early morning or late afternoon. This is because sun is positioned high in the sky at midday and the path of the sun's rays through the earth's atmosphere is shortened. Consequently, less solar radiation is scattered or absorbed, and more solar radiation reaches the earth's surface. When the sun is closer to the horizon, direct beam radiation passes through a longer distance in the earth's atmosphere than when the sun is high in the sky (Figure 3.6). This longer path length results in both more scattering and more absorption of solar radiation.

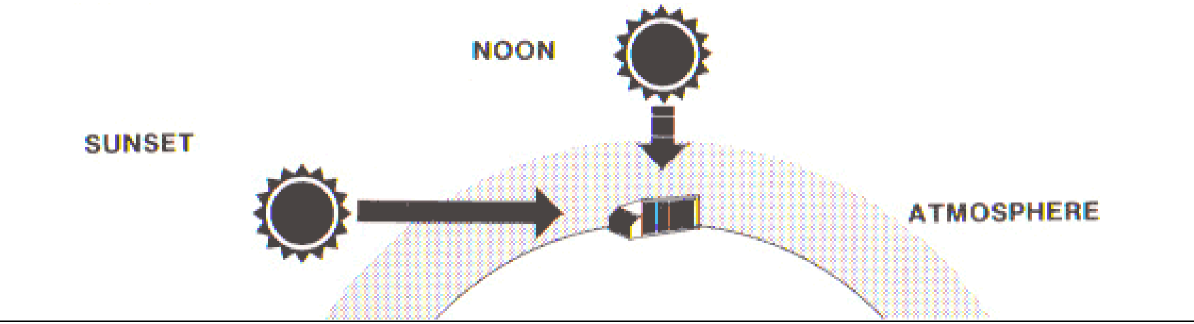


Figure 3.6: The Amount of Solar Energy Reaching the Earth's Surface is determined by the amount of atmosphere through which it must pass (AZSC, 2001)

In the northern hemisphere, south-facing surfaces also receive more solar radiation at midday, as the sun's rays are nearly perpendicular to the collector surface. In the northern hemisphere, more solar radiation during summer than winter can be expected because there are more daylight hours. This is more noticeable at higher latitudes. The total or global solar radiation striking a surface has two components: "The scattered radiation is called diffuse radiation, while the part which arrives at the surface of the earth directly from the sun is called direct or beam radiation" (Muneer, 1997). For sunny days with clear skies, most solar radiation is direct beam radiation, while in overcast days, clouds obscure the sun and the direct beam radiation can be reduced to a zero value (RRDC, 2002).

Air temperature and solar radiation act together to generate one sensation of heat in the human body. Thus, the thermal impacts of the sun's rays must be considered in combination with heat convection and the total effect has to be measured by the capability to maintain temperature levels near the "comfort zone" (Olgyay, 1992). If radiation is received in the afternoon (as in the case of orientation toward the west) the temperature peak and the radiation peak are added together. This produces a greater heat impact in the afternoon compared with the low temperature in the forenoon.

3.5.3.1 Criterion of Optimum Orientation

Many plants (for example the common sunflower) are phototropic and the adaptation of certain plant life to thermal stresses can be observed in many cases. Sometimes the leaves of the plant may turn as much as 270^0 to follow the sun. Conversely, some plants orient their leaves parallel to sunrays to reduce the impact of radiation (Olgyay, 1992). The sun's movement was investigated in Egypt, and temples and tombs from many periods were found to be accurately aligned, either with the cardinal directions, or their subdivisions.

Building orientation is usually affected by many factors, such as the local topography, privacy requirements, the reduction of noise, and the climatic factors of wind and solar radiation. As far as the impact of the sun's heat is concerned, the building orientation is affected by quantities of solar radiation falling on different sides at different times. The utilization of the sun's heat varies according to regions and seasons. Under cold conditions, its additional radiation will be welcomed and the building should be positioned to receive as much radiation as possible, while under the condition of excessive heat, the orientation of the same building should avoid undesirable solar radiation. An optimum building orientation would offer maximum radiation in the underheated period, while reducing it to the minimum in the overheated period.

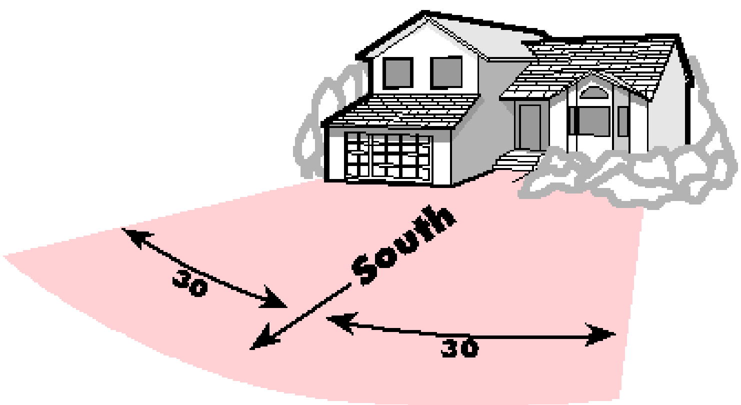


Figure 3.7: Passive Solar Orientation of Buildings (Oikos, 2002)

It is necessary to position the building so as to take the best advantage of sun value for thermal effect, hygiene and its psychological benefits. A building's orientation determines the solar exposure of the building, which should be maximised during winter and minimised in summer. " As far as a single building is concerned, it is known that a building with its longer axis oriented east-west gets most sun in winter and least sun in summer" (Koenigsberger, 1974). This passive solar orientation places the building on the site so that it gains maximum advantage of the sun's natural heat (Figure 3.7). By facing the long side of the building to the south and the short sides to the east and west, the building will capture maximum solar heat in the winter and minimise solar gain in summer (Figures 3.8 and 3.9). Although it is preferable to face the building directly into the sun, it can be oriented up to 30 degrees away from due south and lose only few percent of the potential savings (Oikos, 2002).

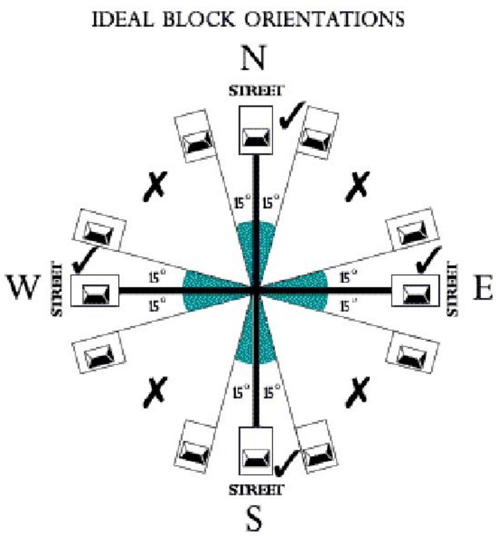


Figure 3.8: The Orientation of Buildings Versus the Orientation of Roads (Murdoch University, 2001)

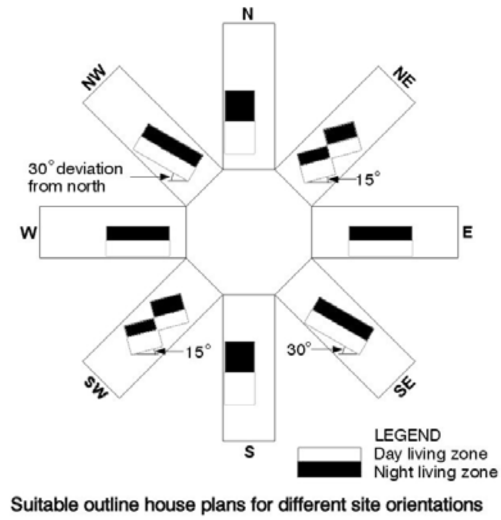


Figure 3.9: Suitable Outline House Plans for Different Site Orientations (CBM, 2001)

Building orientation usually follows the orientation of roads by positioning the main façade to face the main road. As the southern side of the building is the one that can be easily shaded during summer and is the most advantageous one for solar heat collection during winter, buildings on an east-west road are the best for both summer cooling and winter heating needs.

Olgyay (1992) reported that the calculations on sun intensities conducted by Felix Marboutin indicated that the principal south-facing façades of buildings offer better living conditions, i.e. warmer in winter, cooler in summer (Figure 3.10). Facades facing southeast and southwest are colder in winter and warmer in summer than facades facing the south. East and west exposures are warmer in summer and colder in winter than the south, southeast, and southwest exposures.

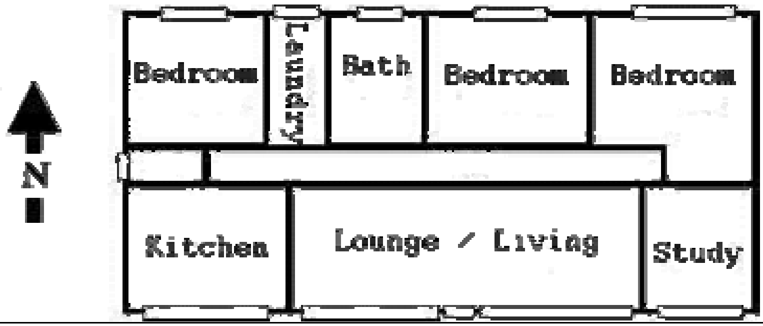


Figure 3.10: Principal South-Facing Facades of Buildings (Mr Solar, 2001)

Olgyay (1992) indicated that Bardet found that the south is the preferred orientation. However, he allows variations up to 30^0 to the southeast and southwest. He also mentioned Hilberseimer's conclusion that east and west orientations are the least advantageous, that southeast and southwest are reasonably satisfactory, and that south is the most advantageous. This certainly produces the greatest amount of radiation at the winter solstice and the least amount of insolation at the summer solstice.

However, sometimes the living areas of building face orientations other than the optimum zone. This mainly occurs if a building is not of the unilateral type and the living areas are distributed in different directions, such as the bilateral type, where the living areas are located in opposite directions. This can be a back-to-back arrangement of residential units or a building in which the two sides belong to the same apartment. Thus, it can be stated that two buildings with the same shape but with different arrangements of living spaces and glass surfaces will require different orientations to utilise the sun's impact in the best possible way. This mainly depends on the individual design and the distribution of living spaces inside the buildings. Therefore, in architectural practice, careful consideration will be necessary to find the most advantageous orientation conditions for each individual design (Olgyay, 1992).

Olgyay (1992) pointed out that the south side of the building receives approximately twice as much radiation in the winter as in summer in the upper latitudes. This condition is even more obvious at the lower latitudes, where the ratio is about one to four. Also, in the upper latitudes, the east and west sides receive about 2.5 times more radiation in summer than in winter. In summer, these sides can receive two to three times as much radiation as the south elevation. On the west side, the afternoon radiation effects maximise high temperature impacts. In all latitudes the north side receives only a small amount of radiation, and this comes mainly in the summer. However, in low latitudes the north side receives in summer nearly twice the impact of the south side. The amount of radiation received on an horizontal roof surface in summertime exceeds all other sides. The roof heat-impact requires special attention, as its area sometimes equals all wall surfaces of the house added together.

3.5.4 Wind Effects and Air Flow Patterns

The irregular distribution of the sun's heat on the earth's surface generates variations in density in the atmospheric mass. The rising air of the equatorial zone descends around the 30^{0} latitudes to be moved toward the south and the north where it combines with the cold polar flow. This flow system, set in motion by the earth's rotation, is complicated by the earth's inclination, resulting in seasonal variations. Geographical features provide individual characteristics to the prevailing winds and accordingly, a careful wind analysis is required.

3.5.4.1 Criterion of Optimum Orientation

Fathi (1973) pointed out that the orientation of the building would be determined partly by sun and partly by wind. It is well known that the best orientation for the sun would be with the long axis of the building lying east-west. However, it is also necessary to utilise wind that will penetrate through the building and cool it. Fathi mentioned the architectural practice of some architects who compromise between the two aspects (wind and sun). As the prevailing wind in the region of Egypt comes from the northwest so, ideally, the house should be northeast to southwest perpendicular to the wind direction. A compromise can be effected by bisecting the angle between the two indicated orientations and setting the house east north-east to west south-west. Fathi also indicated that the use of the wind-catchers can free designers from the need to orientate the building for the wind and they could mainly consider the solar orientation (Fathi, 1973).

Air movements should be avoided during the cold season. Conversely, desirable air movements should be utilised for cooling in hot periods and as a relief from vapour pressure in zones of high humidity. In hot climate zones, ventilation has particular importance as a relief against high temperatures and humidity. Town layouts on the shores of some Mediterranean cities show street arrangements which bring the coolness of the sea breezes into the centre of the city (Figure 3.11). The use of light latticework in some areas allows the slightest breeze to bring refreshment into the structure and protect it from the sun's heat at the same time. The Egyptian close-packed houses use roof ventilators, the "Malguf," to catch airflow.

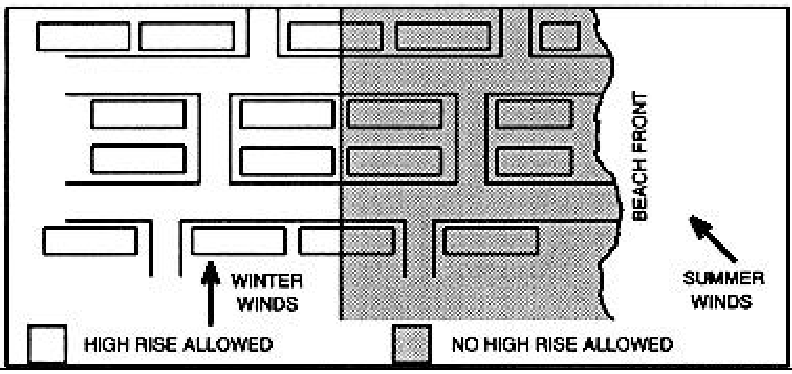


Figure 3.11: Town Layouts on the Shore Bring Breezes into the City (CBM, 2001)

In places exposed to wind, the least exposure is the usual principle and sheltered locations are preferable. Allard (1998) pointed out that the actual dimensions of the building are relatively insignificant, as the proportions of the building determine the size and character of the air movement pattern. The shape and dimensions of a wake depend on the form and orientation of the building that generates it. In low buildings, the adaptation for wind orientation is not critical, as the use of windbreaks, landscape elements, and the arrangement of openings in the high and low-pressure areas can help to improve the airflow situation. On the other hand, for high buildings, where the surrounding landscape has a smaller effect on the upper storeys, careful consideration has to be given to wind orientation.

3.5.4.2 Wind Breaks

Wind protection can be provided by windbreaks and the positioning of buildings. In addition, they can provide shadow and an aesthetic value. The significance of windbreaks lies also in their ability to reduce wind velocities. This effect brings noticeable changes both in temperature and air humidity. While large air masses cannot be altered in their motion, which is directed by the differences of air pressure, velocities near ground level can be controlled to a certain extent. The nearest surroundings close to low structures have considerable effects on airflow patterns. The resistance and obstructions created by trees and landscape elements result in diversions in the airflow which may be utilised to produce advantageous effects.

Natural ventilation can be utilised by a building’s orientation, air movements produced by pressure differences and air changes caused by differences in temperature. The landscape design elements, including plants, walls and fences can create high and low pressure areas around the buildings. It is evident that large openings, placed opposite each other and positioned at the high and low-pressure areas, will provide better air changes within the structure. This can free the building to a certain extent from rigid orientation requirements. Yearly air movements can be divided into wind and breeze, according to the under-heated and over-heated periods. Arrangements should be made in order not to eliminate the desirable cooling breeze during overheated periods. Landscape elements should also be designed to direct and accelerate beneficial air movements into the building.

A windbreak diverts air currents upward and an area of relative calm is created near the ground. The most protected part of this area is close to the windbreak on the leeward side; it becomes more exposed as the distance from the windbreak increases until air currents again reach full velocity. There is also a smaller calm area on the windward side, especially if the windbreak is dense (Olgyay, 1992).

CHAPTER 4

AN OVERVIEW OF THE PALESTINIAN BUILT ENVIRONMENT

4. An Overview of the Palestinian Built Environment
4.1 Geographical Location

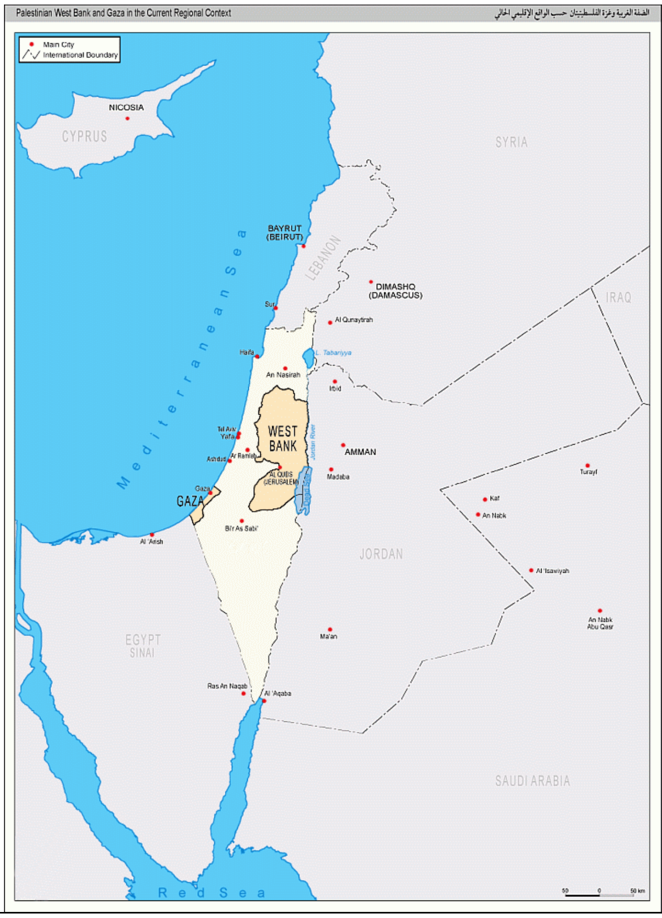


Figure 4.1: General Location of the State of Palestine (ARIJ, 2000)

Palestine can be considered as a focal point of the world's three monotheistic religions. It has a global influence which greatly exceeds its small size. It is a tiny piece of land located at the meeting point between Eurasia and Africa. Plants and animals of the three continents have interacted and spread throughout history. Palestinian land is featured as being part of the first man's home, whose coexisting religious, ethnic and political diversity is echoed in the remarkable range of ecological variation (Figure 4.1 shows the geographical location of Palestine) (ARIJ, 1997).

Palestine was the place where ancient civilizations emerged. It was also a bridge for commercial activities and military incursions across so many different historical eras. In the ancient time, Palestine represented one of the most important trade routes. Palestine is located in the middle of several Arab countries; it is a place that allows for easy travel to other adjacent places. So, it was a bridge or crossing point for people over a long period. It connected the civilizations of the Nile Valley and the Arab peninsula on the one hand and the northern areas in Belad El-Sham (In addition to Palestine, Sham contains Lebanon, Syria and Jordan.) and Iraq on the other. Palestine has always been a passage for trade caravans before and after the coming of Islam. Moreover, the strategic location which Palestine enjoys, allowed it to be a connecting point between the continents of the ancient worlds of Asia, Africa and Europe.

Stations Location	Monthly Mean Air Temperature (Co) By Station Location In The Palestinian Territories 1997											
	January	February	March	April	May	June	July	August	September	October	November	December
Jerusalem	10.2	6.5	8.9	13.2	21	22.3	23.7	22.4	21	20.6	13.5	11.4
Nablus	11.8	8.9	11.3	15.4	22.2	23.5	25.2	23.8	22.5	21.5	16.8	12.4
Jenin	13.3	11	13.4	17.7	23.2	26.3	28.1	26.8	26.7	24.5	19.1	14.6
Tulkarm	14.1	12.2	13	17.4	21.6	25	27.5	26.5	25.4	23.6	19.5	15.2
Maythaloun	10.6	7.8	10.9	14.9	19.8	23.6	26.4	24.6	23.3	20.4	16.7	11.9
Jericho	14.5	12.4	15	20.6	27	29.8	31	30	28.8	25.5	20.5	16
Arroub	9.5	6.9	9.6	14.5	19.2	22.3	23.6	22.6	20	19	14.1	11.1
Hebron	9.3	5.4	7.8	12.2	20.1	21.2	22.6	21.2	19.9	19.4	12.6	10.2
Gaza	15.2	13	15	18.2	21	24.2	26.6	26.3	25	23	20	16.3
Stations Location	Monthly Mean Relative Humidity (%) By Station Location In The Palestinian Territories 1997											
	January	February	March	April	May	June	July	August	September	October	November	December
Jerusalem	65.0	70.0	70.0	50.0	40.0	50.0	50.0	55.0	50.0	50.0	65.0	75.0
Nablus	63.0	65.0	64.0	54.0	42.0	57.0	60.0	66.0	67.0	57.0	64.0	74.0
Jenin	73.0	72.0	68.0	53.0	52.0	59.0	60.0	63.0	63.0	60.0	63.0	72.0
Tulkarm	68.0	75.0	73.0	67.0	73.0	67.0	70.0	71.0	70.0	68.0	68.0	73.0
Maythaloun	70.0	72.0	72.0	65.0	52.0	53.0	52.0	55.0	54.0	55.0	61.0	73.0
Jericho	68.0	65.0	64.0	53.0	43.0	45.0	46.0	53.0	54.0	58.0	64.0	71.0
Hebron	65.0	72.0	70.0	50.0	38.0	51.0	49.0	60.0	52.0	50.0	58.0	70.0
Gaza	65.0	65.0	67.0	60.0	75.0	75.0	47.0	70.0	68.0	70.0	65.0	65.0

Table 4.1: Monthly Mean Air Temperature and Mean Relative Humidity in Palestine (PCBS, 1997)

Palestine lies to the west of the Asian continent (Latitude: 31° 47' N, Longitude: 35° 13' E). The daily average temperatures in the coastal areas are 24 °C and 15 °C in summer and winter respectively. In the hilly areas of the West Bank, temperatures are usually less by 1-3°C than in coastal areas, while it is always higher in the Jordan Valley. Temperatures in the Jordan Valley can rise in summer to 45°C with an annual average of 24°C. Rainfall is limited to winter and spring months, notably between October and April (ARIJ, 1997). The Monthly Mean Air Temperature and Relative Humidity are illustrated in Table 4.1.

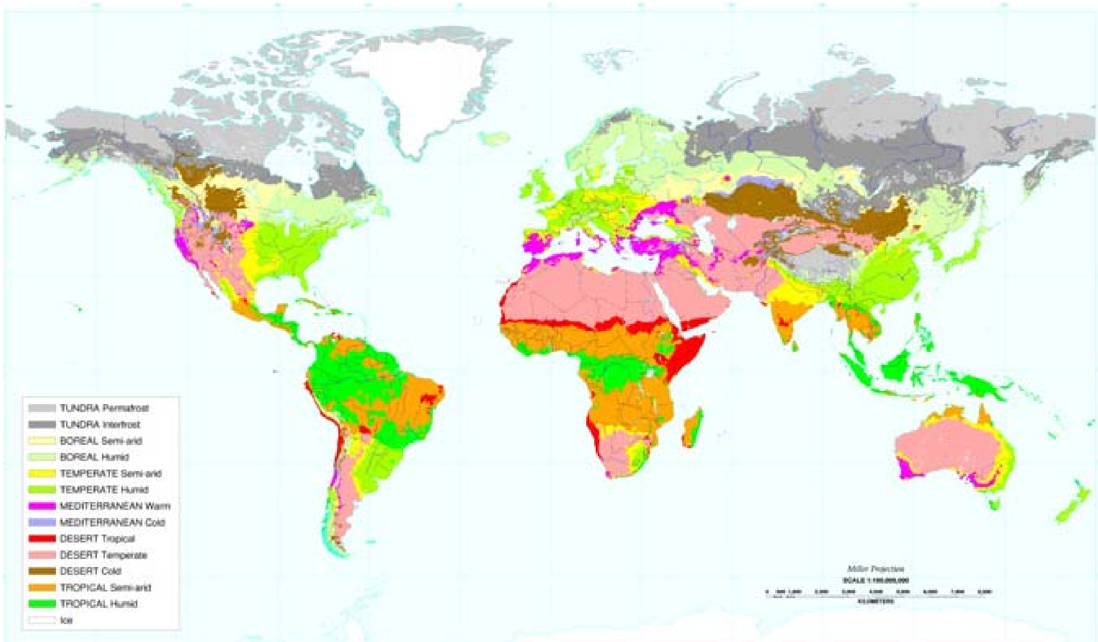


Figure 4.2: World Climate Regions (BPB, 2000)

The Palestinian Territories are located in a transitional climatic zone between the Mediterranean and the arid tropical zones (Figure 4.2). As they are affected by sea and desert, the climate of Palestine fluctuates between the climate of the Mediterranean Sea and the desert climate (Figure 4.3). Although the climate of the sea is prominent, Palestine's climatic conditions vary widely from one place to another. The Palestinian Territories could be divided into three climatic zones: coastal areas, hilly areas and the Jordan valley. The coastal climate (in the Gaza Strip and the north-western part of the West Bank) is hot and humid during summer and mild during winter. In the hilly areas of the West Bank, cold winter conditions and mild summer weather prevail. The climate in the Jordan Valley is hot and dry in summer, and warm and humid during winter.

Figure 4.3: Palestinian Territories (UTA, 2001)

The geography of Palestine comprises the originality of Bedouin life in the south and the style of long settlement in the north. The West Bank and the Gaza Strip are situated between the high rainfall region of Lebanon and the low precipitation region of Egypt. Therefore, there is a wide variation in rainfall according to the location. For example, the central mountainous region has an average rainfall ranging from 400 to 700 mm, while the coastal plains receive about 300 mm of rain annually. The Jordan Valley, which is a semi-arid region, receives an average of about 200 mm rainfall annually (UNCTAD, 1995).

The area of Palestine under the British mandate was 27,000 square kilometres, and the length of its borders, on both land and sea, was 949 km, 719 km of which are land borders and 230 km of which were sea borders. The Palestinian-Jordanian border is the longest land border for Palestine. It was about 360 km long, whereas the length of the border with Egypt was around 210 km, the border with Lebanon was about 79 km and with Syria around 70 km. The Palestinian coast on the Mediterranean was about 224 km, and the length of the coast on the Aqaba Gulf was only 6 km.

4.2 The Regional Elevations

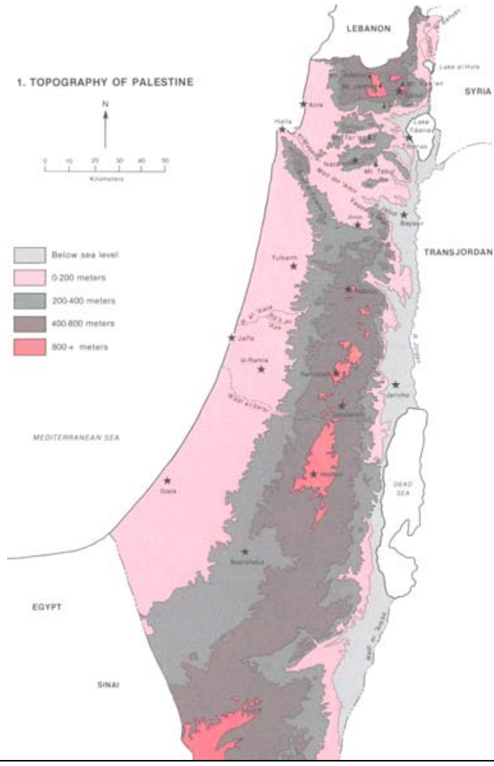


Figure 4.4: Topography of Palestine (Palestine Remembered, 2001)

Palestine is characterized by the simplicity of its geological structure which is composed of various layers of rocky stones of basalt, mud and granite. The shape of the land's surface varies from below sea level depressions and flat plains, which slightly rise above sea level, to the mountain area (Figure 4.4). Despite the fact that Palestine's area is relatively small (27, 000 square kilometres) and its structure is simple, it has the following regional elevations:

4.2.1 The Region of Coastal Plains

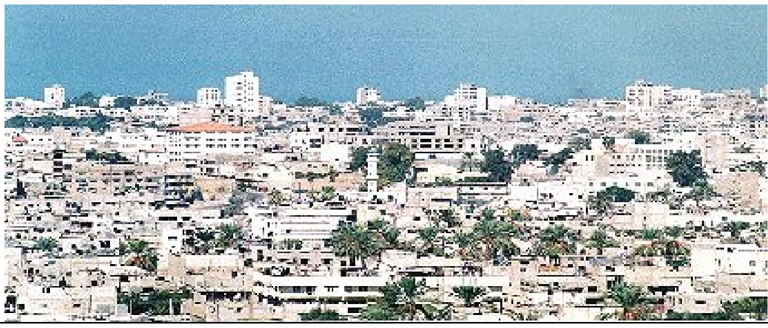


Figure 4.5: The Region of Coastal Plain – Gaza City (MOG, 2001)

This region extends from Ras Al-Nakoura in the north to Rafah in the south. It is confined between mountains in the east and the Mediterranean Sea in the west. This region is composed of plain, flat land close to sea level (Figure 4.5). Though the surface is generally plain, there are some small heights, some sand hills and some narrow valleys coming from the mountain heights and heading to the Mediterranean Sea. The land generally descends from east to west.

4.2.2 The Region of Mountain Heights

Figure 4.6: West Bank – Nablus (ARCHNET, 2001)

This region is composed of mounds and small mountain chains (Figure 4.6) through which there are some internal plains. This region's is often considered as the backbone of the Palestinian land, and it stretches from the north to the farthest point in the south at the Naqab desert. The height of the region land does not generally exceed 1,000 metres. The land gradually descends towards the plains in the west and more towards the east till it reaches the Jordan Valley. Most of the valleys found in this area are dry or seasonal and flood with water immediately after rainfall.

4.2.3 The Region of the Jordan Valley

In Palestine, this valley is the lowest point on the land surface (down to over 300m below sea level). The area lies in the eastern part of Palestine, on the border with Jordan and Syria and it stretches from the Sheik Mountains in the north to the Aqaba Gulf in the south. The River Jordan runs through this area from north to south. The length of the Jordan Valley is more than 420 km long. The area is a very small part of the African-Asian system, which extends down from southern Turkey through Lebanon and Syria to the salty depression of the Dead Sea, where it continues south through Aqaba and the Red Sea to eastern Africa. This area has good soil but very few water resources. Agriculture there depends on irrigation, either from local streams or the River Jordan.

Figure 4.7: West Bank – Jericho (PPW, 2001)

The Jordan Valley is among the depressions that attract great attention all over the world. This is because the Dead Sea is located there, which is the lowest spot below sea level in the entire world. Agriculture there depends on irrigation, either from local streams or the River Jordan (Figure 4.7). The width of the Jordan Valley varies from 5 km to the north of Aqaba to 35 km on the latitude of Areha to the north of the Dead Sea.

4.2.4 The Southern Desert (Al-Naqab)

This region comprises almost half of Palestine land. The area is characterized by a totally arid desert climate, contrasting with the semi-arid Mediterranean climate of the central and northern part of Palestine. This region is composed of a desert mound that extends along the south of Palestine and takes the form of a triangle whose base connects the southern part of the Dead Sea and Gaza on the Mediterranean Sea and whose head is located at the Gulf of Aqaba. This mound is considered to be a junction between the mound of Jerusalem and Hebron to the north and the mound of the semi-island, Seena, to the south. The surface shapes of the mound vary from the mountain chains and small mounds to the closed and small plains. It is low on the north as if it were a plain, but gets rougher in the area of middle Naqab to the south of Beer Sabe', where the heights increase to more than 1,000 metres above sea level (ARIJ, 2001a). The climate has a sharp temperature variation between day and night, summer and winter, and extremely limited amounts of precipitation. Solar radiation and evaporation are strong during all seasons, and relative humidity and cloudiness remain low.

4.3 Palestinian Territories - Physical Characteristics

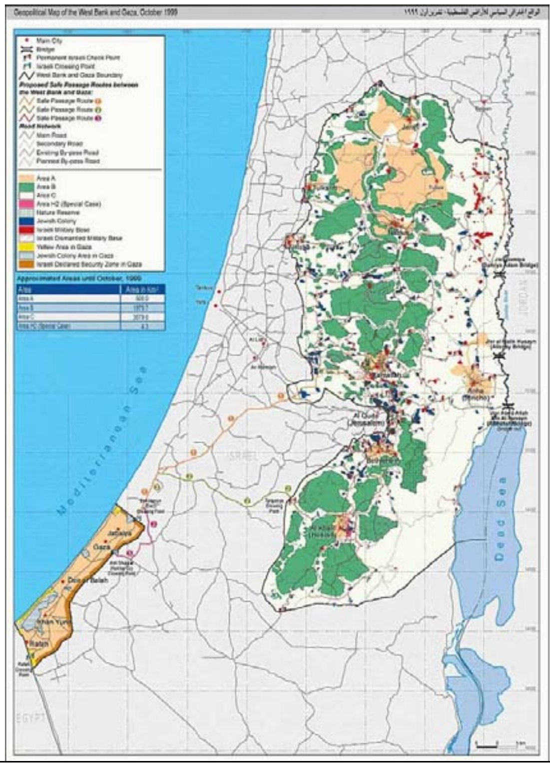


Figure 4.8: Map of Palestine (ARIJ, 2001)

The current Palestinian territories are composed of the West Bank (including east Jerusalem) and the Gaza Strip (Figure 4.8), which are located on the western edge of the Asian continent and the eastern extremity of the Mediterranean Sea. Its area covers 6,170 square kilometres, constituting 23 per cent of the area of the pre-1948 British Mandate Palestine (UNCTAD, 1995). The total area of the West Bank covers 5,820 km^2 while the

Gaza Strip covers 365 km^2. The climatic conditions in Palestine are diverse despite the country's small size.

The Gaza Strip is mainly coastal plain and sand dunes, while the West Bank is more diverse, including four topographic zones. The Jordan River Valley is a fertile plain of around 400 sq. km, while the Eastern Slopes overlooking the Valley are a rocky, semi-arid area of 1,500 sq. km, leading down to the Dead Sea. The Central Highlands constitute the largest zone, of 3,500 sq. km, rising 1,000 metres above sea level in some locations; while the semi-coastal zone covers an area of approximately 400 sq. km. in the west and north-west (UNCTAD, 1995).

4.3.1 The West Bank

Figure 4.9: West Bank (Encyclopaedia of the Orient, 2001)

The West Bank comprises about 6,000 sq km of undulating hills and valleys (Figure 4.9). The West Bank is divided into three main districts with eight sub-districts, each of which is named after one of the main cities. The northern region comprises the sub-districts of Jenin, Tulkarem and Nablus, while the central region comprises Jerusalem, Jericho, Ramallah and Bethlehem and the southern region consists of Hebron (UNCTAD, 1995). The climate of Palestine in general, and the West Bank in particular, is of the

Mediterranean type, characterised by a mild winter and a prolonged dry and hot summer. The hottest month is August when temperatures can reach up 35 to 40 degrees centigrade, although humidity is relatively low.

4.3.1.1 The Topography

Figure 4.10: Topography of West Bank (ARIJ, 2000)

Despite its small geographical area, the West Bank is characterised by a great variation in topography ranging between 1020 metres above sea level and 375 metres below sea level (Figure 4.10). The highest point is located to the north of Hebron City and the lowest point is at the northeast tip of the Dead Sea. This variation is reflected directly on climate, as well as the distribution of agricultural patterns, from irrigated agriculture in the Jordan Valley, to rainfed farming in the mountains. Population distribution and urban centres in the West Bank are affected by such topography (Figure 4.11). The maximum concentrations of built-up areas are found in the mountain zones where the climate is more suitable for human life than in the hot climate of the Jordan Valley.

Figure 4.11: West Bank – Bethlehem Hills (PHH, 2001)

The West Bank is divided into four major climatic/geologic zones: the Jordan Valley, the Eastern Slopes, the Central Highlands and the Semi-Coastal Region. Many drainage and valley systems are spread in and among the above-mentioned four regions. However, the mountainous area of the West Bank serves as the main rainfall collection area for the underground water aquifers.

4.3.1.1.1 The Jordan Valley Region

The Jordan Valley is part of a large depression of the earth's crust, widely known as the Jordan Rift, which forms the eastern boundary of Palestine, running along the edge of the country from north to south, separating it from Jordan (ARIJ, 1997). The Jordan Valley Region extends along the western bank of the River Jordan. It is a low-lying area (up to 375m below sea level), with low rainfall, averaging 158 mm per year. The climate of this region is considered as a semi-tropical climate marked by hot summers and warm winters.

4.3.1.1.2 The Eastern Slopes Region

The Eastern Slopes Region extends along the periphery of the eastern parts of the West Bank, covering an area of approximately 1,500 km^2. The topography of this region ranges from 800 m above sea level to approximately 200 m below. This region is characterized by a semi-arid climate with low rainfall ranging from 200 to 400 mm per year, as it lies in the rain-shadow area of the Central Highlands. Except for underground water, the southern parts of the Eastern Slopes Region are dry, while the northern parts are rich in water resources, mainly springs.

4.3.1.1.3 The Central Highlands Region

The Central Highlands Region includes a range of mountains that extend over the length of the central parts of the West Bank, from Jenin in the north to Hebron in the south. The Central Highlands Region constitutes the main part of the West Bank, covering an area of approximately 3,500 km^2. The elevation in this predominantly mountainous region varies between 400 m to more than 1,000 m above sea level. Most major valleys in the West Bank run either eastward or westward from this area. This region is also the main catchment area which replenishes the underground water aquifers of the West Bank.

4.3.1.1.4 The Semi-Coastal Region

The Semi-Coastal Region is the smallest part of the West Bank regions with an area of approximately 400 km^2. It constitutes the northwestern parts of the West Bank, including parts of the Jenin and Tulkarm districts. This region is considered as an extension of the Mediterranean Coastal Region and is marked by extensive plains. The elevation of the area ranges from 100 to 400 m above sea level. The Semi-Coastal Region is highly cultivated with vegetables and field crops.

4.3.1.2 The Climate

The area of the West Bank is located between 31°21` and 32°33` latitude and between 34°52` and 35°32` longitude. This geographical location makes the area highly influenced by the Mediterranean climate. The Mediterranean climate is characterized by a long, hot, dry summer and a short, cool, rainy winter. Rainfall is limited to winter and spring. Although snow and hail are uncommon, they may occur anywhere in the area, especially to the west of and over the highlands (ARIJ 2001b).

4.3.1.2.1 Temperature

Temperature increases from north to south. The annual amount of rainfall, on the other hand, decreases from north to south. Also, there is a gradual decrease in the annual, monthly, and diurnal average of relative humidity from north to south and from west to east throughout the whole area. The mean monthly temperature in the West Bank during the summer months, from June to August, ranges from 21.7° to 23.7° C. In winter, December to February, the mean monthly temperature in the West Bank ranges from 8° to 14.2° C (ARIJ, 1997). Annual temperature distribution in the West Bank reveals the lowest temperatures in the mountain region. The northern mountains at Nablus have an annual average temperature of 17.8°C, while the annual average in the higher southern mountains in Hebron is about 15.5°C.

4.3.1.2.2 Humidity

The relative humidity in the area varies between 50-70% with a maximum value in January and minimum value in June (MOPIC, 1998). The mean annual relative humidity is 61% in Nablus, 69.6% in Tulkarm and 52% in Jericho. Relative humidity reaches its highest in winter, when the average humidity is 67.2% in Nablus, 73% in Tulkarm, and 68.5% in Jericho. Evaporation is particularly high in summer, due to the rise in temperature, intensive sunshine and low humidity. The rate of evaporation decreases in the area of the coastal plain because of the year around exposure to the humid sea breeze. The evaporation rate is also relatively low during the winter months when solar radiation is minimum. Rainfall ranges between 715 mm in Ramallah, 145 mm in Jericho and even less in the Dead Sea area. The overall annual average rainfall in the West Bank is between 450-500 mm (ARIJ 2001a).

4.3.1.3 Jerusalem

Figure 4.12: Jerusalem (Al-Mashriq, 2001)

Among all cities in Palestine, Jerusalem possesses a special political, economic and religious status for people around the world. Jerusalem is a city of mountains and valleys which have greatly contributed to its history. There are four mountains that lie in a straight line, extending from east to west. The Old City is roughly shaped like a square and has a wall that goes around it (Figure 4.13).

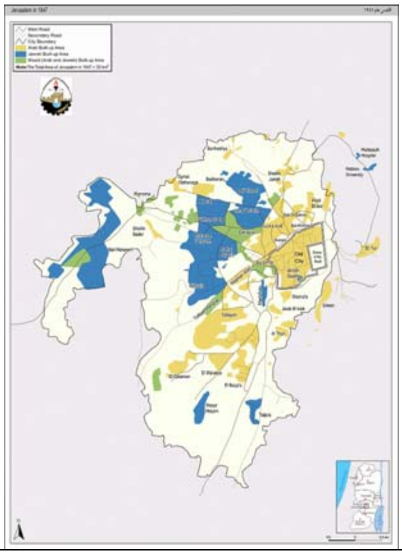


Figure 4.13: Jerusalem and the Vicinity (ARIJ, 1997)

Figure 4.14: Dome of the Rock and Al-Aqsa Mosque in Jerusalem (World Executive, 2001)

The wall has seven gateways. The Old City is divided into four quarters. The north-eastern section is the Moslem Quarter; the north-western section is the Christian Quarter; the south-western section is the Armenian Quarter; and the south-eastern section is the Jewish Quarter.

The third holiest site in Islam, the Haram Ash-Sharif or "Noble Sanctuary", encloses nearly one-sixth of the Old City of Jerusalem with fountains, gardens, mosques, buildings and other structures (Figures 4.12 and 4.14).

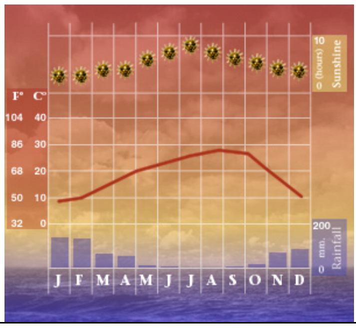


Figure 4.15: Jerusalem Climate Chart (World Executive, 2001)

In general, the climate is typically Mediterranean, with some differences due to the high altitude in Jerusalem. Summers are usually hot and dry; between June and August temperatures can be up to 31 degrees Celsius (Table 4.2). In this season, there is virtually no rain. Winter days can be cool and wet. Winter in Jerusalem, from November to February, brings the rainy season and temperatures range between 5 and 13 degrees Celsius. Generally, the weather is likely to be sunny through the whole year (Figure 4.15).

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	Period
Mean air temperature (°C)	8.9	9.4	13.1	16.4	20.6	22.5	23.9	24.2	23.1	21.1	16.4	11.1	17.6	19
Mean maximum air temperature (°C)	12.8	13.3	18.3	22.8	27.2	29.4	30.6	30.6	29.4	27.2	21.1	15	22.8	19
Mean minimum air temperature (°C)	5	5.6	7.8	10	13.9	15.6	17.2	17.8	16.7	15	11.7	7.2	11.7	19
Absolute maximum air temperature (°C)	25	26.7	30.6	38.9	39.4	41.7	37.8	39.4	39.4	36.1	31.1	26.1	41.7	18
Absolute minimum air temperature (°C)	-3.3	-2.8	-1.1	2.2	5.6	8.3	10	11.1	10	8.3	3.9	-2.8	-3.3	18
Mean relative Humidity (%)	72	66	59	49	40	40	44	47	49	48	58	67	53	9
Mean precipitation (mm)	132	132	64	28	3	2	0	0	2	13	71	86	533	20
Maximum precipitation in 24 h (mm)	99	86	36	38	13	3	0	0	10	23	56	76	99	16
Days with precipitation	9	11	3	3	1	<1	0	0	<1	1	4	7	41	16
Mean sunshine (h)	180	182	231	290	346	412	410	400	339	288	211	185	3474	
Potential evaporation (mm)	16	18	29	56	105	118	133	130	102	82	52	24	865	10

Table 4.2: Mean Climatic Data: Jerusalem (IAUC, 2001)

4.3.2 Gaza Strip

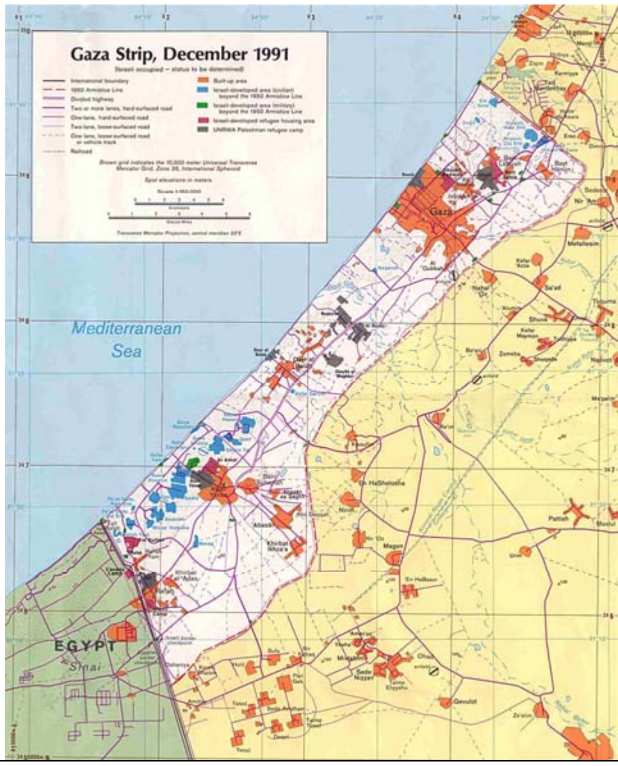


Figure 4.16: Gaza Strip (UTA, 2001)

The Gaza Strip forms part of the coastal foreshore plain bordering the Hebron Mountains in the north-east, the Northern Negev desert in the south-east, and the Northern Sinai desert in the south. It is a narrow coastal zone stretching along the east-south corner of the Mediterranean Sea on the edge of the Sinai Desert (Figure 4.16). It is 45 km long, between 6 and 12 km wide and covers 365 km^2 (MOPIC, 1998). It lies on Longitude 34^o 26` east and Latitude $31^o$ 10` north of the equator. It is composed of five districts: Jabalya, Gaza, Deir AL Balah, Khan Yunis and Rafah and can be divided into major cities, refugee camps and villages. The Gaza Strip is a densely populated region inhabited primarily by Palestinian refugees (Figure 4.17); the majority live in large, overcrowded refugee camps (MOPICa, 1995). It is a highly populated area with an estimated population of 850,000. The average population density is 2330 person / km^2, while the highest, which is registered in the camps, can be 100,000 person / km2 (PCBS, 1997).

Figure 4.17: Jabalia Camp (JPE, 2001)

4.3.2.1 The Topography

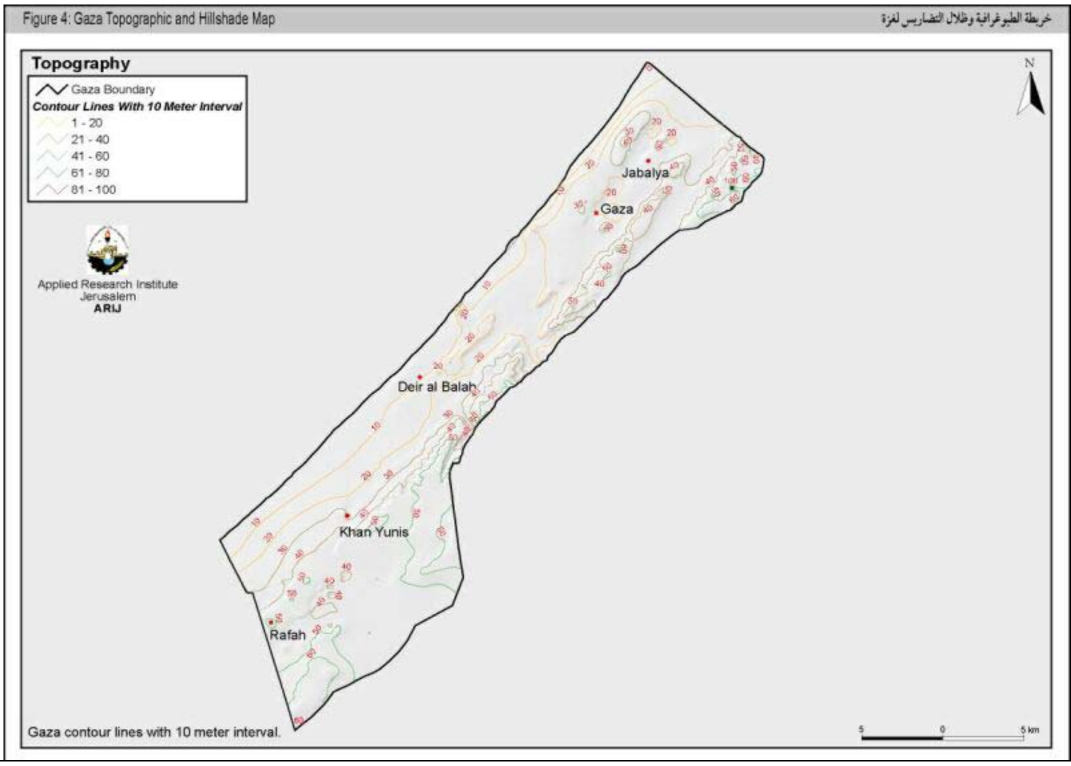


Figure 4.18: Topography of the Gaza Strip (ARIJ, 2000)

The Gaza Strip is a foreshore plain gradually sloping westwards (PEPA, 1994). The topography of the coastal plain is determined by ridges of calcareous sandstone, which appear all along the coast, positioned in parallel to the coast (Figure 4.18). In the northern part of the Gaza Strip, there are four ridges: the coastal ridge (20 m MSL), the Gaza ridge (up to 50 m MSL), the El Muntar ridge (80 m MSL), and the Beit Hanun ridge (90 m MSL). Vast expanses of unspoiled sand dunes can be found near the coast, especially in the southern part between Deir el Balah and Rafah (ARIJ, 2001a). Further inland (west of Khan Younis) are older dunes, stabilized by vegetation, and penetrating an area 4-5 km inland. There is gradual transition from a sandy, dune landscape towards the rolling loess plains of the north-western Negev.

4.3.2.2 The Climate

The Gaza Strip is located in a transitional zone between the arid desert climate of the Sinai Peninsula and the Mediterranean climate along the coast. Therefore, the Gaza Strip is categorized as a subtropical region with a relatively hot summer and mild winter.

4.3.2.2.1 Temperature

Due to its geographical position, the Gaza Strip has a warmer climate than the West Bank with milder winters and hotter summers. The average daily mean temperature (Figure 4.19) ranges from 24°C in summer (May-August), to 15°C in winter (November-February). Average daily maximum temperatures in summer range from 27°C to 19°C and minimum temperatures in winter from 21°C to 11°C (PEPA, 1994).

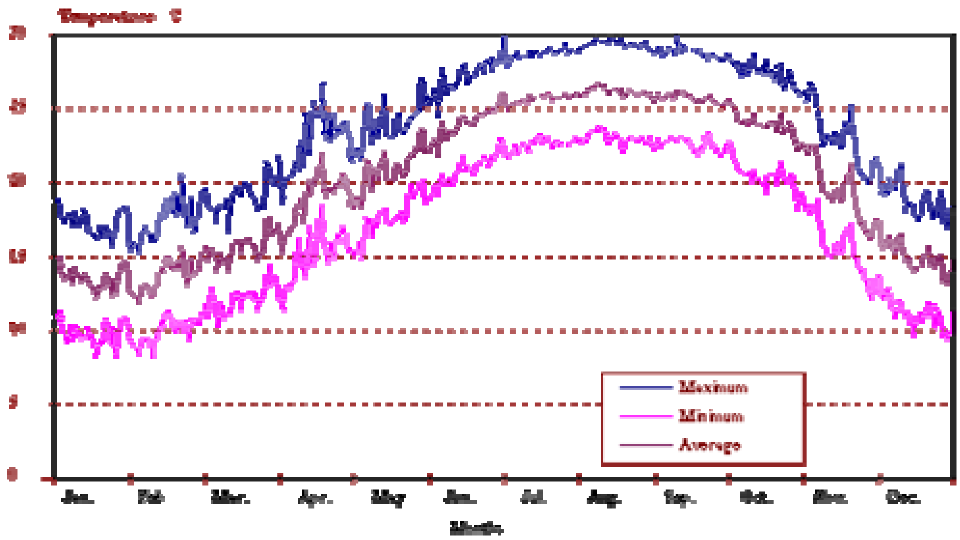


Figure 4.19: Temperatures in the Gaza Strip (PEA, 2001)

4.3.2.2.2 Relative Humidity

The daily relative humidity (Figure 4.20) fluctuates between 65% in daytime and 85% at night in the summer and between 60% and 80% respectively in winter (PEPA, 1994). Compared to the West Bank, the Gaza Strip has a lower level of rainfall. Annual rainfall ranges from 350mm in the north to 150mm in the south. Because of the semi-arid climate, the rate of evaporation is relatively high.

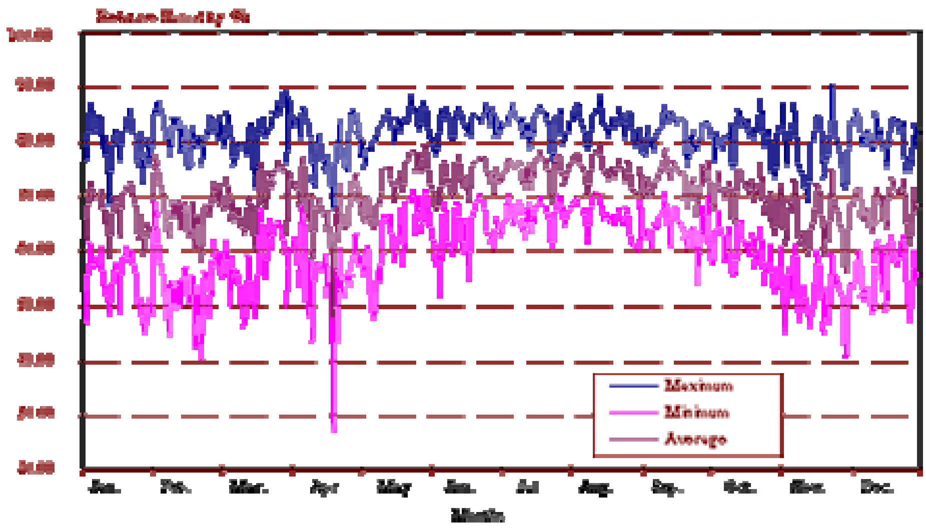


Figure 4.20: Relative Humidity in Gaza Strip (PEA, 2001)

4.3.2.3 Gaza

Gaza City is the principal city and the administrative centre of the Gaza Strip. Gaza is situated in a strategic location on the trade routes between Asia and Africa. The town has long been of commercial significance, a meeting place for the caravans travelling between Egypt and Syria (MOG, 2001). The historic part of the city is compact and extends no further than a 5 minute walk from the main square (the Palestine Square) in the heart of the city. The old city of Gaza was built on a hill rising 45 metres above sea level. It had an area of one square kilometre and was surrounded by a great wall with gates. As it developed, the city spread to the north, south and east.

Figure 4.21: Gaza City - Omar Al-Mukhtar Street (MOG, 2001)

The area of the city is 45 km^2 and is divided into quarters both out of and within the old city limits. The most important street is Omar Al-Mukhtar Street (Figure 4.21), which runs east to west from the main square to the sea. Population density in some areas of Gaza reaches more than 3,000 inhabitants per square mile. The total number of inhabitants is about 400,000 people. The annual average temperature of the city is about 20.3^{o} C with the highest temperature of about 32^{o} C in summer and the lowest temperature of about 6^{o} C in winter. The annual average rainfall is 350 - 400 mm (MOG, 2001).

4.4 Energy Sources in Palestine

4.4.1 The Energy Situation in Palestine

In all countries, energy is of great importance because of its impact on the economy, people's well-being and the quality of life. In Palestine, energy is even more crucial due to the country's high population density and lack of natural resources. Palestine has only minor energy production. There is some production of biomass, solar heat and private generation of electricity. However, most consumed energy is imported from other countries. Furthermore, the gap between supply and demand is growing rapidly as economic activity increases. The following table (4.3) shows the trend in consumption and demand since 1995.

Consumption and demand in the Gaza Governorates				Consumption and demand in the West Bank			
Year	Consumption	Max	Load	Year	Consumption	Max	Load
1995	487.1	94.1	59.1	1995	1008	199	57.8
1996	502.6	93.1	61.6	1996	1104	218	57.8
1997	546.4	102.5	60.8	1997	1223	244	57.2
1998	598.9	106.3	64.3	1998	1411	274	58.8

Table 4.3: Electricity Consumption in the Gaza Governorates and the West Bank (PEA, 2001)

The West Bank and the Gaza Strip contain no cheap or easily exploitable energy resources. In addition, energy consumption is increasing rapidly due to the higher rate of development and population growth (PEC, 1995). The current energy pattern reveals that 70% of consumption is used for residential purposes, 18% for commercial use, and 7 % for industrial applications (MOPIC, 1998).

4.4.2 Solar Insolation in Palestine

Solar energy represents a major energy source that is available in most Palestinian areas. Both the West Bank and the Gaza Strip are considered as ideal places for using solar energy. Solar insolation in Palestinian territories has an annual average of 5.4 kWh/m^2.day with approximately 300 sunny days throughout the year. The measured values demonstrate that the annual average insulation values are about 5.24 kWh/m^2.day, 5.63 kWh/m^2.day, 5.38 kWh/m^2.day in the coastal area, hilly area and the Jordan Valley respectively. The following figure (Figure 4.22) shows the annual scheme of monthly averages of solar radiation in the three climatic zones.

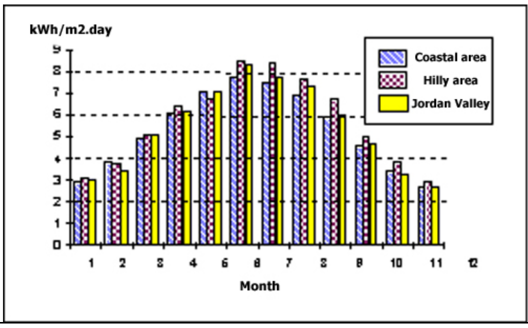


Figure 4.22: Annual Monthly Average Variations in Solar Radiation in the Three Climate Zones of Palestine (PEA, 2001)

The Gaza Strip has relatively high solar radiation. The daily average solar radiation on the horizontal surface is about 222 W/m2 (7014 MJ/m2/yr). It has approximately 2861 annual sunshine hours throughout the year. The following figure (Figure 4.23) illustrates the variations in the monthly daily averages of the total insolation on the horizontal surface for each month (PEA, 2001).

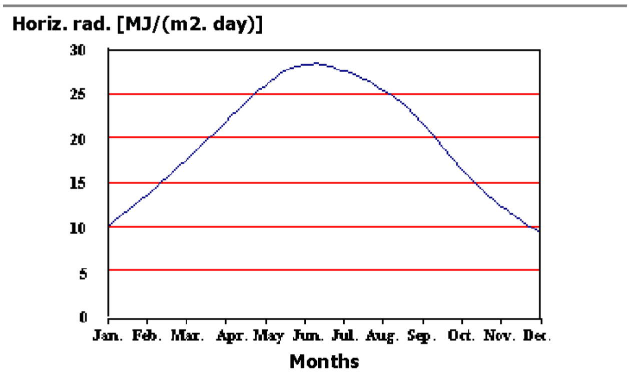


Figure 4.23: Annual Variations in Solar Radiation in the Gaza Strip (PEA, 2001)

4.4.2.1 Passive Solar Heating

Passive solar heating is one of the most economically attractive uses of solar energy, particularly when incorporated in the design of new buildings in regions where the climate is suitable. Although Palestine offers an ideal climate for passive solar heating, with clear sky conditions for most of the year, a great amount of energy is wasted annually to heat buildings. Even though air-conditioning and a proper heating system might be considered a necessity in some periods during summer and winter respectively, a considerable part of the urban structure in Palestine relies upon other methods for providing thermal comfort. It is normally not affordable due to economic circumstances, and partially due to the fact that both summer heat and winter cold are not so severe, as the region, in general, falls within the Mediterranean climate. In such a case, the implementation of passive design principles will be of more significance.

From a designer's point of view, given such conditions, passive heating should be an integral part of the urban design process. So far in Palestine, however, it has been relatively little used. In general, hot summers and cool winters characterise the Mediterranean climate. Thus, a solution suitable for the winter conditions might not be appropriate for the summer conditions, and vice versa. As was previously mentioned, Palestinian territories have four climatic zones: the coastal plain, the Eastern Slopes, the Central Highlands, and the Jordan Valley. Where climatic conditions vary across a country, it may be of benefit to map the potential of different areas for the application of various techniques for energy-conscious design. Therefore, where climatic conditions vary from one part of the country to another, different standards may be applied to each region and these zones may require relatively different solutions. Shaviv (1999) has pointed out that the climate of the mountain area (which has a cold winter and a temperate summer) demands better passive solar heating systems for the winter, while passive solar solutions of a limited extent are required for the climate along the coastal plain (which has a hot, humid summer and a temperate winter).

4.4.2.2 Current Usage Of Solar Energy
4.4.2.2.1 Thermal transfer for solar energy

The main energy sources in Palestinian households are electricity, gas and biomass. However, solar water heaters are widely used. The climate is ideal for employing passive solar heating. Solar water heaters are the most common feature of solar utilisation in the Palestinian territories and cover rooftops all over the country (Figure 4.24). It is estimated that more than 70 percent of houses in Palestine have installed domestic solar water heating (SWH). In this case, the integration of the collectors into the building design in such a way that thermal performance is suitable and the structure is aesthetically appropriate is recommended (Duffie and Beckman, 1980).

Figure 4.24: Solar Water Heaters - The Most Common Feature of Solar Utilisation in Palestine (PHC, 2002)

SWHs are manufactured locally by more than 15 major workshops in Palestine, 10 of them in the West Bank and 5 in the Gaza Strip. The current annual production rate of these workshops is estimated at about 24.000 units. It is expected that this market will expand due to the noticeable growth of the building sector. The system payback period, based on electricity prices, is usually less than 2 years (about 1.3 years). These systems operate at an annual average efficiency of approximately 50%. Therefore, such a unit can save about 2,000 kWh per year in electricity costs. The unit raises the temperature of the water by approximately 30^{o}C above its starting point on an average day, i.e. heating water to a temperature of around 50^{o}C. Hence, most days of the year there is no need to operate the electrical backup-heating coil (which all units contain). Solar water heaters have proved to be feasible in providing energy compared with other alternatives. Thus, their application is widespread in Palestinian territories.

4.4.2.2.2 Photovoltaic Transfer For Solar Energy

This use of Photovoltaic transfer was applied to nine clinics in remote villages in Palestine. They proved to be a viable solution in these cases, since a large number of clinics located in remote villages have no electricity at all. In these buildings, electricity loads can be easily and reliably covered by a small PV generator with a peak power of only 400 W.

4.5 Urban Structure in Palestine
4.5.1 Urban Social Structure

The 1948 war resulted in a massive migration of Palestinians. These political events resulted in huge urban and rural population movement never known in the long history of Palestine. Nearly one million Palestinian refugees were forced to leave their homes, properties, businesses and farms to live in 52 refugee camps scattered in the West Bank, Gaza (Figure 4.25), Jordan, Lebanon and Syria. The initial dwellings for these refugees were temporary tent camps, which were gradually changed into fixed and semi-fixed shelters (UNCTAD, 1994). These events created new urban realities and have negatively affected the urban socio-economic structure, mainly with regard to the residential areas and urban-rural settlement patterns. In the 1967 war, Israel occupied the remaining territory of Palestine, until then under Jordanian and Egyptian control (the West Bank and the Gaza Strip). This also included the remaining part of Jerusalem (DPA/UN, 2001). This was coupled with building new Israeli settlements which affected urban growth and development in Palestine.

Figure 4.25: Beach Camp – Gaza (PHH, 2002)

The population of Palestine in 1922 was 752,048 and increased in 1948 to 2, 115, 000, of which 1.4 million were Arabs, 649,633 were Jews and the rest were different minorities. This increase was mainly due to Jewish migration from Europe, Asia and the Middle East during the British Mandate. This resulted in an increase of the Jewish population from 5% in 1910 to 32.4% in 1944, and the occupation of 79% of the area of Palestine in 1948 (Al-Qutub, 1996). About 29 % of the Palestinian population resided in the District of Nablus with a similar percentage in the District of Jerusalem, 10 % in the District of Hebron, and the remaining 32 % in the Gaza Strip. More than 50 % of the population still lives in small towns and villages which have a population less than 5000 persons (Al-Qutub, 1996).

According to the Palestinian Central Bureau of Statistics (PCBS), the actual population living in the West Bank and the Gaza Strip, including East Jerusalem, was 2.89 million people in 1997, of which 1,470,506 were males and 1,425,177 females. 1.66 million Palestinians live in the West Bank (5.5% living in refugee camps); 1.02 million live in the Gaza Strip (24.5% living in refugee camps), and 210,000 Palestinians live in East Jerusalem. There are also 161,000 Jewish settlers living in the West Bank, 5,500 in the Gaza Strip, and 180,000 in East Jerusalem (Aronson, 1996).

According to the PCBS, the annual rate of population growth is estimated to have reached 4.5 percent in 2000. Fertility rates in the Gaza Strip is higher than those in the West Bank, reaching 7.41 compared to 5.44 in the West Bank. The infant mortality rate is estimated at 25.5 per 1,000 (24.4 in the West Bank and 27.3 in Gaza). Young people represent the largest percentage of the population with 47 percent below the age of 15 in 1999 (UNCTAD, 1995). In contrast, the percentage of people aged 65 years and above is very small, not exceeding 3.5% of the total population in either region (ARIJ, 2001a).

4.5.2 Settlement Patterns

At present, Palestinian territories are divided into two geographic areas: the West Bank, including East Jerusalem, and the Gaza Strip. The UNCTAD Report (United Nations Conference on Trade and Development) divides Palestine into four settlement patterns: Urban, semi-urban, rural, and refugee camps (Table 4.4). The urban pattern refers to settlements with a population over 10,000 persons with administrative, commercial and service facilities. This group includes: Jerusalem, Jenin, Toulkarim, Nablus, Ramallah, El-Biereh, Bethlehem, Hebron, Gaza, Khan Younis and Rafah. The semi-urban includes settlements with a population ranging from 5000-10,000 persons and has municipal or rural council status. These include: Qalqilia, Anabta, Toubas, Ram, Doura, Bier Zeit, Bank Zaid, Salfit and Jabalya. Rural settlements are those with a population of 5000 and less with prevailing agricultural and farming features. Regarding refugee camps, there are 28 camps distributed between Gaza (representing 30.4% of its population) and the West Bank (representing 17% of its population). However, almost 40 percent of the resident population are registered as refugees from the wars of 1948 and 1967 (26 per cent of the West Bank population and 65 per cent of the Gaza Strip population) (UNCTAD, 1995).

Area	Total	Urban		Semi-urban		Rural		Refugees	
		No	%	No	%	No	%	No	%
West Bank	1,604,810	401,792	25	357,105	22.3	737.932	46	107,981	6.7
Gaza	894,984	372,572	41.6	69,211	7.7	181,263	20.3	271,938	30.4

Table 4.4: Population Distribution in the West Bank and Gaza (Al-Qutub, 1996)

The high occupancy densities characterize the Palestinian housing sector (Figure 4.26). The Palestinian population density has increased due to high birth rates and the loss of land as a result of confiscation of land by Israel. This situation is exacerbated by the strict limitations on land-use imposed by the Israeli Authority and the area segregation imposed by the Oslo Accord. The housing stock in the West Bank and the Gaza Strip is not homogenous, but varies according to geographic location and types of community. Nevertheless, overcrowding has been a common phenomenon and density remains high in all communities. Density varies from one district to another and among different types of Human settlements. In the West Bank, density reaches 342 persons per sq. km, whereas the situation in the Gaza Strip is much worse, where population density reaches more than 3,600 people/km^2 (PCBS, 1997). This phenomenon has not been limited to refugee camps, but has also affected low-income families in most towns and villages. In recent years, increases in population, coupled with rapidly deteriorating economic conditions, had forced people in urban, rural and refugee communities to resort to the upgrading and expansion of existing buildings, both vertically and horizontally (UNCTAD, 1994).

Figure 4.26: City of Khan Younis (JPE, 2001)

The characteristics of new buildings have varied depending on location and socio-economic conditions. The basic construction materials have been reinforced concrete with stone facing. However, in rural towns and villages, construction has been mostly of cement blocks and/or reinforced concrete. In the West Bank, especially in cities and urban areas, new residential buildings have taken the form of detached and semi-detached houses, or apartment buildings. Multi-storey buildings have prevailed as a result of the scarcity of land and the high population density, especially in the Gaza Strip. In recent years, the construction of multi-apartment residential buildings for sale or rent has emerged in the larger urban centres such as Nablus, Ramallah, East Jerusalem, Bethlehem, Hebron and Gaza City. These projects were carried out by individual investors, informal partnerships or real estate development companies. The new urban communities certainly create new patterns of social relations, especially in multi-storey apartment buildings. Such new forms of urban housing may require adaptation, adjustment and changes in behaviour patterns (UNCTAD, 1994).

4.5.3 Housing Strategy

Figure 4.27: Large-scale Housing Projects – The Palestinian Housing Council (PHC, 2002)

Waltz (2000) pointed out that the existing housing crisis in the Palestinian Territories is mainly a result of 30 years of occupation. In about 60% of the occupied territories, the Palestinian Authority so far has no control and legal rights. The housing situation has constituted one of the most serious economic and social challenges confronting the Palestinian people in the West Bank and the Gaza Strip since the Israeli occupation. The occupying force is still hindering Palestinians in a large proportion of their land to build and develop their human settlements. These political developments have hampered the socio-economic development of the Palestinian people. The construction and housing sector has been among the sectors which were greatly affected, mainly because Israel expropriated and confiscated vast areas of Palestinian land. This action was described by UNCTAD (1994) as depriving the Palestinian construction and housing sector of a substantial resource-base essential for development. Consequently, housing facilities and infrastructure in the occupied Palestinian territory are inadequate.

The absence of a legitimate Palestinian Authority in the West Bank and Gaza, following the Israeli occupation in 1967, left the housing sector without an institutional, legal, financial and planning mechanism (Waltz, 2000). Palestinians have been prevented from developing their construction sector in a way that would adequately meet housing and other physical infrastructure requirements. In addition, the prolonged occupation dampened efforts to develop national institutions capable of planning, implementing and managing socio-economic development. Furthermore, severe restrictions were imposed on the use of land remaining in Palestinian hands.

The lack of adequate building codes, regulations and standards represented another constraint for any large-scale housing constructions. Many regulations and laws, which had been placed by Israeli regulations and reflect other considerations, still exist or influence building and construction (Waltz, 2000). Many of the existing codes and regulations had not been updated for three or four decades and were thus in need of extensive review and modification to improve their efficiency and compatibility with new requirements (UNCTAD, 1994).

As a result, there is a severe crisis in housing; the problem mainly concerns the high living density and overcrowding in the existing housing stock. More than 30 percent of families in the West Bank and 33 percent of families in the Gaza Strip lived in housing units with more than three persons per room, and in both regions more than 6 percent of the households had densities exceeding five persons per room. Furthermore, around one quarter of all households had no running water, one fifth had no electricity and over one third had no toilet facilities (UNCTAD, 1994). Around 100,000 of the existing housing units need extension, rehabilitation and renovation of their facilities, and require an infrastructure supply. They constitute about one quarter of households. Within the next decade, around 300,000 new housing units will be required to meet the future needs of a population growth of around 4%, including natural growth, returnees and displaced persons from 1967 (Waltz, 2000).

As a result of the Oslo Agreement in 1994, after which the Palestinian National Authority was established, the Ministry of Housing was created. The Ministry aimed to develop a national policy for housing in cooperation with NGOs and the private sector. The Palestinian Housing Council (PHC) was entrusted to introduce the concept of new urban communities in Palestine within the boundaries of the existing major cities and towns (Figures 4.27 and 4.28).

Figure 4.28: Beit Hanoun – One of the Palestinian Housing Council Projects (PHC, 2002)

The new housing projects were planned to contribute to urban housing and community development. The goal of implementing these projects was to provide durable and affordable housing units distributed equally between Gaza and the West Bank. The models were designed to respond to the needs of families according to their income and members. It has been possible to establish 18 new housing projects, each with distinct construction and geographical features. Unlike the private sector housing projects, where owners of apartments are usually left without formal management, PHC new housing projects apply the method of communal management and supervision through cooperative housing societies. Through this system, a collective consciousness and awareness for self-control and self-service can be developed (Al-Qutub, 1996).

PART 2: PARAMETRIC STUDIES CHAPTER 5

THE RELATION BETWEEN THE URBAN FORM AND THE INSOLATION PERFORMANCE: A Comparison between Radial and Rectangular Forms

5. The Relation between the Urban Form and the Insolation Performance: A Comparison between Radial and Rectangular Forms

5.0 Overview

The main goal of the study is to investigate 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. This research aims to make a comparison between the performances of different urban forms, and to establish a comprehensive approach and methodology by which any urban form can be fully investigated, in terms of the generated shadow patterns. Analyses include the evaluation of the amount of the shaded area generated in the over-heated and under-heated periods, as well as over the year. Also, the investigations illustrate the distribution of the shaded area during the daytime period. This comprehensive approach gives a full explanation of the status of the generated shadow, which facilitates the best interpretation of results, and also allows deriving maximum benefits from it. As the variations in the shaded area between the forms are expected to be relatively small, and in order to ensure a high standard of accuracy, it was necessary to conduct the simulation using computer software which has the ability to give a numerical calculation for the shaded area. Among the considerations, which will be also investigated, is the inter-relationship between the solar insolation and thermal performance of urban patterns. The experiment examines more sophisticated forms that can create self-shading effects. This part of the research mainly focuses on discovering the main characteristics of the radial form. Finally, the chapter discusses the possible application of these forms 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.

5.1 Solar Geometry and Shading
5.1.1 Solar Geometry
5.1.1.1 The Motion of the Earth Around the Sun

Before entering into the description of the solar shading, it is necessary to give a short summary of the astronomical relations of sun and the earth. It is well known that the Earth is rotating about its own axis (N,S) at the rate of one revolution per day. This celestial motion takes 365 1/4 days to complete one cycle around the sun. The Earth's orbit around the sun is elliptical (Figure 5.1). Duffie and Beckman (1980) reported that “the eccentricity of the earth’s orbit is such that the distance between the sun and the earth varies by 1.7%”. This elliptical orbit causes the Earth's distance from the sun to vary annually. This annual variation in the distance from the sun does not cause the seasons. However, this phenomenon does influence the amount of solar radiation intercepted by the Earth by approximately 6 % (Pidwirny, 2003a). The average distance of the Earth from the sun over a one year period is 150 million kilometres.

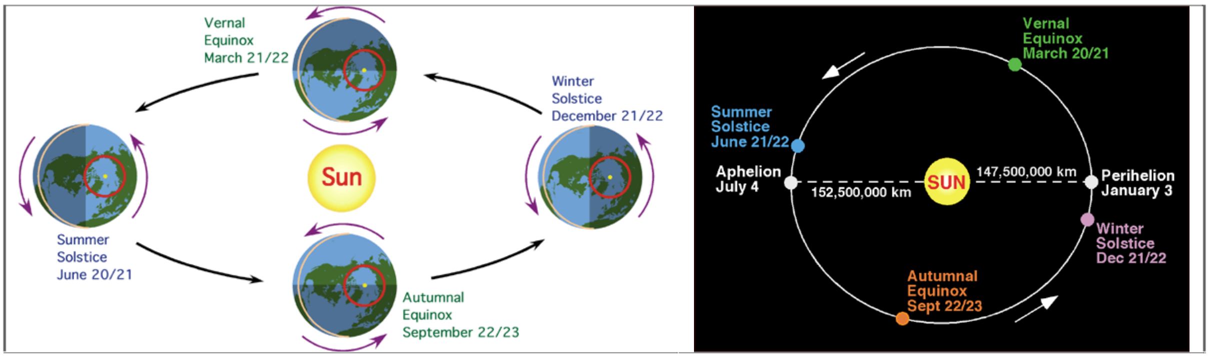


Figure 5.1: Annual Change in the Position of the Earth in its Revolution Around the Sun (Pidwirny, 2003a)

The sun travels in an arc, rises in the East and sets in the West and reaching its highest altitude in the South (for Northern hemisphere). Muneer (1997) defined the solar day as "the interval of time from the moment the sun crosses the local meridian to the next time it crosses the same meridian". The length of the solar day is different depending on the time of year. This phenomenon is due in part to the tilt of the earth's axis on the plane of the earth orbit around the sun and in part to the unequal motion of the earth around the sun, caused by the elliptical orbit (Muneer, 1997).

The earth moves faster in its orbit when it is closer to the sun (CMSE, 2003). Thus, Earth moves faster in January and slower in July as Earth is closer to the sun in January than in July. Thus, the standard time, which is measured by clocks running at a constant speed, differs from the solar time. The difference between the standard time and the solar time at a given location is known as the equation of time (EOT). Apparent solar time (AST), which is used in all solar geometry calculations, is the time based directly on the Sun's position in the sky. So, in addition to the equation of time, it is necessary to apply the corrections due to the difference between the longitude of the given locality (LONG) and the longitude of the standard time meridian (LSM).

Astronomers define sunrise and sunset as "the moments at which the centre of the solar disk is along the horizon of the earth" (Muneer, 1997). As sun's position in the sky can be identified in terms of the elevation angle (SOLALT) and the azimuth of the sun's beam

(SOLAZM) by using Equation (5.24). Hence, the sunrise/sunset instance can be determined by setting SOLALT = 0 (Muneer, 1997). Then, the estimation of sunrise/sunset instance can be obtained by using Equation (5.2).

Muneer (1997) stated that “the actual sunrise and sunset do not occur at the time when the sun’s elevation is zero”. This is attributed to the refraction of light by the terrestrial atmosphere. Because of this, the actual sunrise becomes visible slightly before astronomical sunrise and actual sunset takes place after astronomical sunset. In addition, the sun will appear in the morning slightly earlier in the case of locations higher than sea level. Therefore, the instance of actual sunrise or sunset can be obtained by applying corrections for the refraction and altitude effects. These corrections can be estimated by having SOLALT equals ($-0.8333 - 0.0347\ H^{0.5}$), where H is to be given in meters above sea level (m ASL) (Muneer, 1997).

The Earth axis (N, S) is not perpendicular to the plane of its orbit, it is tilted 23 ° 27’ with respect to the plane of the earth’s orbit around the sun. The angle between the earth-sun vector and the equatorial plane is called the solar declination angle (DEC) (Muneer, 1997). The two are parallel at the spring and fall Equinox and therefore the declination angle is 0° on these two dates. The declination angle varies between +23.5° on June 21 and –23.5° on December 21.

5.1.1.2 Tilt of the Earth's Axis

The earth’s position provides the geometric basis for the annual variation in solar energy received on the earth’s surface. The 23.5° tilt of the earth's axis affects the angle of incidence of solar radiation on the earth's surface. The earth’s position, tilted with respect to its orbital plane around the sun, also causes the seasons, by altering the intensity and duration of sunlight received by locations on the Earth (Pidwirny, 2003a). On March 21 and September 21, the sun’s light beams are parallel to the earth’s equatorial plane. Thus, the lengths of day and night are almost equal everywhere in the world (ESRU, 1992). On June 21, the Earth is positioned in its orbit so that the North Pole is leaning 23.5° toward the sun (Figure 5.2). During this summer solstice, all locations North of the equator have day lengths greater than twelve hours, while all locations South of the equator have day lengths less than twelve hours. On December 21, the Earth is positioned so that the South

Pole is leaning 23.5° toward the sun (Figure 5.2). During this winter solstice, all locations North of the equator have day lengths less than twelve hours, while all locations South of the equator have day lengths greater than twelve hours (Pidwirny, 2003a).

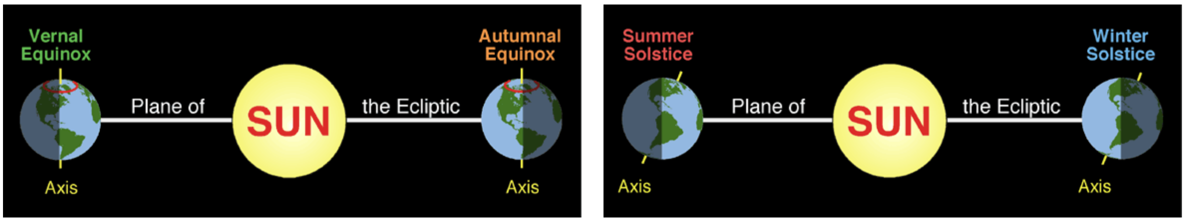
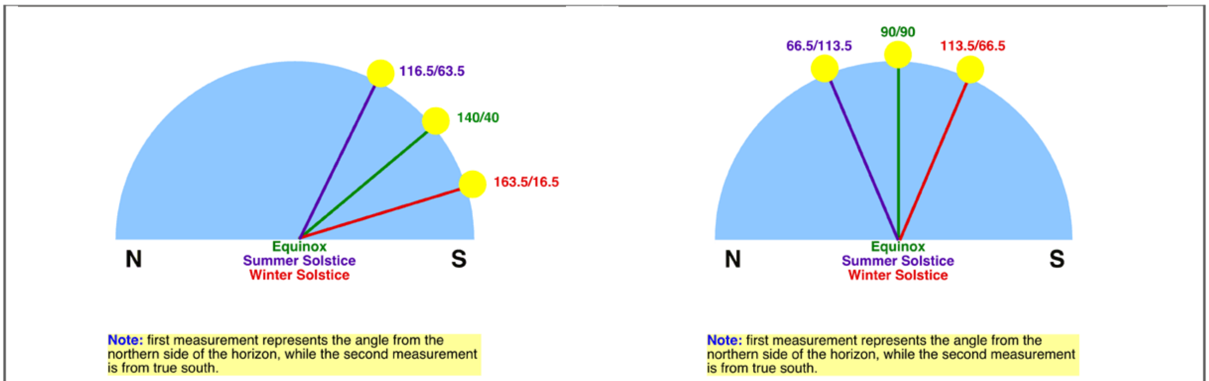


Figure 5.2: Summer and Winter Solstice (Pidwirny, 2003a)

Solar declination is the annual fluctuation of the sun between the two tropics and varies between –23 and +23 degrees latitude. This annual change in the relative position of the Earth's axis in relationship to the sun causes the height of the sun to vary in the sky. The total variation in maximum solar altitude for any location on the Earth over a one-year period is 47° (2 x 23.5 = 47) (Figure 5.3).



At 50° North At the Equator

Figure 5.3: Variations in Solar Altitude at Solar Noon During the Summer Solstice, Equinox, and Winter Solstice (Pidwirny, 2003a)

Pidwirny (2003a) identified the subsolar point as "The location on the Earth where the sun is directly overhead at solar noon". The subsolar point occurs on the equator during the equinoxes (Figure 5.4). During the summer solstice, the subsolar point moves to the Tropic of Cancer. The subsolar point is located at the Tropic of Capricorn on the winter solstice.

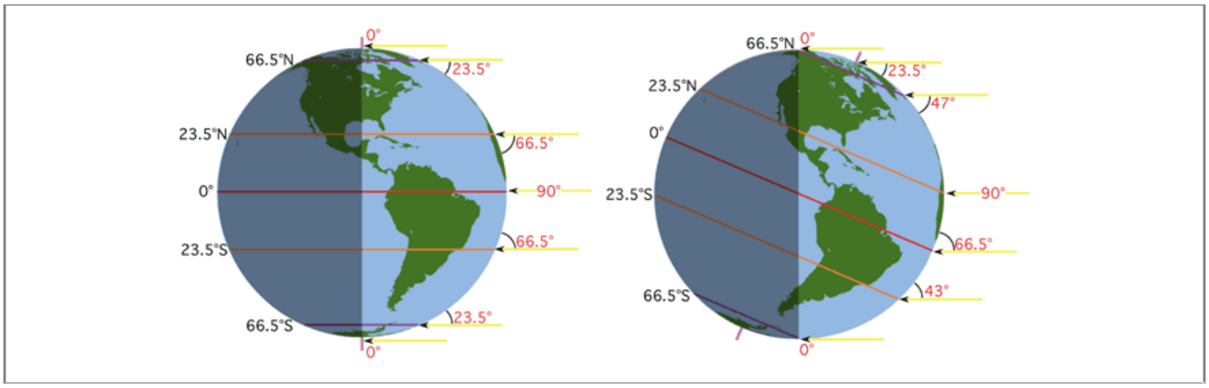
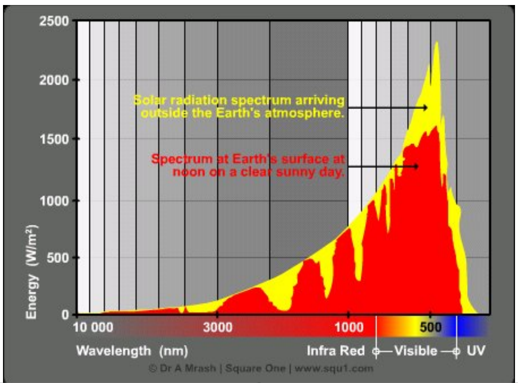


Figure 5.4: Relationship of Maximum Sun Height to Latitude for the Equinox (left) and Summer Solstice (right) (Pidwirny, 2003a)

5.1.1.3 Solar Radiation

5.1.1.3.1 Brief description of the nature of Solar Radiation

Muneer (1997) emphasised the significance of solar radiation and daylight to life on earth as solar radiation influences the earth's weather processes, which control the natural environment. Solar radiation is a general term for the electromagnetic radiation emitted by the sun. This radiation is in the form of ultra-violet, visible and infra-red electromagnetic radiation (INMS, 2003). According to Muneer (1997), the energy of the solar spectrum can be approximately distributed as follows: UV (ultraviolet) 8 %, visible band 46 % and NIR (near infrared) 46 %. Solar radiation is commonly divided into various bands on the basis of wavelength (Acra, et al., 1990). Solar radiation has a spectral distribution from short wavelength radiation (gama and X-rays) to long wavelength radiation (long radio waves) (EERE, 2003). Figure 5.5 below gives the Spectral content of incident solar radiation together with their approximate wavelength ranges.



Ultraviolet	0.20 - 0.39μ
Visible	0.39 - 0.78μ
Near-Infrared	0.78 - 4.00μ
Infrared	4.00 - 100.00μ

Figure 5.5: Spectral Content of Incident Solar Radiation (Square One, 2003)

The rate at which solar radiation strikes earth's upper atmosphere is known as the "solar constant". This equals the summation of all energy received at individual wavelengths in the solar spectrum (Muneer, 1997). The solar constant has been identified by Muneer (1997) as "the irradiance received on a surface normal to the sun's rays at the top of the earth's atmosphere and at a sun-earth distance equal to 1 astronomical unit (1 AU = 1.496 x 10^{11}m)". The distance between the earth and the sun varies as the earth moves around the sun on its elliptical orbit. However, this variation in the distance does not have a significant effect on the amount of solar radiation reaching the earth (EERE, 2003). The earth is farthest from the sun in late June and closest to the sun in late December.

In accordance with the International System of Units, the units for the intensity of solar radiation are watts per square metre (W/m^2), or joules per square metre (J/m^2) (Acra, et al., 1990). The measurements of solar radiation reaching the upper atmosphere resulted in a value of the solar constant, G_{sc}, of 1353 W/m^2 (Duffie and Beckman, 1980).

5.1.1.3.2 Atmospheric Effects on Incoming Solar Radiation

Solar radiation is partially depleted as it traverses the atmospheric layers. This attenuation of the solar radiation prevents a substantial portion of it from reaching the earth's surface. This phenomenon is due to absorption, scattering, and reflection in the atmosphere (Acra, et al., 1990). These processes modify the solar radiation, passing through our atmosphere destined to the Earth's surface, when it interacts with gases and suspended particles found in the atmosphere. As sunlight passes through the atmosphere, some of the radiation is absorbed, scattered, and reflected by air molecules, water vapor, clouds, dust, and pollutants. Sunlight reaching the Earth's surface unmodified by any of the above atmospheric processes is called direct beam solar radiation. "Atmospheric conditions can reduce direct beam radiation by 10 percent on clear, dry days, and by 100 percent during periods of thick clouds" (EERE, 2003). Solar radiation that reaches the Earth's surface after it was altered by the process of scattering is called diffused solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation. Some of the radiation received at the Earth's surface is redirected back to space by reflection (Pidwirny, 2003b).

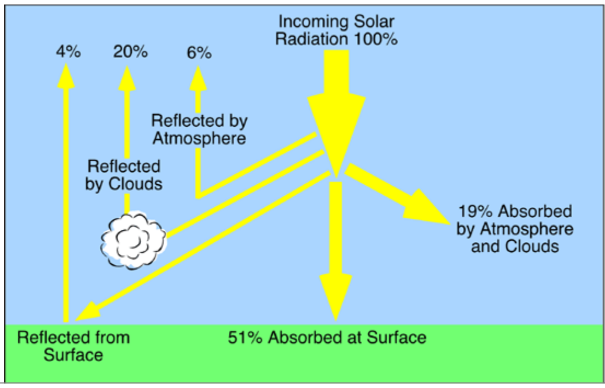


Figure 5.6: Global Modification of Incoming Solar Radiation by Atmospheric and Surface Processes (Pidwirny, 2003b)

Figure 5.6 illustrates the alteration of solar radiation by atmospheric and surface processes for the whole Earth over a period of one year. According to Pidwirny (2003b), Only 51 % of all the sunlight that passes through the atmosphere annually is available at the Earth's surface. This energy is used to heat the Earth's surface and lower atmosphere, melt and evaporate water, and run photosynthesis in plants. Of the other 49 %, 4 % is reflected back to space by the Earth's surface, 26 % is scattered or reflected to space by clouds and atmospheric particles, and 19 % is absorbed by atmospheric gases, particles, and clouds (Pidwirny 2003b).

5.1.1.3.3 Solar Radiation at the Earth’s Surface

The amount of solar radiation reaching any one "spot" on the earth’s surface varies with latitude, geographic location, season, cloud coverage, atmospheric pollution, elevation above sea level, and solar altitude (Acra, et al., 1990). However, the major factors affecting the available energy are cloud cover and other meteorological conditions, which vary with location and time (INMS, 2003). Solar radiation reaches the earth's surface either by being transmitted directly through the atmosphere (direct solar radiation), or by being scattered or reflected to the surface (diffuse sky radiation) (NSIDC's, 2003). The amount of the radiation received at any spot on the earth’s surface varies on an hourly, daily, and seasonal basis. The intensity of sunlight reaching that spot is determined by the angle of the sun’s position in the sky relative to a point on the earth’s surface. “The lower the sun is in the sky, the more of the earth’s atmosphere that the sunlight passes through before it reaches the surface, and the more it is diffused” (EERE, 2003). Therefore, direct solar radiation is generally most intense at solar noon, since the sunlight is most perpendicular in the sky, and has the least amount of the atmosphere to pass through.

Over the course of a day, the noon sun is more intense than the rising or setting sun, as the solar altitude influences the intensity of solar radiation. (NSIDC's, 2003). In proportion to surface reflectivity (albedo), incoming solar radiation that strikes the earth's surface is partially reflected and partially absorbed. Darker surfaces have a lower albedo and absorb more solar energy than do lighter surfaces.

For locations at and north of 23.5 degrees (north latitude), it is most intense at solar noon on June 21st (the summer solstice). At that time, the sun is at the highest point in the sky, and it is at this point that sunlight passes through the least amount of the earth's atmosphere. The summer solstice is also the longest day of the year. For these same locations, the shortest day of the year, and the day when sunlight is the least intense is December 21st (the winter solstice). The opposite is true for locations in the southern hemisphere. Higher latitudes have more hours of sunlight in the summer and less hours of sunlight in the winter, relative to lower latitudes. On the equator, the sun will be most intense around March and September 21st as these are the days when the sun is directly overhead (EERE, 2003).

As a result of the previous mentioned variables such as solar altitude, which is associated with latitude and season, and atmospheric conditions, which are associated with cloud coverage and degree of pollution, solar radiation is irregularly distributed throughout the world. According to Acra et al. (1990), the most favourable belt (15-35° N) includes many of the developing nations in northern Africa and southern parts of Asia. This belt has limited cloud coverage and more than 90% of the incident solar radiation comes as direct radiation. The moderately favourable belt (0-15° N), or equatorial belt, has high atmospheric humidity and cloudiness, which increase the proportion of the scattered radiation. Because of the slight seasonal variations in this belt, the global solar intensity is almost uniform throughout the year. In the less favourable belt (35-45° N), the scattering of the solar radiation is significantly increased because of the lower solar altitude. In addition, cloudiness and atmospheric pollution reduce the solar radiation intensity. Regions beyond 45° N have less favourable conditions for the use of direct solar radiation, as almost half of it is in the form of scattered radiation, which is more difficult to collect for use (Acra, et al., 1990).

5.1.1.3.4 Estimation of Clear Sky Radiation

The most common measurement of solar intensities received at ground level is the estimation of global solar radiation, which is the sum of the direct beam plus the diffuse component on a horizontal surface. Total insolation for clear sky radiation can be calculated using the following equations from Duffie and Beckman (1980).

Variation of Extraterrestrial Radiation: The seasonal variation of the earth-sun distance leads to variation of extraterrestrial solar irradiance (G_{on}). This causes extraterrestrial radiation to be about 3.0% higher than G_{sc} in January and 3.0% lower in June (where G_{sc} is the solar constant).

The dependence of extraterrestrial radiation on time of year is indicated by Equation (5.1).

$$G_{on} = G_{sc} [1+0.033 \cos (360n/365)] \quad (5.1)$$

Where G_{on} is the extraterrestrial radiation, measured on the plane normal to the radiation on the n^{th} day of the year.

Solar Time: The standard time is converted to the solar time by applying two corrections. The first correction is the constant correction for the difference in longitude between the observer's meridian location and the meridian on which the local standard time is based. Secondly, the correction derived from the equation of time, which takes into account the perturbation in the earth's rate of rotation, is applied.

$$\text{Solar Time} = \text{Standard Time} + 4 (L_{st} - L_{loc}) + E \quad (5.2)$$

Where E is the equation of time, L_{st} is the standard meridian for the local time zone, and L_{loc} is the longitude of the location.

$$E = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B \quad (5.3)$$

Where $B = [(360 (n - 81))/364]$, n = day of the year, $1 \leq n \leq 365$

Direction of Beam Radiation: The geometric relationships between a plane of any particular orientation relative to the earth at any time and the incoming beam solar radiation can be described in terms of several angles (Figure 5.7).

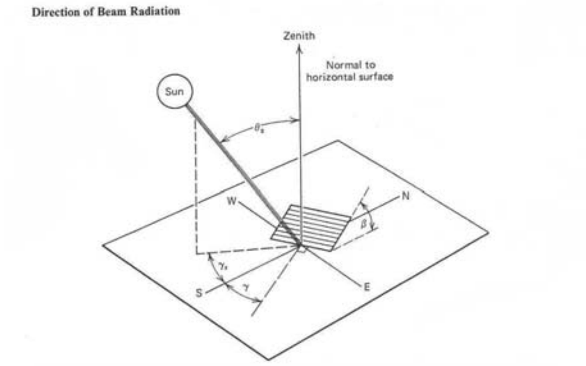


Figure 5.7: Zenith angle, slope and surface azimuth angle for a tilted surface (Duffie and Beckman 1980)

- Latitude (ø): the angular location north or south of the equator, north positive $\{-90 \leq ø \leq 90\}$
- Declination (δ): the angular position of the sun at solar noon with respect to the plane of the equator, north positive $\{-23.5^0 \leq \delta \leq 23.5^0\}$
- Slope (β): the angle between the plane surface and the horizontal $\{0 \leq \beta \leq 180\}$
- Surface Azimuth Angle (γ): the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, west positive $\{-180 \leq \gamma \leq 180\}$
- Hour Angle (ω): the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour, morning negative afternoon positive.
- Angle of Incidence (θ): the angle between the beam radiation on a surface and the normal to that surface.

The equation relating the angle of incidence of beam radiation, θ, and the other angles is:

$$\cos\theta = \sin\delta \sin ø \cos\beta - \sin\delta \cos ø \sin\beta \cos\gamma + \cos\delta \cos ø \cos\beta \cos\omega + \cos\delta \sin ø \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega \quad (5.4)$$

For fixed surfaces sloped toward the south or north, i.e. with surface azimuth angles, γ of 0^0 or 180^0, the last term drops out. For vertical surface $\beta = 90^0$ and the equation becomes:

$$\cos\theta = -\sin\delta \cos ø \cos\gamma + \cos\delta \sin ø \cos\gamma \cos\omega + \cos\delta \sin\gamma \sin\omega \quad (5.5)$$

For horizontal surfaces, $\beta = 0^0$, and the angle of incidence is the zenith angle of the sun, θ_z, Equation (5.4) becomes:

$\cos \theta_z = \cos \delta \cos ø \cos \omega + \sin \delta \sin ø$ (5.6)

Equation (5.6) can be solved for the sunset hour angle, ω_s, when $\theta_z = 90$

$\cos \omega_s = - \tan ø \tan \delta$ (5.7)

The number of daylight hours can be calculated by:

$N = 2/15 \cos^{-1} (-\tan ø \tan \delta)$ (5.8)

Ratio of Beam Radiation on Tilted Surface to That on Horizontal Surface: The geometric factor, R_b, the ration of beam radiation on the tilted surface to that on a horizontal surface at any time can be calculated by appropriate use of Equation (5.4).

$R_b = \cos \theta / \cos \theta_z$ (5.9)

$\cos \theta$ and $\cos \theta_z$ can be both determined from equation (5.4)

Extraterrestrial Radiation on Horizontal Surface: Several types of radiation calculations are usually done using normalised radiation levels, which is the ratio of radiation level to the theoretically possible radiation that would be available if there were no atmosphere. For these calculations, a method to calculate the Extraterrestrial radiation is needed. The following equation can be used to calculate the solar radiation outside the atmosphere incident on a horizontal plane at any point in time:

$G_o = G_{sc} [1 + 0.033 \cos (360n/365)] \cos \theta_z$ (5.10)

Where G_{sc} is the solar constant, and n is the day of the year. Equation (5.6) gives $\cos \theta_z$.

It is often necessary for calculations of daily solar radiation to have the integrated daily extraterrestrial radiation on a horizontal surface, H_o. this is obtained by integrating Equation (5.10) over the period from sunrise to sunset. If G_{sc} is in watts per square meter, H_o in Joules per square meter is:

$H_o = [(24*3600\ G_{sc})/\ \pi] * [1 + 0.033 \cos(360n/365)] * [\cos ø \cos \delta \sin \omega_s + ((2\ \pi\ \omega_s)/360) \sin ø \sin \delta]$ (5.11)

Where ω_s = sunset hour angle, in degrees, from Equation (5.7).

Estimation of Clear Sky Radiation: As the effects of the atmosphere in scattering and absorbing radiation are variable with time, it is useful to define a standard clear sky, and calculate the radiation which would be received on a horizontal surface under these standard conditions. The method, presented by Hottel (1979), can be used to estimate the beam radiation transmitted through clear atmosphere. This method takes into account zenith angle and altitude for a standard atmosphere and for four climate types.

The atmospheric transmittance for beam radiation, τ_b is $G_{bn}/\ G_o$ and is given in the form:

$$\tau_b = a_o + a_1 e^{-k/\cos\theta z} \quad (5.12)$$

The constant a_o, a_1, and K for the standard atmosphere with 23 km visibility are found from a_o^*, a_1^*, and K^*, which are given for altitudes less than 2.5 km by:

$$a_o^* = 0.4237 - 0.00821\ (6 - A)^2 \quad (5.13)$$
$$a_1^* = 0.5055 + 0.00595\ (6.5 - A)^2 \quad (5.14)$$
$$K^* = 0.2711 + 0.01858\ (2.5 - A)^2 \quad (5.15)$$

Where A is the altitude of the observer in kilometres

Correction factors are applied to a_o^*, a_1^*, and k^* to allow for change in climate types. The correction factors $r_o = a_o/\ a_o^*$, $r_1 = a_1/\ a_1^*$ and $r_k = k/k^*$ are given in the table (5.1). Thus the transmittance of this standard atmosphere for beam radiation can be determined for any zenith angle and altitude up to 2.5 km.

Climate type	r_o	r_1	r_k
Tropical	0.95	0.98	1.02
Mid-Latitude Summer	0.97	0.99	1.02
Subarctic Summer	0.99	0.99	1.01
Mid-Latitude Winter	1.03	1.01	1

Table 5.1: Correction Factors for Different Climate Types

The clear sky beam normal radiation is then:

$$G_{cnb} = G_{on} \tau_b \quad (5.16)$$

Where G_{on} is obtained from Equation (5.1)
The clear sky horizontal beam radiation is:

$$G_{cb} = G_{on} \tau_b \cos \theta_z \quad (5.17)$$

For periods of an hour, the clear sky horizontal radiation is:

$$I_{cb} = I_{on} \tau_b \cos \theta_z \quad (5.18)$$

To get the total radiation, it is necessary to estimate the clear sky diffuse radiation on a horizontal surface. The empirical relationship between the transmission coefficient for beam and diffuse radiation for clear sky, which was developed by Liu and Jordan (1960), can be used:

$$\tau_d = 0.2710 - 0.2939 \tau_b \quad (5.19)$$

Where τ_d is G_d/G_o (or I_d/I_o) the ratio of diffuse radiation to the extraterrestrial radiation on a horizontal plane. So, the clear sky horizontal diffuse radiation is:

$$I_{cd} = I_{on} \tau_d \cos \theta_z \quad (5.20)$$

5.1.1.4 Sol-air Temperature

The Sol-Air temperature is used to summarize the surface temperature of the opaque parts of the building envelope. It is a method of determining the heating effect of the outside surface due to solar irradiance. When the external surface is exposed to solar radiation, the temperature of the external face of the opaque element increases; therefore, heat flow to the interior or the building will also increase. This superficial temperature is termed the sol-air temperature. Sol-air Temperature is the equivalent outdoor temperature that will cause the same rate of heat flow at the surface and the same temperature distribution through the material as the current outdoor air temperature, the solar gains on the surface and the net radiation exchange between the surface and its environment.

$T_s = T_o + (G * a * R_{so})$
(5.21)

where:

T_s = Sol-air temperature (°C),

T_o = Outside air temperature (°C),

G = total incident solar radiation (W/m²),

a = solar absorptance of surface (0-1), and

R_{so} = outside air-film resistance.

Indirect Gains: The incident solar radiation on opaque elements acts to increase the external surface temperature of the element, which increases the ΔT value of the conduction gain component. As a result, more heat will flow from outside to inside. In order to isolate indirect gains, it has to be dealt with the increased temperature due to solar radiation separately from the outside air temperature. In this case, only the sol-air excess temperature can be used:

$Q_s = U\ A\ (G\ abs\ R_{so})$ (5.22)

Where:

Qs = total direct solar gain in Watts (W),

U = the U-Value of the specified element,

G = the total solar radiation incident on the specified window (W/m²),

A = the surface area of the opaque element in m²,

abs = the surface absorption of the element, and

R_{so} = the outside air-film resistance.

Surface absorption is a function of colour and material, referring to the amount of solar radiation absorbed by the surface. Air film resistance results from convection currents at the surface of a material. As the surface heats up or cools down, it affects the temperature of the adjacent air. The U-Value represents the air-to-air thermal transmittance of an element, which refers to how well an element conducts heat from one side to the other.

The units of the U-Value are Watts per metre squared Kelvin (W/m² K). This means that, if a wall material had a U-Value of 1 W/m² K, for every degree of temperature difference between the inside and outside surface, 1 Watt of heat energy would flow through each metre squared of its surface. The total heat gain due to conduction through the wall can be calculated as follows:

$$Q = U\ A\ \Delta T \quad (5.23)$$

Where:

Q = the resultant heat flow (Watts)

A = the surface area through which the heat flows (m²)

ΔT = the temperature difference between the warm and cold sides of the material (K).

5.1.2 Solar Shading

For an efficient solar control in architecture the relationship between the sun and the building should be understood in order to achieve an efficient design. The solar-control tends to minimize the sun's effect on the building when more heat is not required during overheated period of the year. To get maximum solar radiation when heat is needed during the under-heated period. For solar control, it is necessary to determine the position of the sun in relation to the building elevation on a specific date (EMU, 2003). The basic position of the sun at any instant can be identified by two angles (Figure 5.8): the solar altitude (angle gamma) and azimuth (angle alpha).

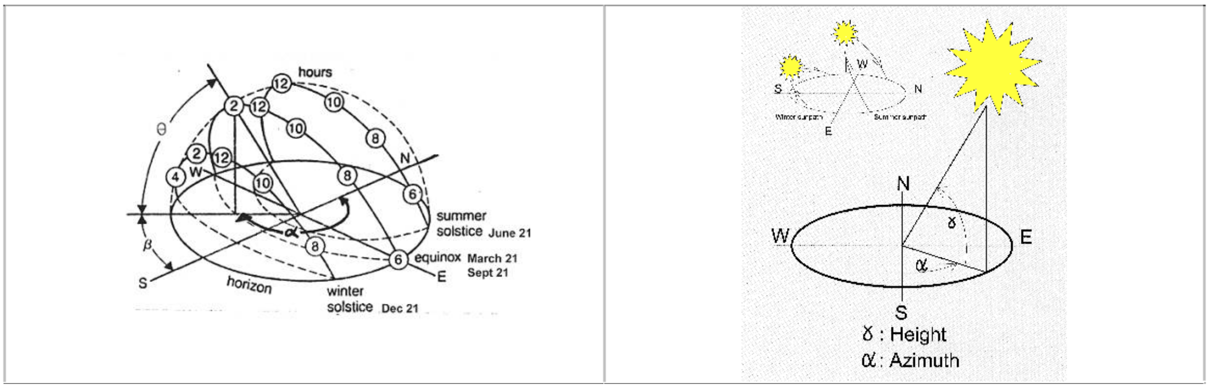


Figure 5.8: The Position of the Sun in the Sky Hemisphere and Solar Angles (EMU, 2003, and ESRU, 1992)

5.1.2.1 Solar Altitude and Azimuth

The variations in solar altitude and azimuth, as was previously mentioned, are the consequences of the daily rotation of the earth about its polar axis, and the annual movement of the earth about the sun. Therefore, the angular position of the sun as seen from a particular place on the surface of the earth varies from hour to hour and from season to season. The position of the sun in the sky hemisphere can be determined by two angles (EMU, 2003);

a. Solar Altitude Angle (SOLALT) is the vertical angle at the point of observation, between the horizon plane and the line connecting the sun to the observer.
b. Solar Azimuth Angle (SOLAZM) is the angle at the point of observation measured at the horizontal plane between the north direction and the vertical plane containing the sun.

Thus, the solar geometry can by identified by the following equations (Muneer, 1997):

$$\sin SOLALT = \sin LAT \sin DEC - \cos LAT \cos DEC \cos GHA \quad (5.24)$$

$$\cos SOLAZM = \cos DEC (\cos LAT \tan DEC + \sin LAT \cos GHA)/\cos SOLALT \quad (5.25)$$

Where GHA = Greenwich Hour Angle

5.1.2.2 Sun Path Diagrams

The angular relationship between the sun, the building and obstructing bodies have to be considered in order to assess site and building layouts for passive solar design. Different approaches exist to analyse the direct solar beam: Graphical plots; Computer based trigonometric methods; Scale models examined using a sundial device; and Scale models using a device that mechanically reproduces the geometric movement of the sun (heliodon) (ESRU, 1992).

Sun charts can assess the degree of shading on the building facades due to surrounding buildings, facade projections and local landscape features. There are several methods of projections to present the apparent movement of the sun on the sky hemisphere. By using such methods, the apparent three-dimensional movement of the sun can be represented on a two-dimensional chart which is called Solar Charts or Sun Path Diagram (EMU, 2003). Sun path diagram prepared by the aid of the equidistant projection provides easy and direct reading for the required information.

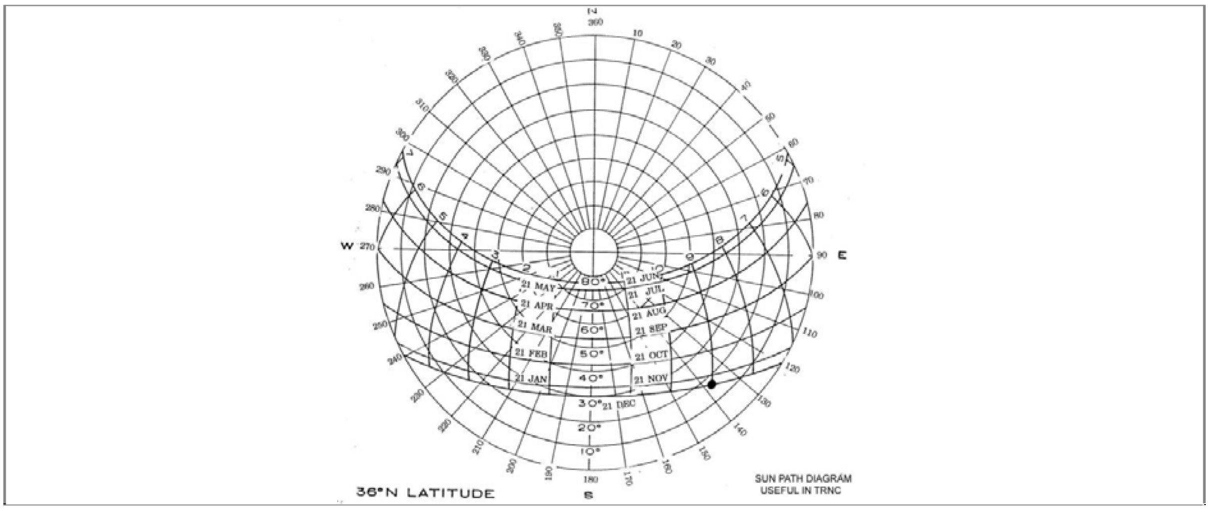


Figure 5.9: Sun Path Diagram (EMU, 2003)

The altitude of the sun above the horizon is read on the various concentric circles, from 0 to 90 degrees. The azimuth scale is set around the perimeter of the chart. The azimuth angle can be read by setting a straight line from the centre of the chart to the intersection of the required hour and date path lines and observing where it crosses the chart perimeter (ESRU, 1992). Group of curves extending from East to West show the sun path at various dates. The two extreme curves represent sun path in two solstices, June 21 and December 21. Sun paths for other days are located between these extremes. Vertical radius in the chart represent solar noon, while group of curved lines on both sides of the vertical radius represent solar hours between sunrise and sunset. Sunrise and sunset times can be read from the intersection of sun path curve and the peripheral circle (EMU, 2003). In equinox days, March 21 and September 21, the sun rises at 6:00 am and sets at 6:00 pm. In summer the sun rises earlier and sets later, in winter it rises late and sets earlier. For different latitudes, different Sun Path Diagrams are required (ESRU, 1992).

5.2 A Comparison between Radial and Rectangular Forms

5.2.1 Introduction to Parametric Studies

The parametric studies are structured into four chapters (Figure 5.10). Each chapter represents a distinctive contribution towards overcoming the deficiencies and limitations of the techniques applied at present. Each study raises separate but overlapping issues and the four studies together cover the basic classified types of urban forms. The possible application of these experimental models in Palestine is discussed, in order to highlight the focal point of the research.

The first experiment compares radial and rectangular forms in order to explore the solar behaviour of the radial form and to illustrate the methodology adopted by the researcher to evaluate the urban forms with regard to the generated shadow patterns and thermal performance. The second experiment compares radial and rectangular urban canyons to clarify the influence of the self-shading effect of the radial form. The experiment intends to evaluate the most suitable spacing between buildings to avoid overshadowing and maintain good solar accessibility. Moreover, the experiment compares patterns with different orientations, in order to investigate 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 to determine the urban fabric that allows the achievement of high urban density under optimal solar insolation conditions.

The third experiment contains studies related to aspects of solar insolation in bilateral types of building, where the distribution of exposed areas, in a way that assures the access of sunrays to all residential units located on both sides of the form, is crucial. The study compares different radial forms varying in the extent of their concavity to find out the one with the minimum variation of exposed areas between the two opposite facades. The final experiment of the parametric studies deals with the evaluation and analysis of the radial forms and the rectangular U-shape. This experiment aims to prove the capability of the methodology which was developed in this research, to evaluate such complex forms.

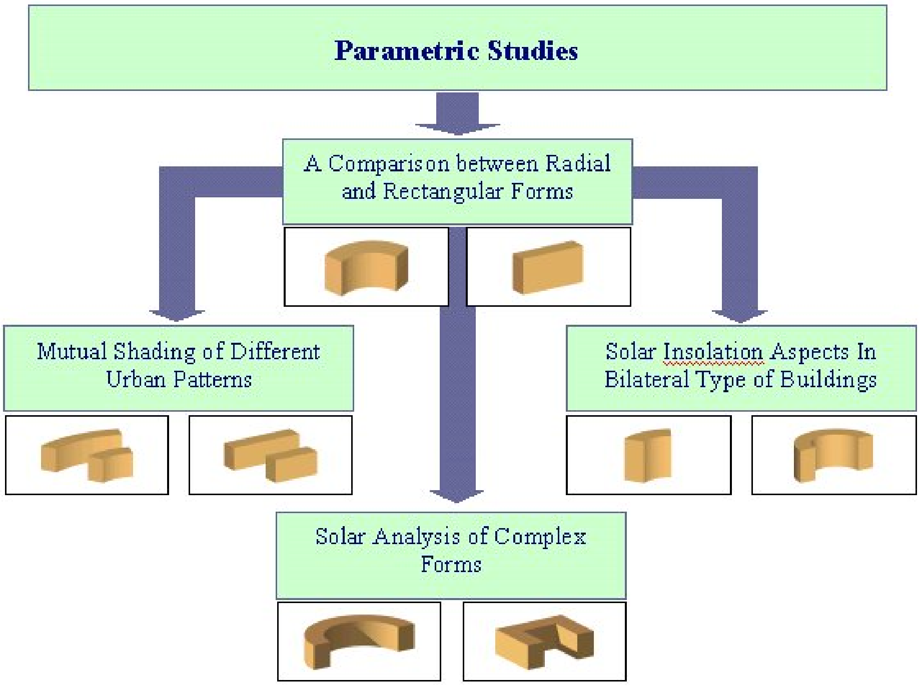


Figure 5.10: The Structure of Parametric Studies

5.2.2 Background

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 5.11), 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.

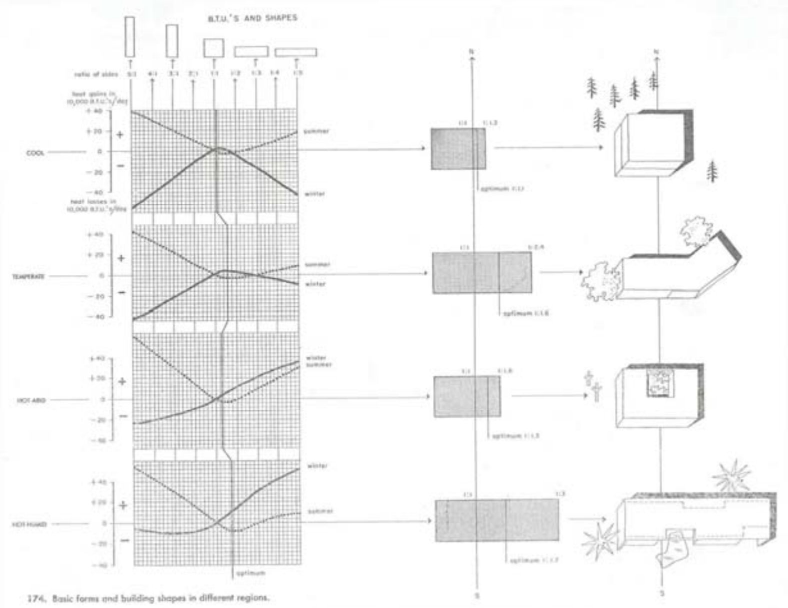


Figure 5.11: Regional Effects on House Shapes: Basic Forms and Building Shapes in Different Regions (Olgyay, 1992)

In addition, Martin and March (1966, 1972) examined a number of simplified or archetypal forms (Figure 5.12) 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.

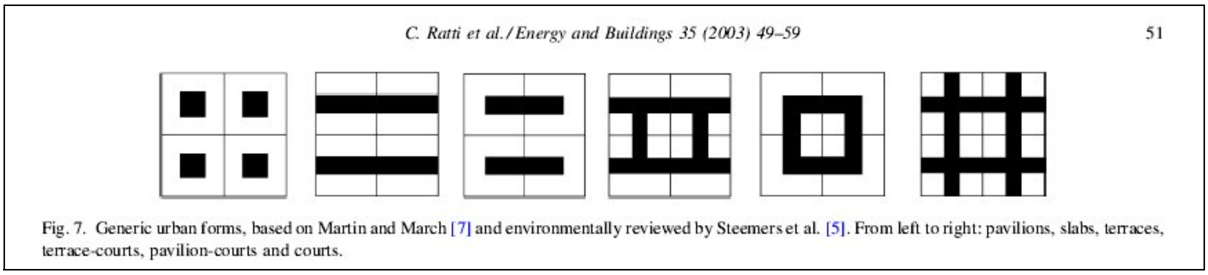


Figure 5.12: Generic Urban Forms, Based on Martin and March (Ratti et al., 2003)

Hence, 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. 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 5.13). 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. 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.

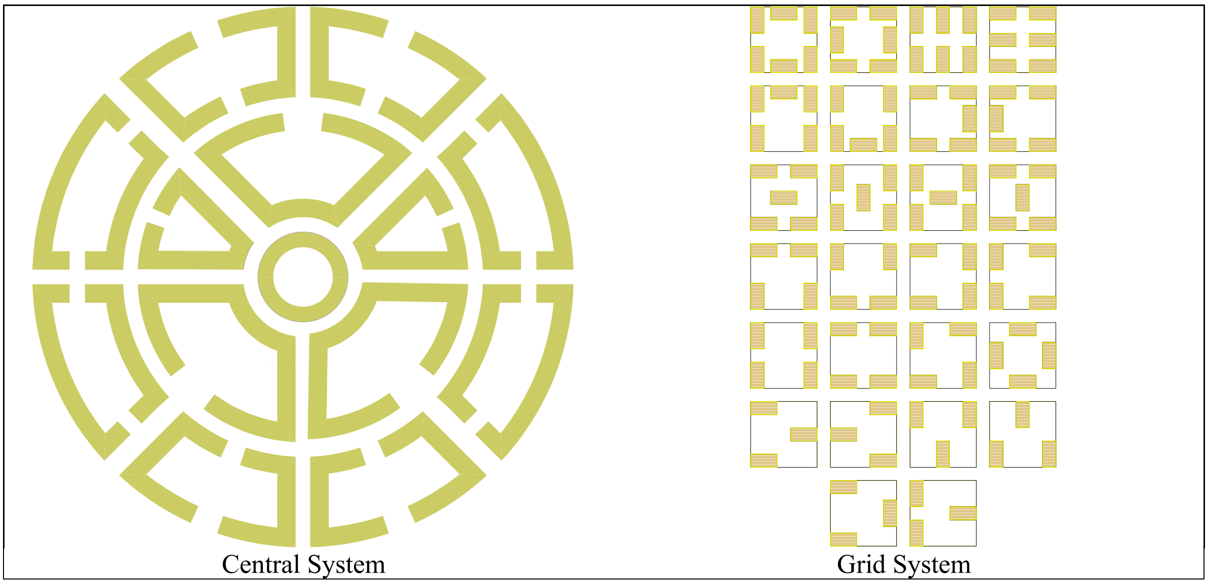


Figure 5.13: Urban Planning Systems

Previous research 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 5.14: Curvilinear Buildings (Brantacan, 2002)

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 5.14). 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.

5.2.3 Aims and Objectives

The experiment aimed to examine the solar performance of the curvilinear form in comparison to the rectangular one. Finding a relation between the geometry of the form and its thermal performance 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 receive maximum radiation during the underheated period while 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 and during the whole year, was conducted to investigate the form which could be most suitable for heating requirements and the one that is most suitable for cooling. 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. Finally, the inter-relationship between solar insolation and the thermal performance of the forms was clarified.

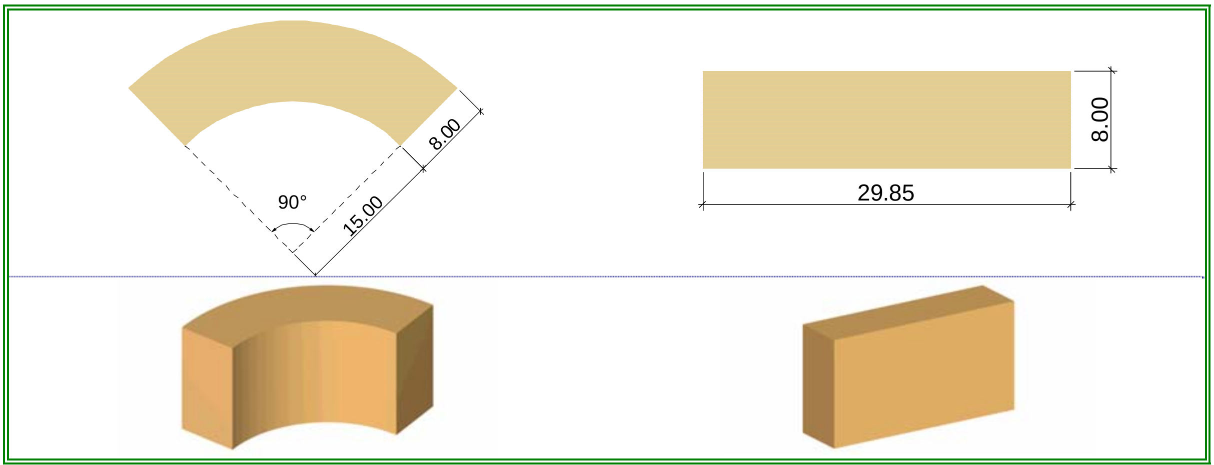


Figure 5.15: The Dimensions of the Radial and Rectangular Forms

The Urban Site: 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 5.15). 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.

5.3 A Comparison between the North-facing Radial Form and the Rectangular Form (Jerusalem Latitude)

i. The Shadow Patterns in Summer

The graph shows the generated shadow pattern in the two opposite facades for both forms in the summer period (Figure 5.16). 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%.

The Rectangular Form			The North-facing Radial Form		
South Facade	North Facade	Average	South Facade	North Facade	Average
57.14 %	42.86 %	50 %	48.57 %	68.01 %	58.29 %
The Variation			The Variation		
14.28 %			19.44 %		
The Average Daily Shaded Area per Hour in Summer					

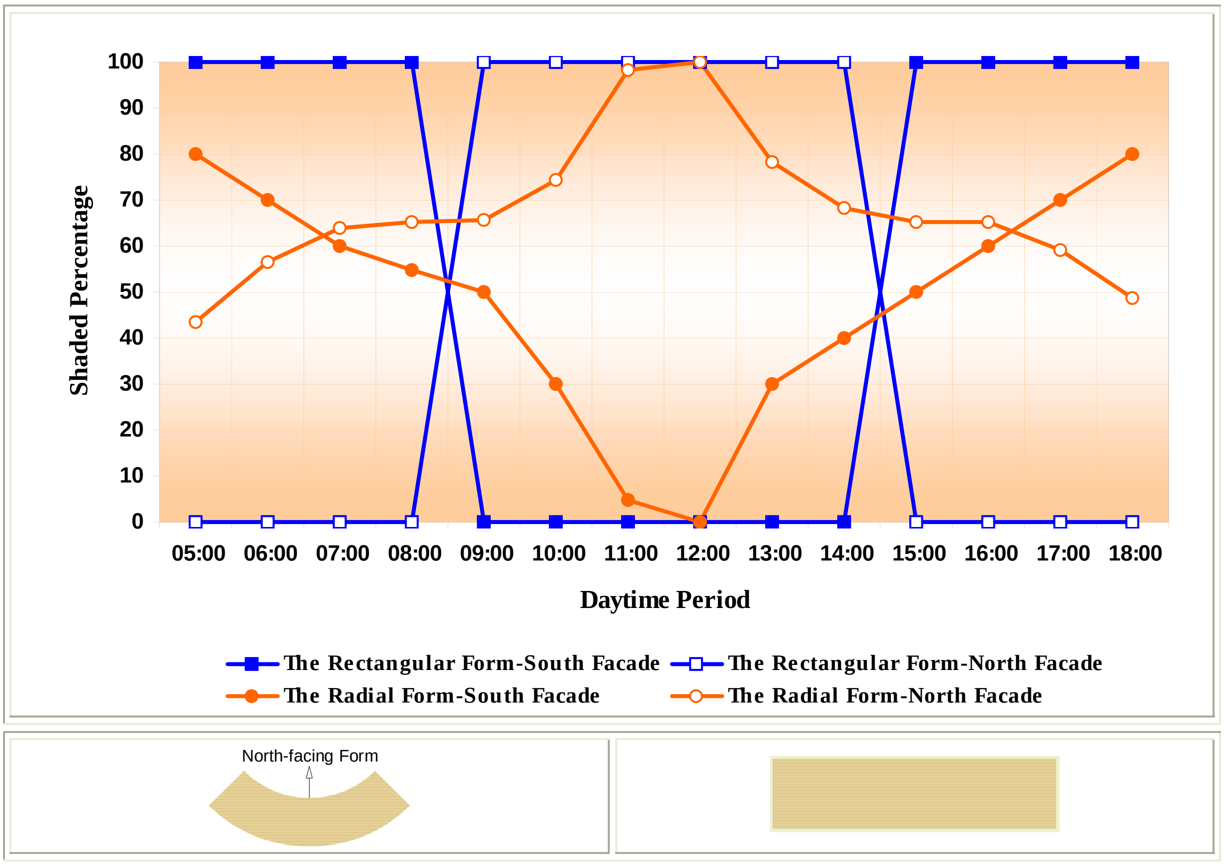


Figure 5.16: The North-facing Radial Form and the Rectangular Form: Shadow Patterns in Summer

The graph reveals that in the rectangular form, the north facade is more exposed to sunrays than the south facade. The north facade is exposed for 8 hours: 4 hours during the forenoon period and 4 hours during the afternoon period. The south facade is exposed for 6 hours during the noon period. This period takes place between approximately 9:00 a.m. and 15:00 p.m. The exposure of the south facade starts when sunrays come directly from the east and ends when sunrays exceed the west direction i.e. when solar azimuth angle is between 90^0 and 270^0 (Figure 5.17). Both facades are either completely shaded or completely exposed, as sunrays exchange their influence on both facades during the daytime period.

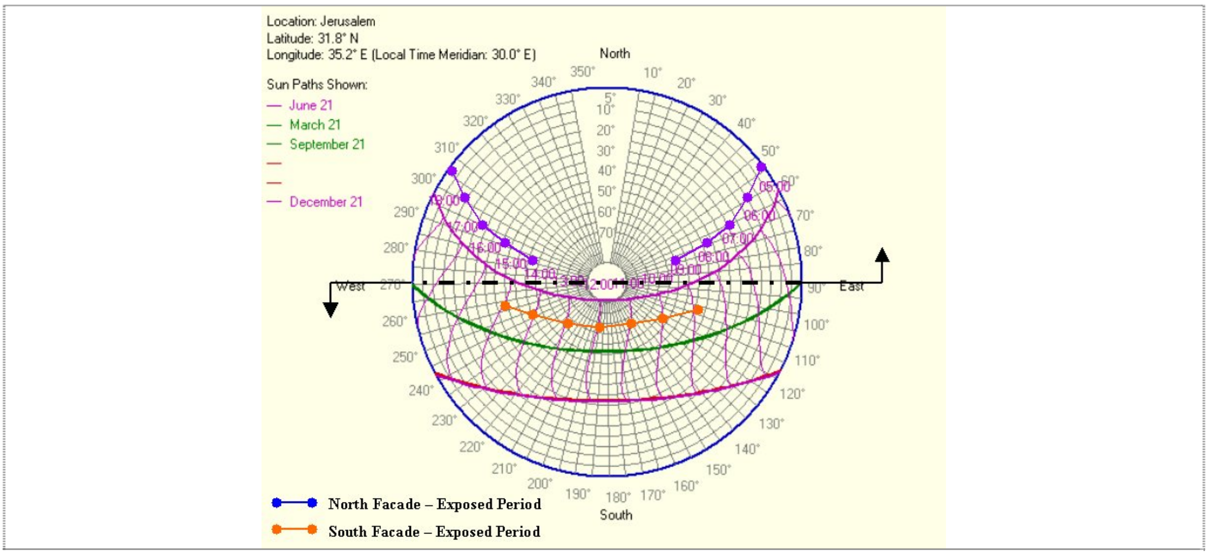


Figure 5.17: The Period of Exposure for the Two Facades of the Rectangular Form

In the radial form, the south facade is more exposed to sunrays than the north facade. The variation between the two facades is maximal at noon, where the south facade is completely exposed for one hour and the north facade is completely shaded at the same time. This period takes place approximately at 12:00 p.m., i.e. when solar azimuth angle equals 180^0. In general, the two facades are partially exposed and can enjoy the sun for the majority of the daytime period. The increment of the increase or decrease of the shaded area in the facades is always higher during the noon period, as the azimuth of the sun changes rapidly during this period. In general, the radial form is more shaded and has more variation between the two opposite facades.

ii. The Shadow Patterns in Winter

The Rectangular Form	The North-facing Radial Form

South Facade	North Facade	Average	South Facade	North Facade	Average
0 %	100 %	50 %	4 %	99.9 %	51.95 %
The Variation			The Variation		
100 %			95.9 %		
The Average Daily Shaded Area per Hour in Winter					

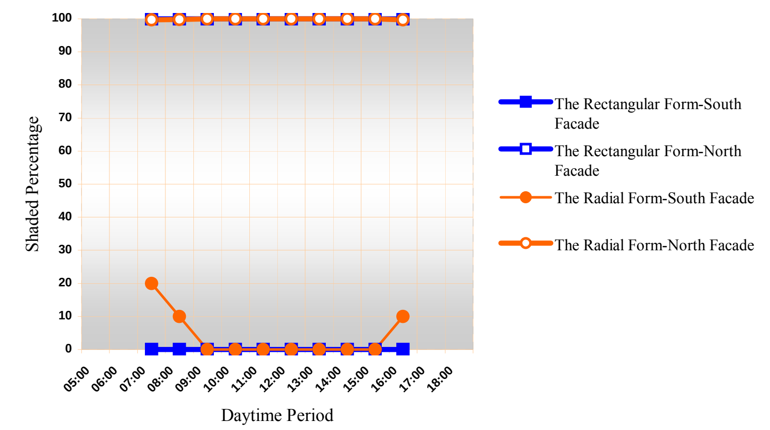


Figure 5.18: The North-facing Radial Form and the Rectangular Form: Shadow Patterns in Winter

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 5.18). 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. In general, the radial form is more shaded and has less variation between the two opposite facades (Figure 5.18).

5.4 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					

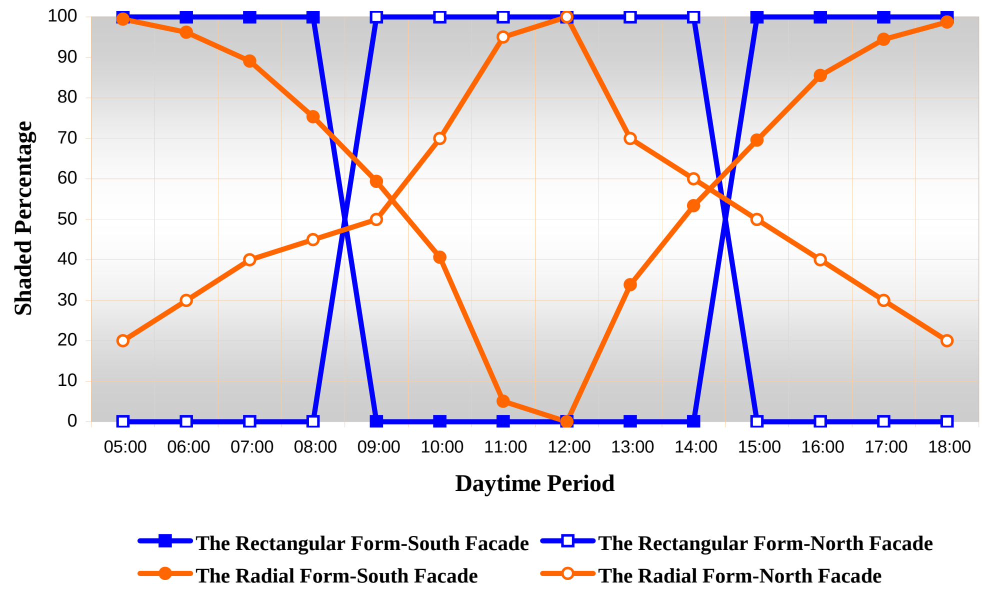


Figure 5.19: The South-facing Radial Form and the Rectangular Form: Shadow Patterns in Summer

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 (Figure 5.19). 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.

The two facades receive the same amount of sunrays twice during the daytime: before and after noon (approximately at 9:00 a.m. and 15:00 p.m.). This takes place when sunrays are approximately parallel to the long axis of the forms (when sunrays come directly from the east or the west direction). In this period, in the rectangular form, sunrays exchange their influence on the two main opposite facades (north and south facades).

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					

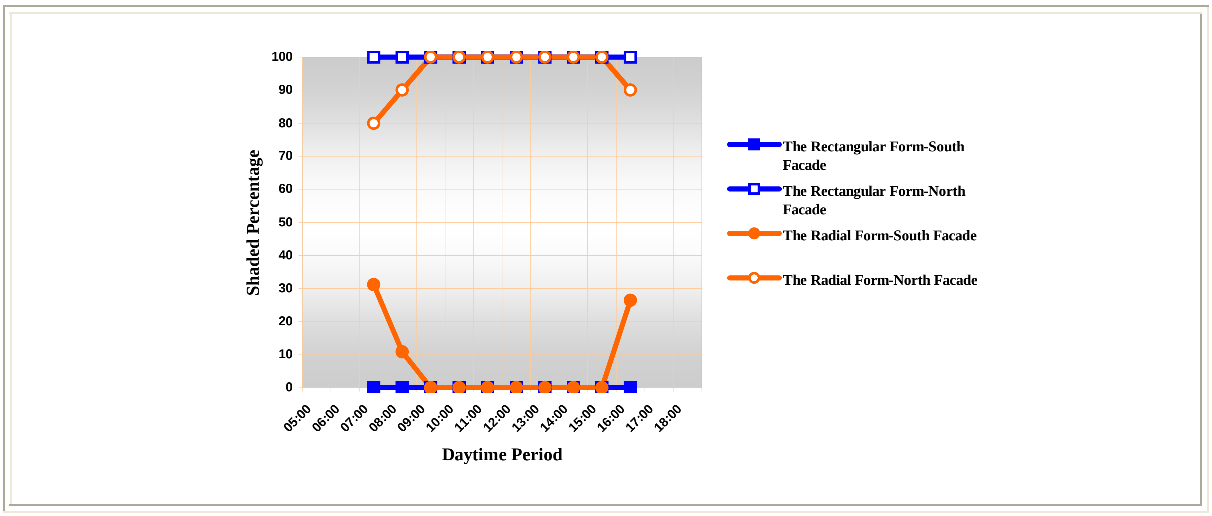
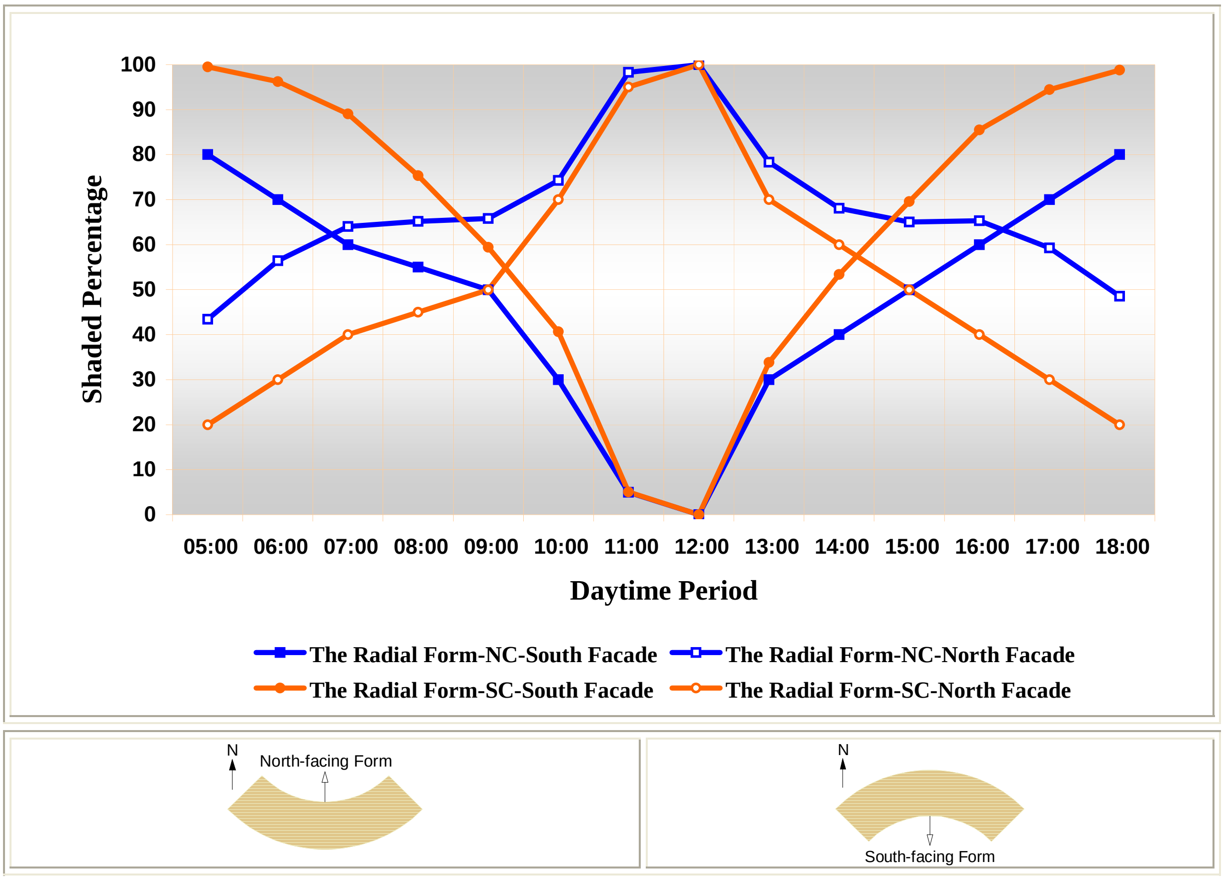


Figure 5.20: The South-facing Radial Form and the Rectangular Form: Shadow Patterns in Winter

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 (Figure 5.20). 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. Thus, the radial form still has the winter sunrays on both facades and therefore the radial form can be more Suitable for bilateral type of buildings. 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.

As the north facade of the rectangular form receives no sunrays at all in wintertime. This situation provides advantages to living areas located to the south side and undermines the northern ones. The radial form receives winter sunrays on both facades. So, the radial form could distribute solar insolation in winter among all living areas in a more even manner.

5.5 A Comparison between the Two Radial Forms
i. Shadow Pattern in Summer



The North-facing Radial Form			The South-facing Radial Form		
South Facade	North Facade	Average	South Facade	North Facade	Average
48.57 %	68.01 %	58.29 %	64.34 %	51.43 %	57.89 %
The Average Daily Shaded Area per Hour in Summer					

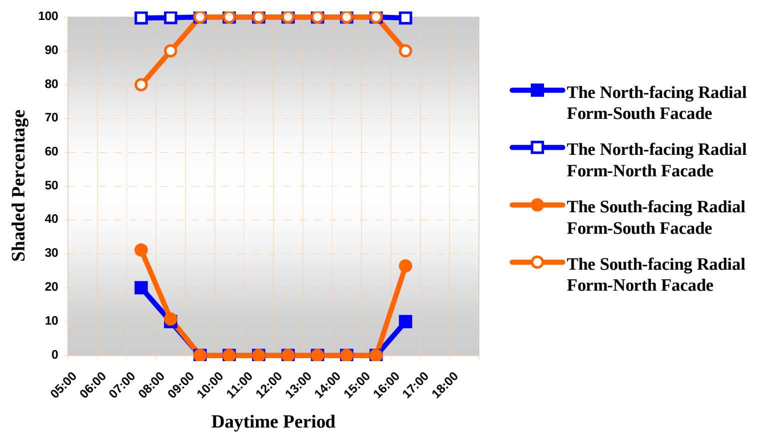
Figure 5.21: The South-facing and North-facing Radial Forms: Shadow Patterns in Summer

This graph (Figure 5.21) illustrates that the north facades in both curves are better exposed to sunrays during the morning and afternoon periods, while the southern facade is better exposed at the noon period. The north facade in the south-facing radial form is more exposed than the southern one, while in the north-facing radial form the opposite is true.

The biggest variation between the two opposite facades in both forms occurs during the noon period; while the south facade is completely exposed and the northern one is completely shaded at this time. This period takes place during the noon period, approximately at 12:00 p.m., i.e. when solar azimuth angle equals 180^0. In general, the largest shaded or exposed areas always occur when the vertical plane of sunrays are perpendicular to the convex or concave facades.

The differences in the shaded areas between the two opposite facades in the early morning and the late afternoon are less for the north-facing radial form. The biggest shaded percentage takes place in the north concave facade of the north-facing radial form. Also, the least shaded percentage takes place in the south convex facade of the same form. The higher shaded percentage always takes place on the concave facade.

ii. Shadow Pattern in Winter



The North-facing Radial Form		The South-facing Radial Form	
South Facade	North Facade	South Facade	North Facade
4 %	99.9 %	6.8 %	96 %
The Average Daily Shaded Area per Hour in Winter			

Figure 5.22: The South-facing and North-facing Radial Forms: Shadow Patterns in Winter

The graph shows (Figure 5.22) that the best-exposed facade is the south facade of the north-facing radial form. Also, the north facade in the same curve generates the biggest area of shadow. The least variation between the two opposite facades in both forms takes place in the early morning and late afternoon. During the rest of daytime period, the north facades of the two forms are fully shaded, while the south facades are fully exposed. It becomes clear from this graph that the north convex facade of the south-facing radial form still has the possibility of receiving sunrays in the early morning and the late afternoon. Therefore the south-facing radial form can be more suitable for bilateral type of buildings as it has less variation between the two opposite facades.

iii. Shadow Patterns in the Two Seasons

The South-facing Radial Form				The North-facing Radial Form			
Summer		Winter		Summer		Winter	
South F.	North F.	South F.	North F.	South F.	North F.	South F.	North F.
64.34 %	51.43 %	6.8 %	96 %	48.57 %	68.01 %	4 %	99.9 %

Table 5.2: The Average Shaded Area per Hour in the Two Opposite Facades in the Two Seasons

It is clear from this table (5.2) that the least amount of shaded percentage takes place in the south convex facade of the north-facing radial form in the winter period. The biggest amount of shaded area takes place in the north concave facade of the same form in the same period. It means that this form in the winter period has the largest variation between the two opposite facades with respect to the generated shaded areas.

5.6 Conclusion

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).

As the concavity of the radial form is relatively small, the variation between the amounts of the 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 (the shadow pattern) during the daytime period. This variation in the generated shadow patterns between the radial and rectangular forms is more significant in the summer period due to the increased self-shading effect of the radial form in this period.

One of the clear implications from these graphs is that, in the rectangular facade, the shaded and the exposed periods start and finish suddenly and the two periods exchange their influence on the facades. In the radial form, the shaded and the exposed periods start and finish gradually and the two opposite facades can be exposed to sunrays simultaneously.

5.7 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. Therefore, it is necessary to evaluate the solar performance of both forms in the two seasons. In order to investigate the total shaded area of the two radial forms in both seasons, the shaded area of the side facades for the two forms have to be calculated.

The Shaded Area of the Side Facades of the Two Forms in Both Seasons		
	Summer	Winter
The Shaded Area of the Side Facades for the South-Facing Radial form	46.43 %	20 %
The Shaded Area of the Side Facades for the North-Facing Radial form	53.57 %	80 %
The Average Shaded Area of the Two Forms in Both Seasons		
	Summer	Winter
The Average Total Shaded Area of the South-Facing Radial Form	54.39 %	52.17 %
The Average Total Shaded Area of the North-Facing Radial Form	55.675 %	49.91 %

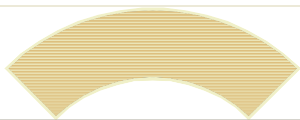
Summer	55.68 %	54.39 %
		
Winter	49.91 %	52.17 %
Average	52.79 %	53.28 %
The North-facing Radial Form is More Preferable in Temperate Climate		

Table 5.3: The Daily Average Shaded Area per Hour in the Two Seasons

The calculation reveals that the north-facing form has the least amount of shaded percentage in winter and the biggest amount of shaded area in summer (Table 5.3). Therefore, it is less exposed to sunrays in summer when avoiding radiation is preferable. It is more exposed to sunrays in winter when receiving radiation is welcomed. Thus, it could be concluded that the north-facing form is preferable in a temperate climate, where it is preferable to receive more sunrays in winter and to avoid them in summer.

For qualitative indicators to compare the relative performance of both forms, the efficiency factor, E_W (a measure of building performance in a temperate climate and for those regions where winter heating is a necessity) can be used (Knowles, 1974). The insulation efficiency of a building form can be measured by comparing the summer solar exposure with the winter solar exposure. The ratio of the winter values to the summer values of this measure reflects the amount of seasonal solar shading inherent in the built forms of the blocks. This factor confirms the suitability of the north-facing form in a temperate climate, as the insolation efficiency of this form is more significant than the insolation efficiency of the south-facing form (Table 5.4).

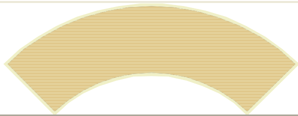
E_W = Winter Solar Exposure/Summer Solar Exposure * 100	
The North-facing Radial Form	E_W = 50.09/44.325 * 100 = 113 %
The South-facing Radial Form	E_W = 47.83/45.61 * 100 = 104.87 %

Table 5.4: Solar Insolation Efficiency for the two Radial Forms

5.7.1 Radial Forms with Unilateral Distribution

The calculation of the Ew for the two opposite facades in both forms reveals that the main variation in the insolation efficiency between the two forms occurs in the south facades (Table 5.5). The solar insolation efficiency of the south facades is of more importance in the unilateral types of building. In such types of building, the south facade is usually designed as the principal facade where the majority of living spaces are situated. 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.

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 Form	35.66 %	93.2 %	261.36 %
The North-facing Radial Form	51.43 %	96 %	186.66 %
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 Form	48.57 %	4 %	8.24 %
The North-facing Radial Form	31.99 %	0.1 %	0.31 %



The South-facing Radial Form is More Suitable for Unilateral Type of Buildings

Table 5.5: Solar Insolation Efficiency of the Two Opposite Facades in Both Forms

In Palestine, the choice between the two forms will depend on the location. The preferable orientation of the radial form has to be controlled by the period of major concern. If the major concern is to avoid summer heat, then the south-facing form is more suitable, as its south facade is more shaded in summer. If the major concern is to receive the winter sunrays, then the north-facing form is preferable, as its south facade is less shaded in winter. The period of major concern in Palestine could be observed by finding the variation of the mean temperature in both the under and overheated periods from the optimal standard temperature (Table 5.6).

	West Bank (Hebron)		
	Temperature	Standard Temperature	The Variation
Monthly Mean Air Temperature in Summer	21	18	3
Monthly Mean Air Temperature in Winter	10	18	- 8
The Mountain Area Requires better Passive Solar Heating Systems in Winter			
	Gaza Strip (Gaza)		
Monthly Mean Air Temperature in Summer	24	18	6
Monthly Mean Air Temperature in Winter	16	18	- 2
The Coastal Plain Requires Passive Solar Solutions of a Limited Extent			

Table 5.6: The Variation of West Bank and Gaza Temperatures from the Optimal One in the Two Seasons

As the mountain area (which has cold winters and temperate to hot-dry summers) requires better passive solar heating systems during the winter, the north-facing radial form will be more advantageous. However, as the climate along the coastal plain (which has hot, humid summers and temperate winters) requires passive solar solutions of a limited extent, the south-facing radial form will be more beneficial.

In general, the south-facing form could be more beneficial for cooling requirements, as the south facade in this form is more shaded during both seasons (Figure 5.23); also, the form has a greater average annual shaded percentage. The north-facing form could be more advantageous for heating requirements, as the south facade of this form is less shaded during both seasons and has a smaller average annual shaded percentage.

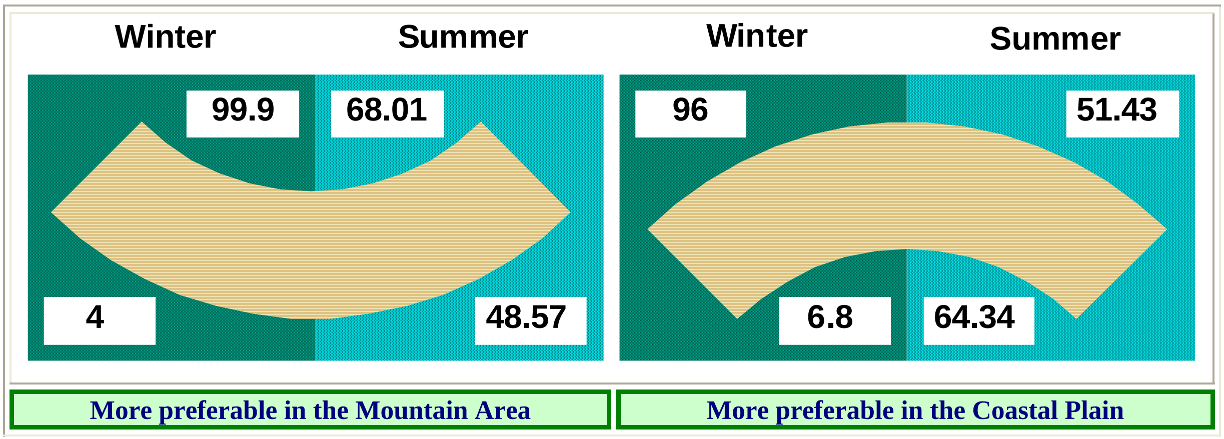


Figure 5.23: The Shaded Area of the Two Opposite Facades in the Two Seasons

5.7.2 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, as this pattern can allow for greater building intensity; in Palestine, the question of building intensity is very important due to the lack of land and the need to accommodate millions of Palestinian refuges and returnees. Such a design is also 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 5.24). 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, especially the south-facing one, 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.

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

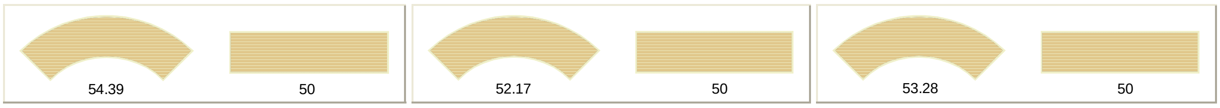
Figure 5.24: Radial and Rectangular Forms with Bilateral Distribution

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.

5.7.3 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 5.7).

The Shaded Area in Summer Period					
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 %	54.39 %
The Shaded Area in Winter Period					
The Rectangular Form			The South-facing Radial Form		
South Facade	North Facade	Average	South Facade	North Facade	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 Facade	North Facade	Average	South Facade	North Facade	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

Table 5.7: The Average Daily Shaded Area for the Radial and Rectangular Forms 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 5.8). 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 %

Table 5.8: The Average Exposed Area for the Radial and Rectangular Forms in the Two Seasons

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 5.25).

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 5.25: The Applications of the Radial and Rectangular Forms in Palestinian Territories

The calculation of Ew (Table 5.9) 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.

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 Form	35.66 %	93.2 %	261.36 %
The Rectangular Form	42.86 %	100 %	233.32 %

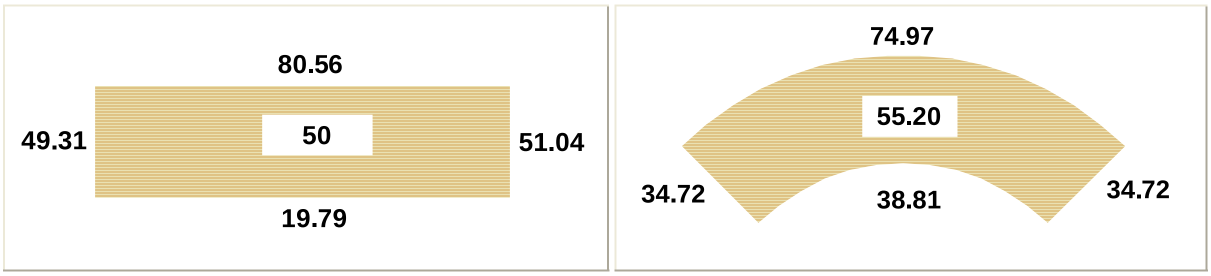
The Solar Insolation Efficiency of the North Facades in the Two Forms			
	The Exposed Area of the North Facades		
	Summer	Winter	Ew
The South-facing Radial Form	48.57 %	4 %	8.24 %
The Rectangular Form	57.14 %	0 %	0 %

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

Table 5.9: Solar Insolation Efficiency of the Radial and Rectangular Forms

5.7.4 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

Table 5.10: 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 (Table 5.10).

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).

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			

Table 5.11: The Variation between the Two Opposite Facades with Regard to the Generated Shaded Area

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 5.11) 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.

	The Average Annual Shaded Area per Hour		The Variation
	The Rectangular Form	The South-facing Radial Form	
The West Facade	49.31 %	34.72 %	14.59 %
The North Facade	80.56 %	74.97 %	5.59 %
The East Facade	51.04 %	34.72 %	16.32 %
The South Facade	19.79 %	38.81 %	19.02 %
Total Average	50 %	55.20 %	5.20 %

Table 5.12: The Variation between the South-facing Radial Form and the Rectangular Form

Table 5.12 shows that the minimum variation in the shaded area is between the north facades and the maximum variation is between the south facades. All facades in the radial form are less shaded than the identical facades in the rectangular form (except the south facade), as these facades are more directed towards the south.

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

Table 5.13: The Average Annual Exposed Area Per Hour for Vertical Surfaces in Jerusalem

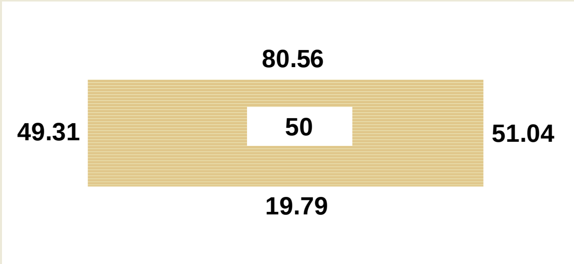
As the rectangular form does not generate any self-shading effect, measurements in this case could be applicable to any vertical surface in Palestine. Although it is well-known among architects in Palestine that the south facade is better exposed than the northern one, this does not recognise clearly 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 5.13). The average annual shaded area per hour for vertical surfaces in Jerusalem for each month is also indicated in the table 5.14.

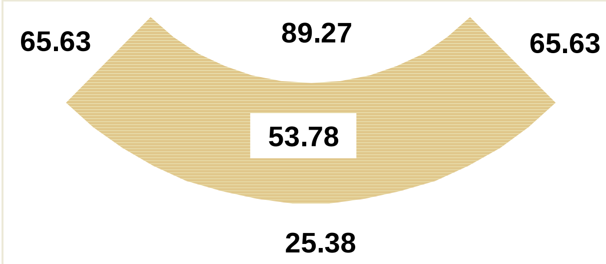
	West Facade	North Facade	East Facade	South Facade	Total
Jan	50 %	100 %	50 %	0 %	50 %
Feb	50 %	100 %	50 %	0 %	50 %
Mar	50 %	100 %	50 %	0 %	50 %
Apr	50 %	76.92 %	50 %	23.08 %	50 %
May	50 %	53.57 %	50 %	46.43 %	50 %
Jun	50 %	42.86 %	50 %	57.14 %	50 %
Jul	50 %	50 %	50 %	50 %	50 %
Aug	50 %	69.23 %	50 %	30.77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

Table 5.14: The Average Daily Shaded Area per Hour for Vertical Surfaces in Jerusalem in Each Month

ii. A Comparison between the Rectangular Form and the North-facing Radial Form

	The Average Annual Shaded Area per Hour	
	The Rectangular Form	The North-facing Radial Form
West Facade	49.31 %	65.63 %
The Outer Surface-South	19.79 %	25.38 %
The East Facade	51.04 %	65.63 %
The Inner Surface-North	80.56 %	89.27 %
Total Average	50 %	53.78 %





More suitable for heating requirements	More suitable for cooling requirements

Table 5.15: The Average Annual Shaded Area per Hour for the Two Forms

Similarly, in this position the radial form generates more shadow over the year than the rectangular one, due to the self-shading effect of the radial form. Therefore, the radial form is more suitable for cooling requirements, while the rectangular form best suits heating requirements (Table 5.15).

The comparison between the identical facades in both forms reveals that the least variation of the shaded percentage is between the south facades. All facades in the radial form have bigger shaded areas than their counterparts in the rectangular form as all facades in the radial form are more directed towards the north (Table 5.16).

	The Average Annual Shaded Area per Hour		The Variation
	The Rectangular Form	The North-facing Radial Form	
The West Facade	49.31 %	65.63 %	16.32 %
The South Facade	19.79 %	25.38 %	5.59 %
The East Facade	51.04 %	65.63 %	14.59 %
The North Facade	80.56 %	89.27 %	8.71 %
Total Average	50 %	53.78 %	3.78 %

Table 5.16: The Variation between the North-facing Radial Form and the Rectangular Form

iii. A Comparison Between the Two Radial Forms

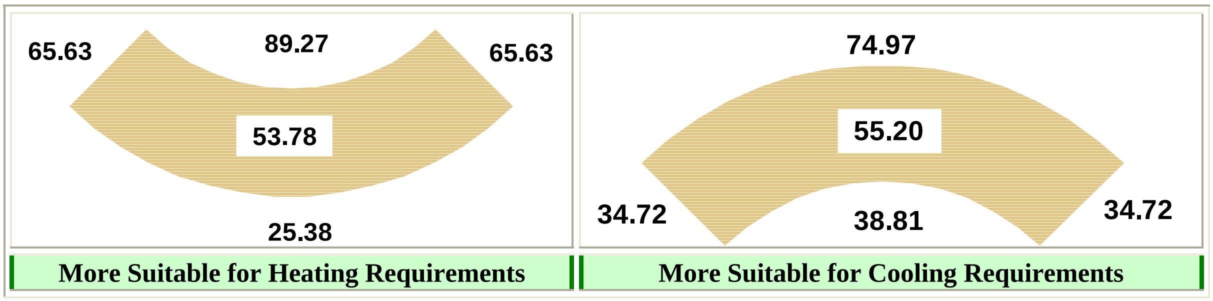


Figure 5.26: The Average Annual Shaded Area per Hour for the Two Radial Forms

By comparing the two radial forms with respect to the generated annual shaded area, it can be observed that the north-facing form is more suitable for heating requirements, as it generates less shadow over the year. On the other hand, the south-facing form is adequate for cooling requirements, as it generates more shadow over the year (Figure 5.26).

It can also be noted that the north convex facade in the south-facing form is less shaded than the north concave facade in the north-facing form. In addition, the south convex facade in the north-facing form is less shaded than the south concave facade in the south-facing form and the greatest shaded percentage always occurs in the concave facades.

	The Average Annual Shaded Area per Hour		The Variation
	South-facing Radial Form	North-facing Radial Form	
The West Facade	34.72 %	65.63 %	30.91 %
The South Facade	38.81 %	25.38 %	13.43 %
The East Facade	34.72 %	65.63 %	30.91 %
The North Facade	74.97 %	89.27 %	14.3 %
Total Average	55.20 %	53.78 %	1.42 %

Table 5.17: The Variation between the Two Radial Forms

Table 5.17 shows that the side facades of the south-facing form are less shaded, as they are more directed towards the south, while the side facades of the north-facing form are more shaded as they are more directed towards the north. The minimum variation in the shaded percentage between the two forms occurs in the southern facades. In both forms, the northern facades generate the maximum shaded area. The side facades in each form have the same amount of shaded area over the year.

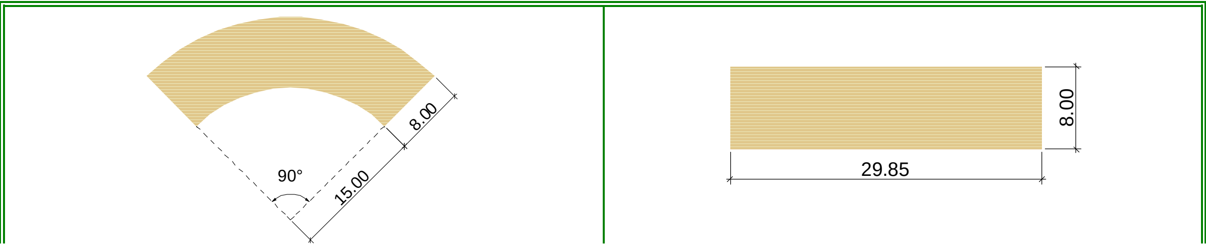
	The South-facing Radial Form	The North-facing Radial Form
The South Facade	38.81 %	25.38 %
The North Facade	74.97 %	89.27 %
The Variation	36.16 %	63.89 %

Table 5.18: The Variation between the Two Opposite Facades in the Radial Forms

Table 5.18 illustrates that the variation between the two opposite facades (northern and southern) is less in the case of the south-facing form, i.e. the distribution of the shade area in this form over the year is more regular. Thus, it is more suitable for bilateral types of building and where having a regular distribution of sunrays in the two opposite facades is crucial.

5.8 A Comparison Between the Radial and Rectangular Forms - London Latitude

In order to illustrate the universality of the approach and to establish the relation between the thermal performance of forms and solar insolation, the radial and rectangular forms were investigated by using Ecotect (Appendix B3). In addition to numerical calculations of the shaded area, the program provides thermal calculations which support the results obtained from analysing the generated shadow pattern. The forms (Figure 5.27) were analysed by using a London environmental profile.



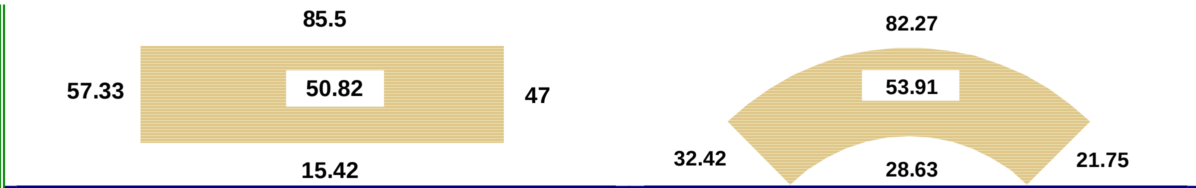
The Urban Site

The height of the forms: 16 m
The depth of the blocks: 8 m
The built volume of the two forms: 3820.8 m3
The floor area of the two forms: 238.8m2
The perimeter of the two forms: 75.7m
The external surface areas of the two forms: 1211.2m2
Fabric: CIBSE concrete block
Environmental File: UK - London

Figure 5.27: The Dimensions of the Radial and Rectangular Forms

5.8.1 The Shadow Patterns
5.8.1.1 The Average Annual Shaded Area

The Average Annual Solar Shade: Location: London, England – UK			
The Rectangular Form		**The Radial Form**	
The South Facade	15.42 %	The South Facade	28.63 %
The North Facade	85.5 %	The North Facade	82.27 %
The West Facade	57.33 %	The West Facade	32.42 %
The East Facade	47 %	The East Facade	21.75 %
Average	50.82 %	Average	53.91 %



More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Table 5.19: The Average Annual Shaded Area for the Radial and the Rectangular Forms

Calculating the average annual shaded area per hour (Table 5.19) reveals that the radial form is more suitable for cooling requirements, as it generates a greater amount of shadow over the whole year, while the rectangular form is more suitable for heating requirements. This result is consistent with the previous derived result regarding the latitude of Jerusalem, and the trend in both cases is almost similar, as both cities have northern latitudes.

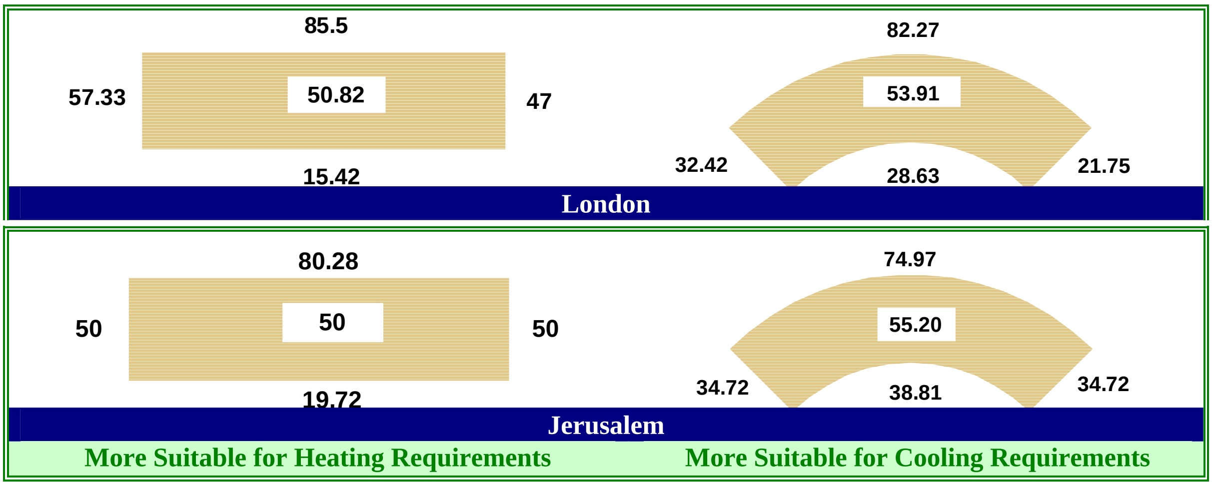


Figure 5.28: The Average Annual Shaded Area for the Radial and the Rectangular Forms in the Two Latitudes

By comparing the result from the London forms with those obtained previously in Jerusalem, it can be observed that in identical forms, the north facades are more shaded and the south facades are less shaded in the case of the London forms (Figure 5.28). Due to the fact that London is located in a more northern latitude than Jerusalem, the north facade is less exposed to sunrays. This variation between the identical facades in both latitudes is more obvious in the radial patterns.

	The Rectangular Form		Variation	The Radial Form		Variation
London	The South Facade	15.42	70.08 %	The South Facade	28.63	53.64 %
	The North Facade	85.5		The North Facade	82.27	
	The Rectangular Form		Variation	The Radial Form		Variation
Jerusalem	The South Facade	19.79	60.77 %	The South Facade	38.81	36.16 %
	The North Facade	80.56		The North Facade	74.97	

Table 5.20: The Variation of the Shaded Area between the Two Opposite Facades in the Two Latitudes

Table 5.20 reveals that the differences in the shaded area between the two opposite facades are smaller in the case of the Jerusalem forms. This trend is greater in the case of the radial forms. Therefore, it can be stated that the effectiveness of bilateral buildings is greater and more suited to the Jerusalem latitude. In London, or latitudes further north, the tendency to have unilateral buildings (with the principal facade facing south) will be preferable because the exposed area is more concentrated on one facade (the southern one).

5.8.1.2 The Average Daily Shaded Area in the Over and Underheated Periods

	The Rectangular Form		The Radial Form	
	The Average Daily Shaded Area			
	Summer	Winter	Summer	Winter
The South Facade	43.94 %	0 %	55.22 %	1.38 %
The North Facade	56.5 %	100 %	61.96 %	98.75 %
The West Facade	56.88 %	51 %	43.75 %	13 %
The East Facade	51 %	51 %	37.5 %	13 %
Average	51.01 %	50.21 %	55.35 %	50.32 %

The Average Daily Shaded Area of the Forms in the Over and Underheated Periods			
	Summer	Winter	Average
The Rectangular Form	51.01 %	50.21 %	50.61 %
The Radial Form	55.35 %	50.32 %	52.84 %

Summer	Winter	Average

Table 5.21: The Average Daily Shaded Area in the over and Underheated Periods

From reviewing the above computation (Table 5.21), it becomes evident that the radial form generates (both in summer and winter) more shaded area than the rectangular one. This mainly refers to the self-shading effect of the radial form. This analysis proves the suitability of the rectangular form (open layout) for heating requirements. 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.

The differences between the radial and rectangular forms are more evident in the summer period, as the variation between the exposed areas in identical facades in the two forms is greatest. This makes the radial form even more advantageous in areas where avoiding summer heat and generating more shadow is required. However, in the London climate, where the major concern is to receive sunrays in winter, the rectangular form will be more suitable.

5.8.1.2.1 A Comparison between London and Jerusalem Forms in the Two Seasons

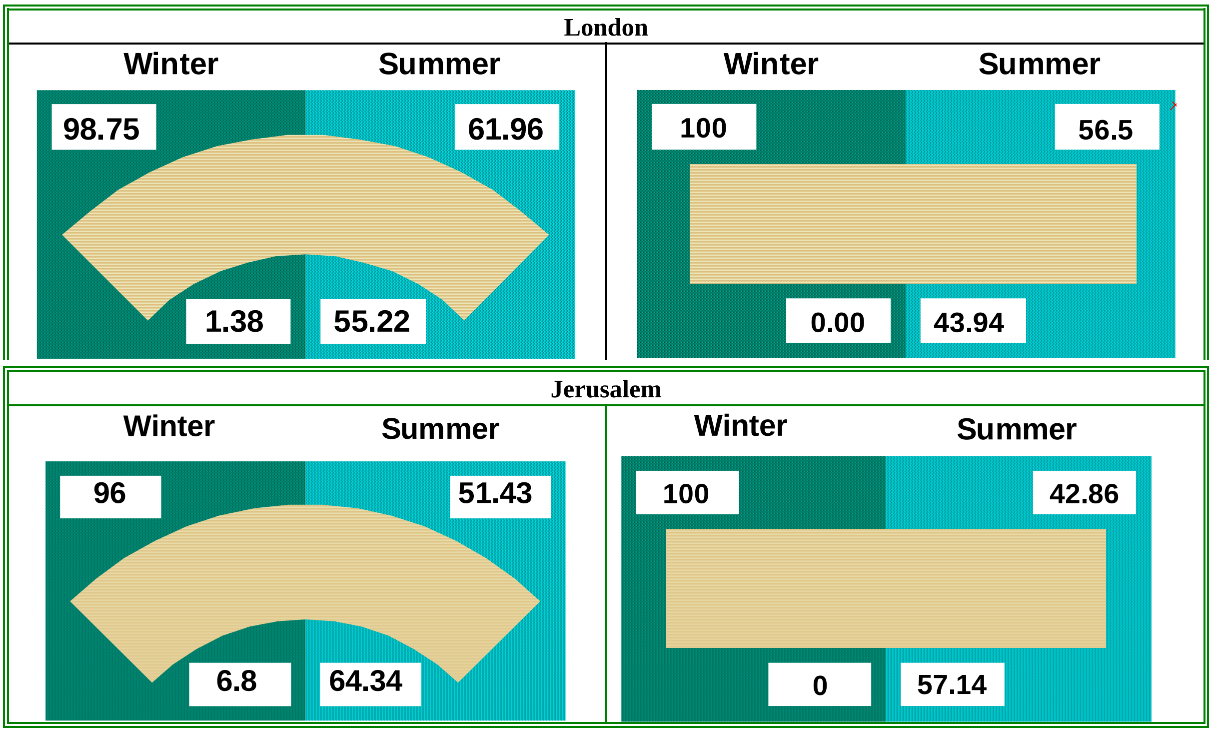


Figure 5.29: A Comparison between London and Jerusalem Forms in the Two Seasons

In the Jerusalem latitude, the north facade is more exposed to sunrays in summer than the southern one, while in the London latitude the north facade is more shaded (Figure 5.29). In both latitudes, the north facades of the rectangular forms receive no sunrays in winter period, while the south facades are fully exposed. In the London latitude, the south facade of the radial form is less shaded than its counterpart in the Jerusalem latitude in both seasons, while the north facade in the London latitude is more shaded than the identical facade in the Jerusalem latitude and the greatest variation between the two latitudes takes place in summer period. This can be refereed to the direction of sunrays, which are more directed towards the south in the case of London latitude.

5.8.1.3 The Daily Shadow Pattern in the Over and Underheated Periods – A Comparison between London and Jerusalem Forms

5.8.1.3.1 The South Facades

i. The Shadow Pattern in Summer

	The South Facades	
	London	Jerusalem
The Rectangular Form	43.94 %	57.14 %
The Radial Form	55.22 %	64.34 %

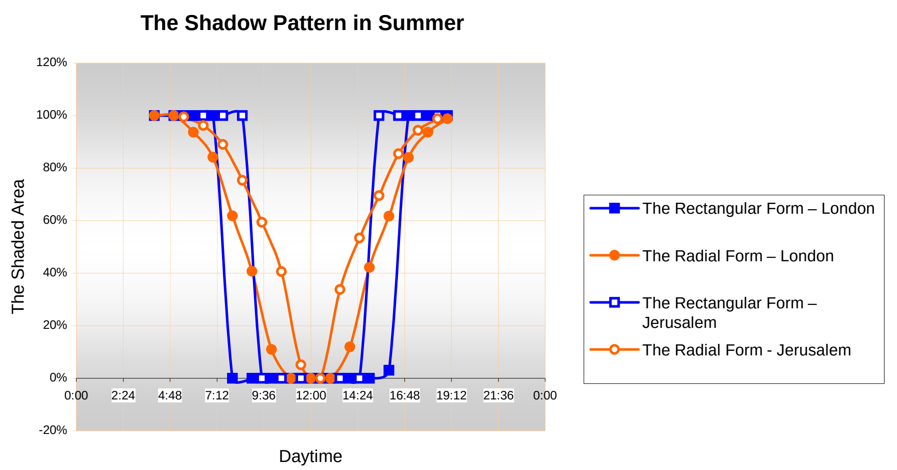


Figure 5.30: The Daily Shadow Pattern in the Overheated Period

The graph shows (Figure 5.30) that facades in the Jerusalem latitude are more shaded. However, in both cases the radial facades are more shaded than the rectangular patterns due to the self-shading effect of the curve. In both latitudes, the rectangular facades are more shaded than the radial ones in the early morning and late afternoon, while the radial facades are more shaded, with greater extent, during the rest of daytime. During the noon period, all facades (radial and rectangular) in both latitudes are fully exposed as sunrays in this period come from the south direction with its vertical plane perpendicular to the centre of the curve, which minimises the self-shading effect of the radial facades.

ii. The Shadow Pattern in Winter

	The South Facades	
	London	Jerusalem
The Rectangular Form	0 %	0 %
The Radial Form	1.38 %	6.8 %

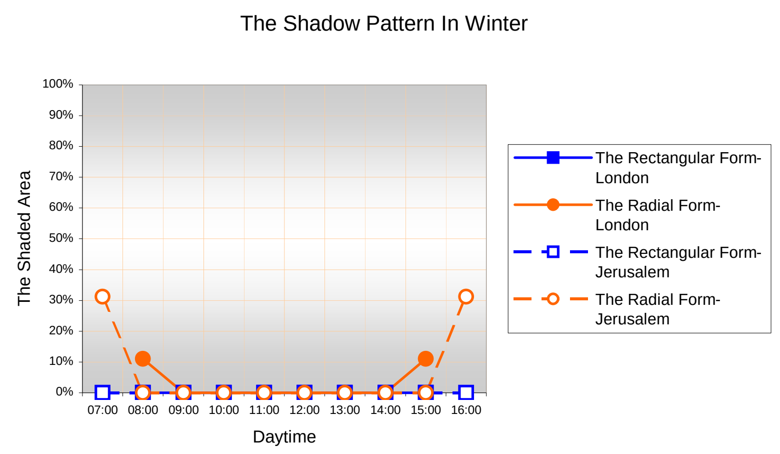


Figure 5.31: The Daily Shadow Pattern in the Underheated Period

The graph (Figure 5.31) illustrates the full exposure of the rectangular facades in winter for both latitudes. On the other hand, the radial facades in both cases are more shaded due to the self–shading effect. However, in the London latitude the facade is less shaded, as sunrays come from more southerly positions. In both latitudes, the self-shading effect of the radial facades occurs during the early morning and the late afternoon, as the self-shading takes place when sunrays are more parallel to the long axis of the radial form. The self-shading effect is mainly produced by sunrays coming from the east and west. The graph also illustrates the shorter daytime period in the case of the London latitude.

5.8.1.3.2 The North Facades
i. The Shadow Pattern in Summer

	The North Facades	
	London	Jerusalem
The Rectangular Form	56.5 %	42.86 %
The Radial Form	61.96 %	51.43 %

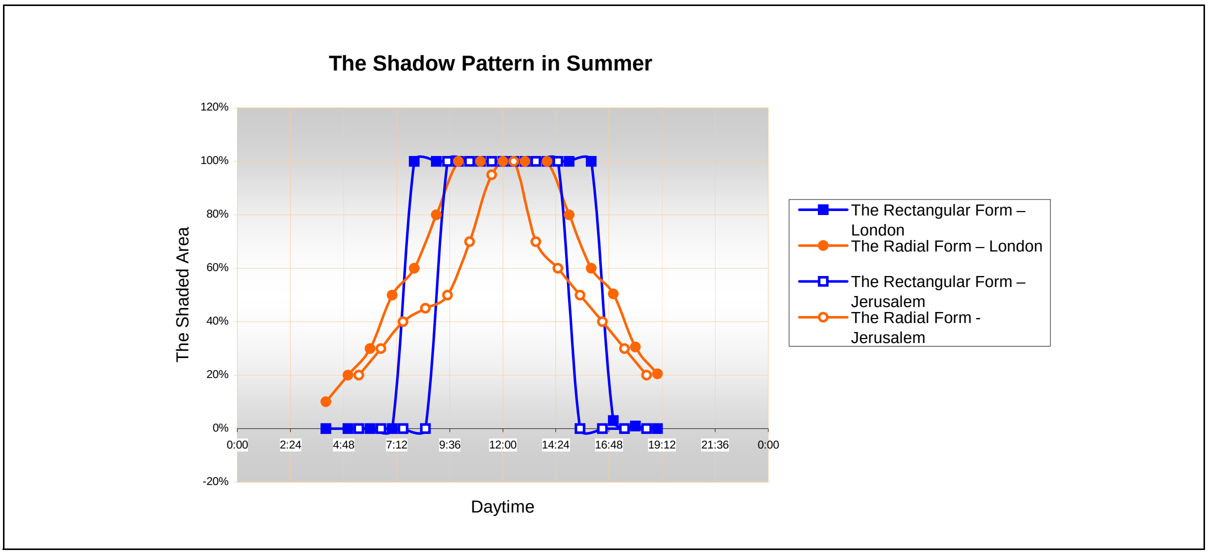


Figure 5.32: The Daily Shadow Pattern in the Overheated Period

The graph (Figure 5.32) indicates that the north facades in the London latitude are more shaded due to the fact that London is located in more northern latitudes, where sunrays come from more southerly positions (Figure 5.33). In both latitudes, the radial facades are more shaded than the rectangular ones. During the noon period, all facades (radial and rectangular) in both latitudes are fully shaded as sunrays in this period come from the south direction with its vertical plane perpendicular to the centre of the curve, which minimises the exposure of the north facades. The graph also illustrates the longer daytime period in the case of the London latitude.

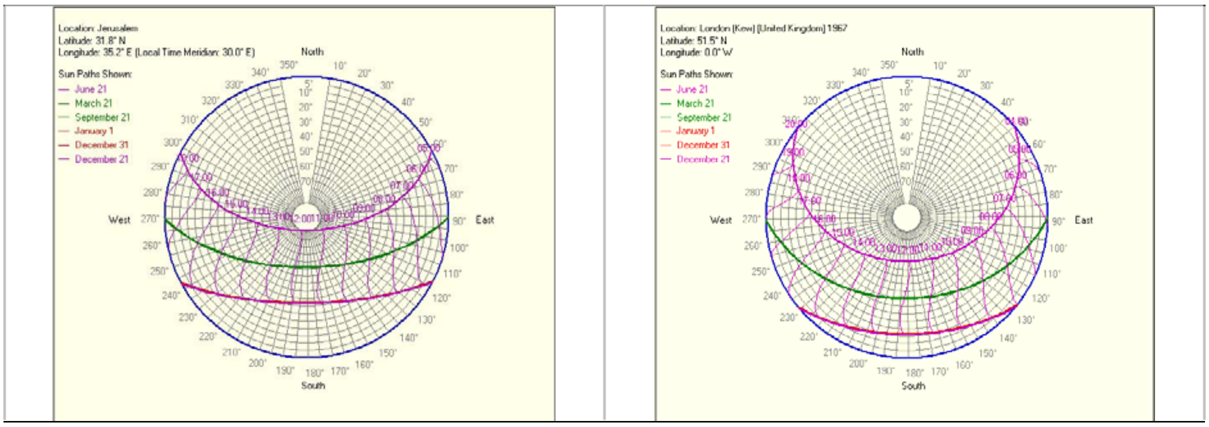


Figure 5.33: Sun Path Diagram for Jerusalem and London Latitudes

ii. The Shadow Pattern in Winter

	The North Facades	
	London	Jerusalem
The Rectangular Form	100 %	100 %
The Radial Form	98.75 %	96 %

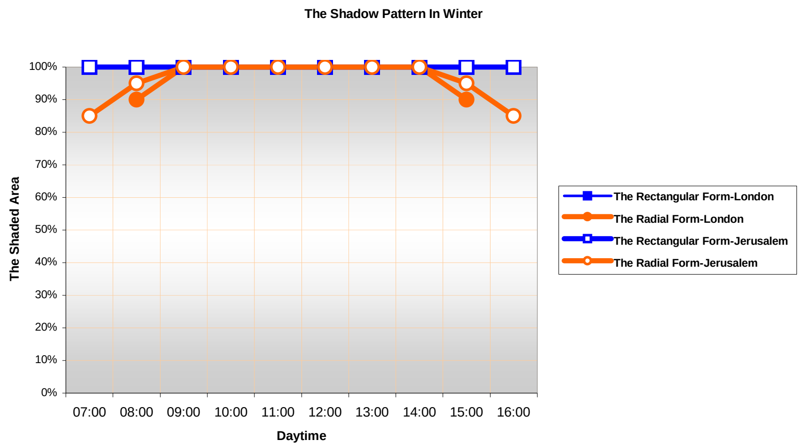
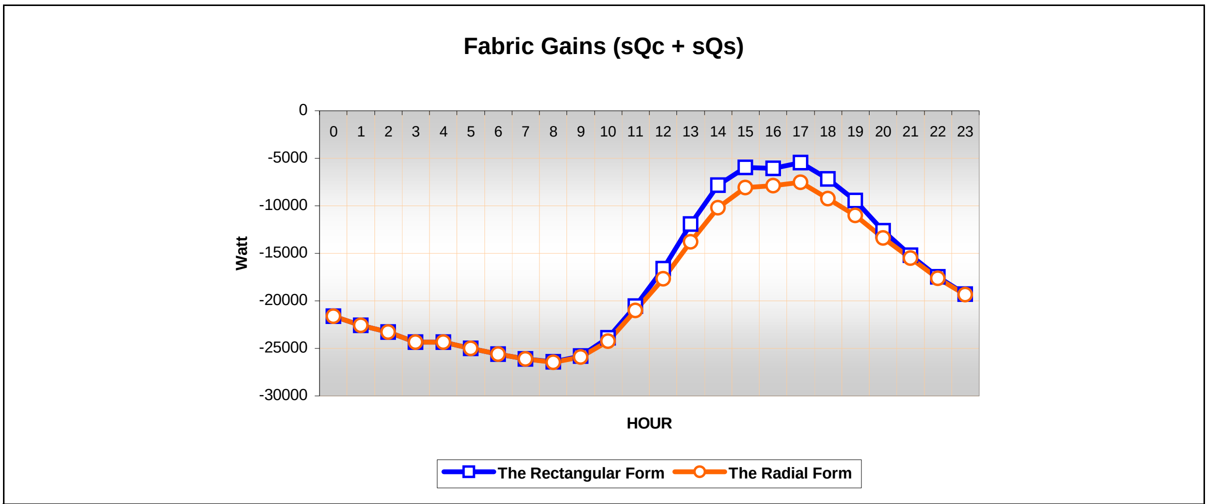


Figure 5.34: The Daily Shadow Pattern in The Underheated Period

The graph reveals that the north rectangular facades in both cases receive no sunrays at all in winter (Figure 5.34). On the other hand, the radial facades receive a small percent of sunrays in the early morning and late afternoon. However, the radial facade in the London latitude is more shaded and the effectiveness of the curve to improve the insolation of the north facade in winter is limited.

It becomes clear from studying this graph that the north convex facade of the south-facing radial form still has the possibility of receiving sunrays in the early morning and the late afternoon. During the rest of daytime period, the north facades of the two forms in both latitudes are fully shaded.

5.8.2 The Thermal Calculation
5.8.2.1 Opaque Forms
5.8.2.1.1 Fabric Gains (sQc + sQs)
i. The Distribution of Fabric Gains during the Daytime Period over the Year



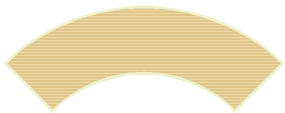
Annual Loads - Fabric Gains - sQc + sQs	
	
-441765 Watt	-424691 Watt
Annual Loads - Fabric Gains - sQc + sQs	
29835 Watt	37037 Watt
Admittance Factor - Fabric Gains - sQc + sQs	
Less Fabric Gains (More Fabric Loss)	More Fabric Gains (Less Fabric Loss)
More Suitable for Cooling Requirements	More Suitable for Heating Requirements

Figure 5.35: Fabric Gains (sQc + sQs) of the two Forms

The fabric gains are presented for both forms as loads and as factors (Appendix B3, Ecotect, the Admittance Method). The graph (Figure 5.35) shows that heat gains from the building fabric, due to both external temperatures and incident solar radiation, are greater in the case of the rectangular form. Thus, it can be stated that the rectangular form is more suitable for heating requirements, while the radial form is more suitable for cooling demands. This mainly refers to the self-shading effect of the radial form. The fabric load peak takes place in the afternoon period due to the thermal mass of the building. It can be also observed that the greatest variation between the two forms occurs during this period.

This finding is consistent with the previously derived results from the shadow analysis, which proved that rectangular forms generate less shaded area than radial forms over the year. Therefore, the rectangular form is more suitable for heating requirements (See Figure 5.36 bellow).

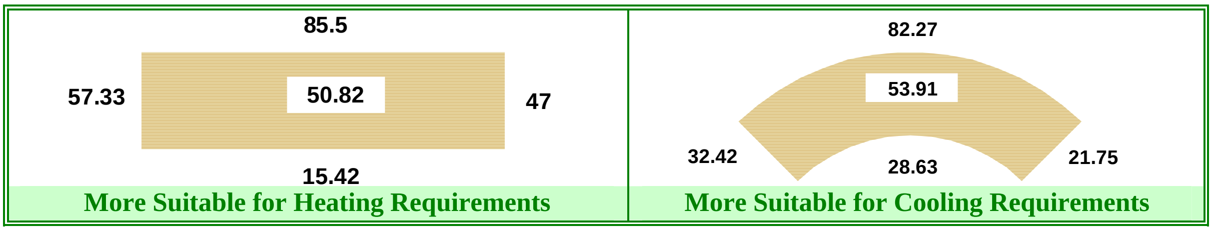


Figure 5.36: The Average Annual Shaded Area for the Radial and the Rectangular Forms

ii. A Comparison between the Variations in the Shaded Areas and the Variation of Heat Fabric Gains

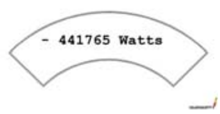
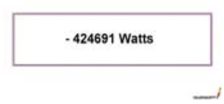
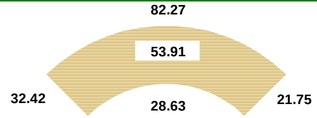
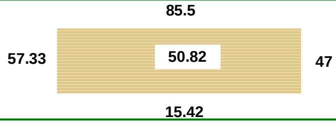
	The Radial Form	The Rectangular Form	The Variation
Fabric Gains (sQc + sQs)	 **-100 %**	 **- 96.14 %**	**3.86 %**
The Average Annual Shaded Area per Hour			
	53.91 %	**50.82 %**	**3.09 %**

Figure 5.37: The Variations of the Shaded Areas and the Heat Fabric Gains

By studying the variation between the two forms, with regard to both generated shaded areas and heat fabric gains, it can be noted (Figure 5.37) that the gained heat is greater where the shaded area is less (the rectangular form), and gained heat decreases where the shaded area is bigger (the radial form). However, the variation in heat gains between the two forms is slightly higher than the variation in the shaded area. This can be attributed to the fact that the biggest variation in the shaded area between the two forms occurs in summer in the south facades (Table 5.22), and in the noon period where the incidence of solar radiation is maximised.

		The Rectangular Form	The Radial Form	The Variation
The South Facades	**Summer**	**43.94 %**	**55.22 %**	**11.28 %**
	Winter	**0 %**	**1.38 %**	**1.38 %**
The North Facades	**Summer**	**56.5 %**	**61.96 %**	**5.46 %**
	Winter	**100 %**	**98.75 %**	**1.25 %**

Table 5.22: The Variation Between the two Forms: The Generated Shaded Area in the Two Opposite Facades

iii. The Distribution of Annual Fabric Gains

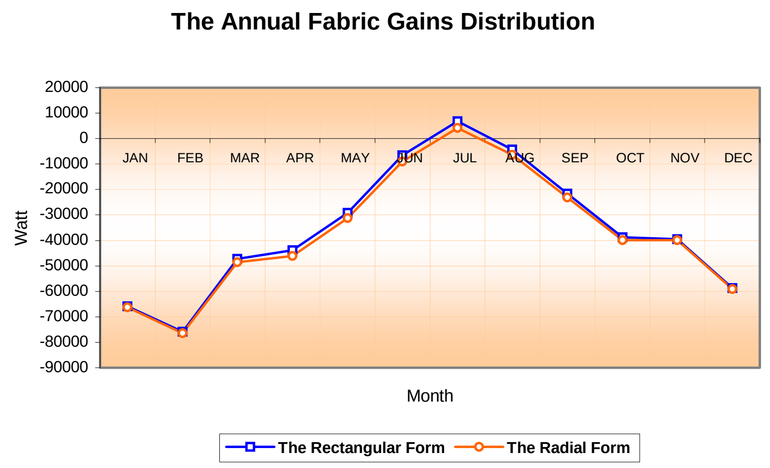
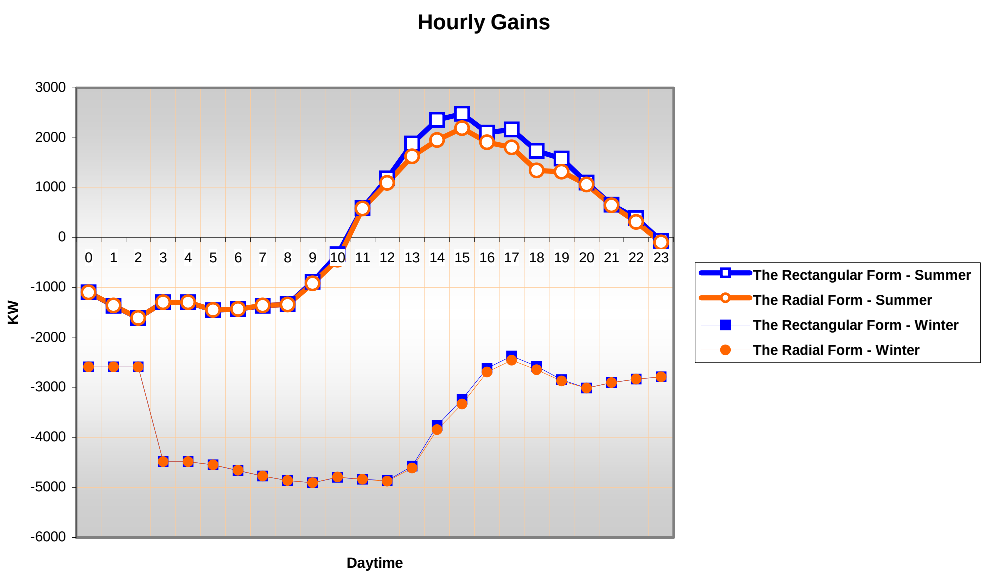


Figure 5.38: The Annual Loads Distribution - Fabric Gains - sQc + sQs

The distribution of fabric gains over the year reveals that most of the heat gains in the two forms are produced in the summer period, while most of the heat loss is generated in wintertime (Figure 5.38). Furthermore, it can be observed that the greatest variation between the two forms, with regard to the gained heat, also takes place in summer. By studying these graphs, it can be concluded that the variation between the two forms is more evident during the noon period and in summer time. This can be attributed to the fact that the two forms in these periods have the biggest variation in terms of the generated shaded area. Therefore, the increased amount of heat gains in the rectangular form coincides with having larger areas that are exposed. However, the peak is slightly shifted to the afternoon period in the case of the heat load, as a result of the thermal lag of the building mass.

5.8.2.1.2 Hourly Heat Gains in the Two Seasons

The graph below (Figure 5.39) reveals that both forms have heat gains in summer and heat loss in winter. However, the amount of heat loss in winter is greater than the gained heat in summer. This makes the heat loss prominent when calculating the annual heat load. The graph also reveals that the rectangular form has more heat gains in summer and less heat loss in winter than the radial one. Therefore, the rectangular form is more suitable for heating requirements.



Hourly Heat Gains in the Two Forms

	Summer		Winter	
	Rectangular Form	Radial Form	Rectangular Form	Radial Form
TOTAL	4784 KW	2218 KW	-88430 KW	-88901 KW

Figure 5.39: Hourly Heat Gains of the Rectangular and Radial Forms

These results are consistent with previously obtained calculations of the shadow analyses, which proved that the rectangular form has less shaded area than the radial one in both seasons (Figure 5.40). So, it becomes evident that the form with less shaded area (the rectangular form) generates more heat gains (or experiences less heat loss) and is therefore more adequate for heating requirements. On the other hand, the form with more shaded area (the radial form) generates less heat gains and consequently will be more suitable for cooling requirements. It can also be observed that the main variation between the two forms, with regard to both gained heat and shaded area, takes place in summer. Thus, greater variations in the shaded areas between the two forms result in greater variations in the obtained heat gains.

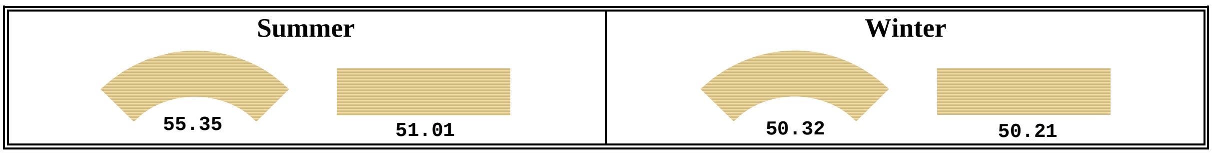
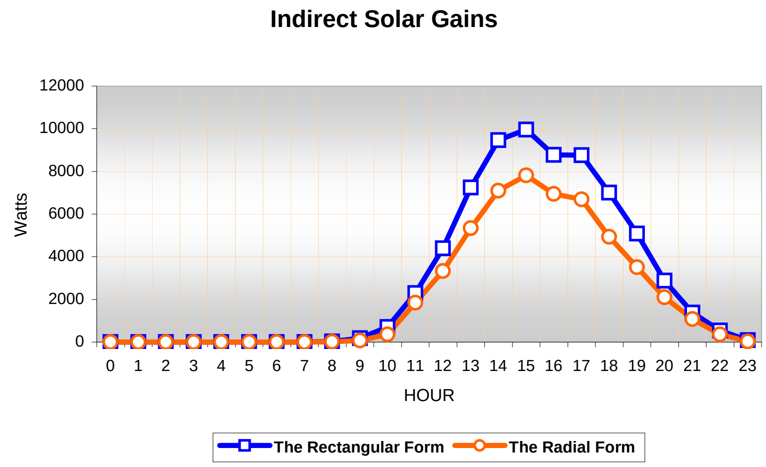


Figure 5.40: The Average Daily Shaded Area in the Over and Underheated Periods

5.8.2.1.3 Indirect Solar Gains – sQss
i. The Distribution of Indirect Solar Gains during the Daytime Period over the Year



Annual Loads - Indirect Solar Gains – sQss

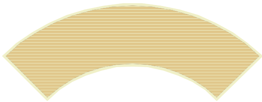
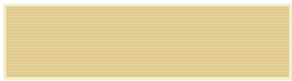
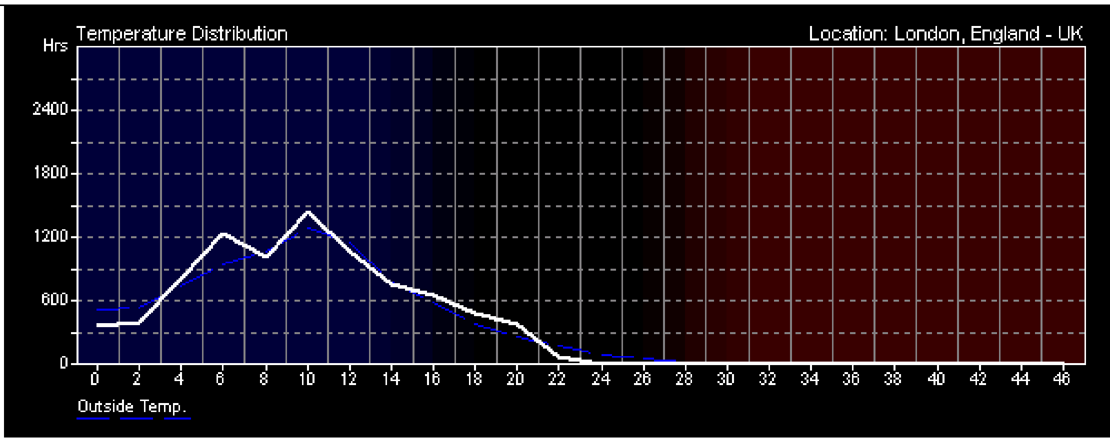
 **51544 Watts**	 **68807 Watts**
Annual Loads - Indirect Solar Gains – sQss	
34171 Watts	**41364 Watts**
Admittance Factor - Indirect Solar Gains – sQss	
Less Fabric Gains	**More Fabric Gains**
More Suitable for Cooling Requirements	**More Suitable for Heating Requirements**

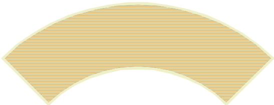
Figure 5.41: Indirect Solar Gains – sQss of the Two Forms

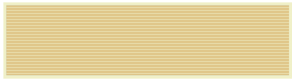
The indirect solar gains from the building fabric due to the incident solar radiation are higher in the case of the rectangular form (Figure 5.41). The greater exposure of the rectangular form allows the building's envelope to collect more solar radiation which increases the obtained heat gains. The reduction of the indirect solar radiation of the radial form results from its self-shading. This effect decreases the area which can be exposed to sunrays and consequently the obtained heat gains. It can be also observed that the greatest variation between the two forms and the fabric load peak occurs during the afternoon period due to the thermal mass of the buildings.

5.8.2.1.4 Temperature Distribution



Annual Temperature Distribution
Comfort Band: 18.0 - 26.0 °C

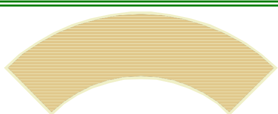


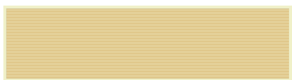


Temp.	Hours	Percent	Temp.	Hours	Percent
COMFORT	952	10.80 %	COMFORT	958	10.90 %
Less Hours Falling within the Comfort Band			More Hours Falling within the Comfort Band		
More suitable for cooling requirements			More suitable for heating requirements		

Figure 5.42: Annual Temperature Distribution of the two Forms

By comparing the forms with regard to the comfort band, it can be noted that the number of hours falling in the comfort band is bigger in the case of the rectangular form (Figure 5.42). In this case, the rectangular form is more suitable in Britain. This finding is consistent with the fact that the open layout is more suitable in cold climates to maximise solar heat gains. This finding is also consistent with previous results from the shadow analysis, which proved the suitability of the rectangular form (open layout) in areas where the major concerns are to receive sunrays in winter. The analysis also proved the suitability of the radial form (closed layout or a layout which is less open) in areas where avoiding summer heat and generating more shadow is required, as the radial form generates more shadow than the rectangular one over the whole year (Figure 5.43).



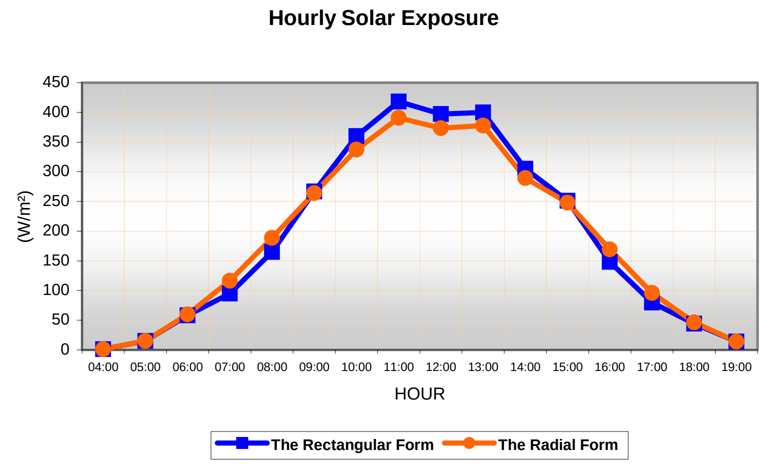


Closed Layout	Open Layout
More suitable in areas where the major concerns are to avoid summer heat	More suitable in areas where the major concerns are to receive sunrays in winter

Figure 5.43: Closed and Open Layout Applications

5.8.2.1.5 The Collected Solar Radiation for the South Facades in Summer

i. Hourly Solar Exposure



The Collected Solar Radiation (W/m²) for the South Facades of the Two Forms

The Rectangular Form	The Radial Form
3018	2987.2

Figure 5.44: The Collected Solar Radiation (W/m²) for the South Facades in Summer

From reviewing the two graphs (Figures 5.44 and 5.45), it can be observed that, in the early morning and late afternoon when the radial form is more exposed, the gained heat in the radial form is greater than in the rectangular one. This small increase of exposure of the radial form occurs during periods, where the incidence of solar radiation is minimised, so its impact is reduced. During the rest of the daytime and approaching the noon period, the rectangular form is more exposed and consequently gains more heat. This larger increase of exposure of the rectangular form also occurs during periods where the incidence of solar radiation is maximised, so its impact is greater. In general, the rectangular facade is less shaded and collects more solar radiation per m^2 than the radial facade.

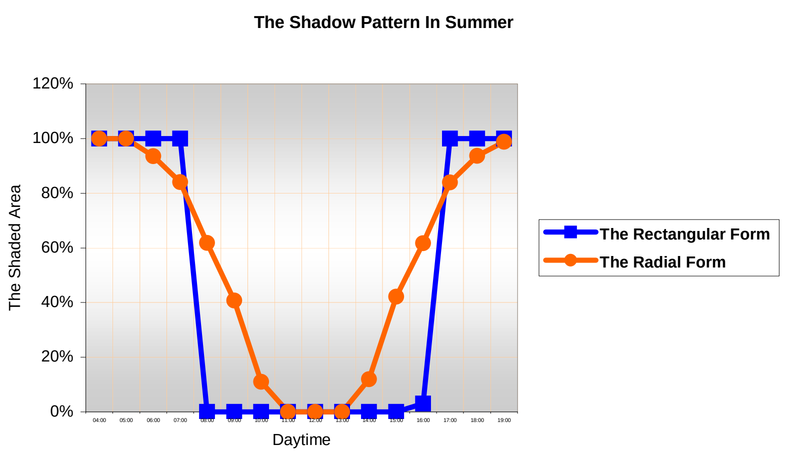
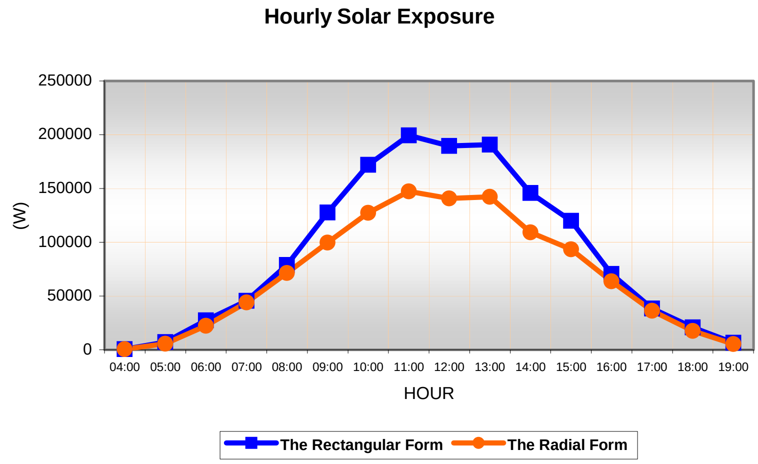


Figure 5.45: The Generated Shadow Pattern of the South Facades in Summer



The Collected Solar Radiation (W) for the South Facades of the Two Forms

The Rectangular Form	The Radial Form
1441589	1127159
100 %	78.19 %

Figure 5.46: The Collected Solar Radiation (W) for the South Facades in Summer

The above graph (Figure 5.46) of the total collected solar radiation during the daytime period in both facades shows that the variation between the two facades increases with its closeness to the noon period. In addition, the calculations reveal that the variation in gained heat between the two facades is greater than the variation in the shaded area (Table 5.23) due to the fact that major differences between the shaded areas in the two facades take place around the noon period. This coincides with the tendency of the incident solar radiation to increase with proximity to the noon period.

	The South Facades - Summer	
	The Shaded Area	The Collected Solar Radiation (W)
The Rectangular Form	43.94 %	100 %
The Radial Form	55.22 %	78.19
The Variation	11.28 %	21.81

Table 5.23: A Comparison between the Variation of the Shaded Areas and the Variation in the Heat Gains

When calculating the received solar radiation by the unit area (m^2) for the two cases, it can be observed that the unit area of the exposed part of the radial facade collects more solar radiation than the rectangular one. However, the increased amount of the shaded area in the radial facade (due to the self-shading effect) makes the total received solar radiation lower than the amount received by the rectangular one (Table 5.24).

	The South Facades - Summer			
	The Exposed Area		The Collected Solar Radiation (W)	
	%	m^2	Total W	W Per m^2
The Rectangular Form	56.06%	267.74 m^2	1441589	5384.29 W
The Radial Form	44.78%	168.88 m^2	1127159	6674.14 W

Table 5.24: The Collected Solar Radiation by the Unit Area of the Exposed Surfaces in Both Facades

ii. The Self-Shading Effect of the South Facade

Previous calculations have revealed that the increase of the shaded area of the radial facade and consequently the decrease in the collected solar radiation is mainly due to the self-shading effect. However, the concavity of the radial facade results in a different orientation of its surfaces. In the previously conducted analysis, the radial facade was divided into 10 segments with different surface azimuth angles, while the rectangular facade has an unvarying surface azimuth angle with clear orientation towards the south. So, the variation between the two forms could be a result of both the concavity and self-shading of the radial facade. The following analysis aims to investigate the effect of self-shading and its impact on the resulting shaded area, and the amount of collected solar radiation. The shaded area and the collected solar radiation were separately investigated for the 10 segments which constitute the radial facade (Figure 5.47). Then the shaded areas generated by these segments were summed, as well as the collected solar radiation. After that, the results obtained were compared with the results obtained for both the unified radial facade and the equivalent area of the rectangular facade.

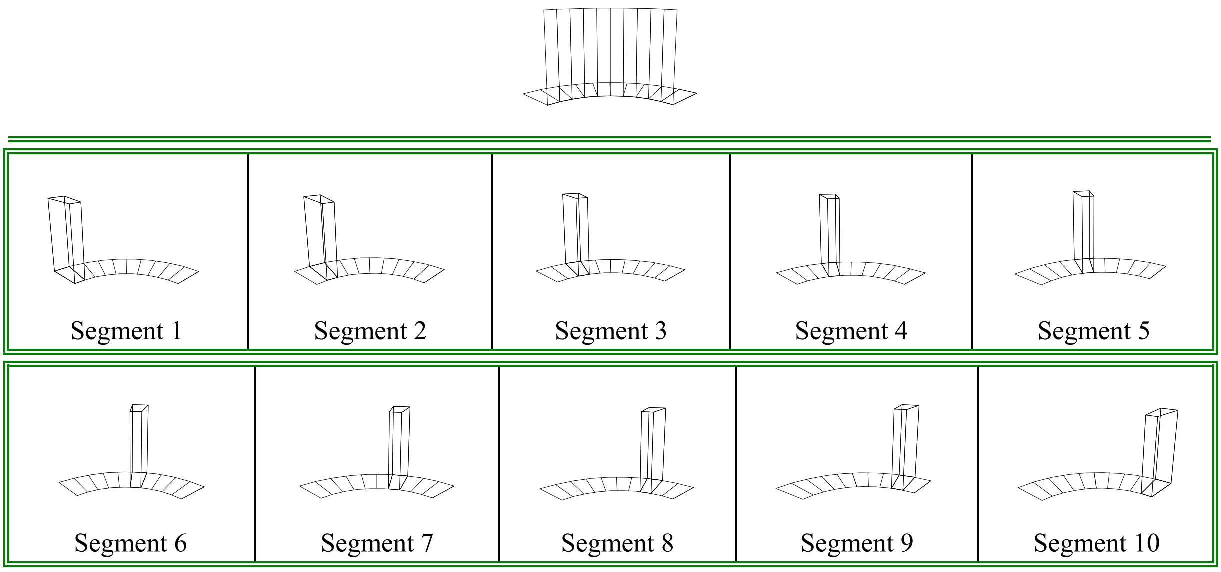


Figure 5.47: The Segments of the Radial Facade

	The Rectangular Facade		The Unconnected Radial Facade (Without Self-shading)		The Unified Radial Facade (With Self-shading)	
Hour	**Solar Shade**	**(W)**	**Solar Shade**	**(W)**	**Solar Shade**	**(W)**
04:00	100%	453	90%	453	100%	451
05:00	100%	5713	80%	5902	100%	5720
06:00	100%	21722	71%	24166	94%	22364
07:00	100%	35845	61%	53433	84%	44074
08:00	3%	61822	43%	77221	62%	71421
09:00	1%	100215	31%	102694	41%	99760
10:00	0%	135717	11%	127108	11%	127343
11:00	0%	157550	0%	147410	0%	147410
12:00	0%	149767	0%	140838	0%	140838
13:00	0%	150717	0%	142395	0%	142395
14:00	0%	115035	10%	109419	12%	109169
15:00	3%	93526	31%	96014	42%	93451
16:00	6%	55246	41%	68762	62%	63717
17:00	100%	30358	61%	42928	84%	36330
18:00	100%	16518	71%	20087	94%	17450
19:00	100%	5261	80%	5429	99%	5275
Totals	44.56%	1135466	42.44%	1164248	55.22%	1127159
The amount of shaded area generated by self-shading effect						
55.22% - 42.44% = 12.78 %						

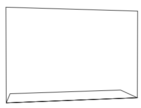
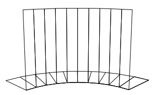
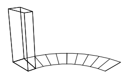
	The Rectangular Facade	The Radial Facade	
		With Self-shading	Without Self-shading
Solar Shade of the South Facade	44.56%	55.22%	42.44%
			
Collected Solar Radiation (W)	1135466	1127159	1164248

Table 5.25: The Shaded Area and the Collected Solar Radiation for the Radial and Rectangular Facades

By studying Table 5.25, it can be observed that the shaded area of the unconnected radial facade (without self-shading) is lower than the shaded area of the rectangular facade, while the unified radial facade (with self-shading) is more shaded than the rectangular one. Thus, it can be concluded that the increased shaded area of the radial facade is caused by the self-shading effect. As regards the collected solar radiation, it can be also observed that the unconnected radial facade collects more solar radiation than the rectangular one, while the unified radial facade collects less solar radiation than the rectangular one. Thus, it becomes evident that the self-shading of the radial facade is the main cause of increased shaded area and consequently, the reduced collected solar radiation compared to the rectangular facade.

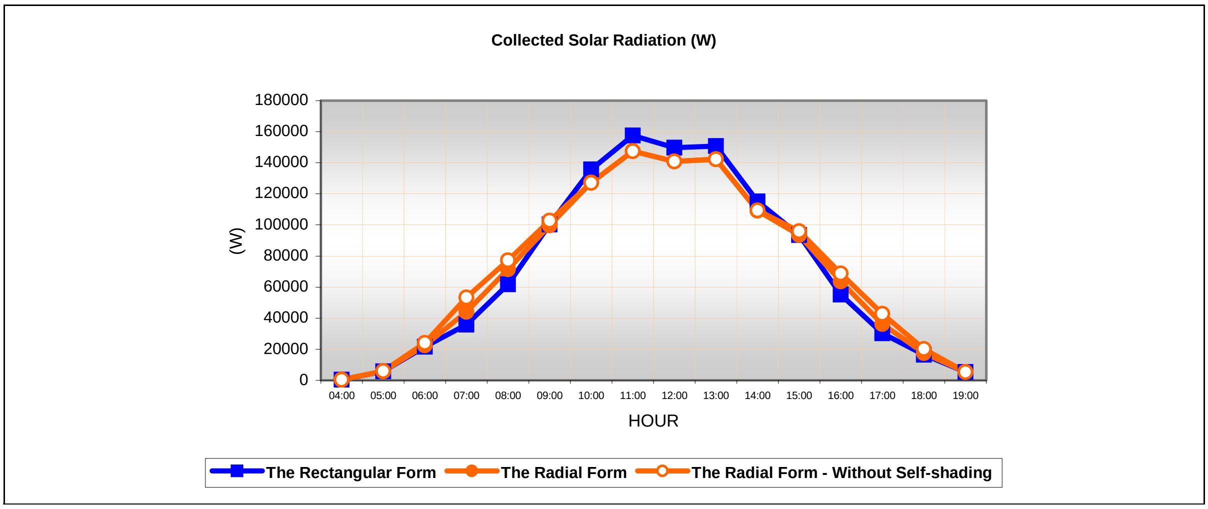


Figure 5.48: The Collected Solar Radiation by the Radial and Rectangular Facades

The comparison between the two radial facades, with regard to the distribution of collected solar radiation during daytime, reveals that the most significant variation takes place in the morning and afternoon periods (Figure 5.48) when the variation in the generated shaded area is maximal (Figure 5.49), while the two facades collect the same amount of solar radiation during the noon period, when both facades are completely exposed. However, with the same extent of exposure during the noon period, the rectangular facade collects more solar radiation than radial facades, as the facade is directly oriented due south. However, the unconnected radial facade collects more solar radiation than the rectangular one in general, as the additional amount of solar radiation collected by this facade during the morning and afternoon, due to its larger exposure, exceeds the additional amount of solar radiation collected by the rectangular facade during the noon period due to its southern orientation (Table 5.26).

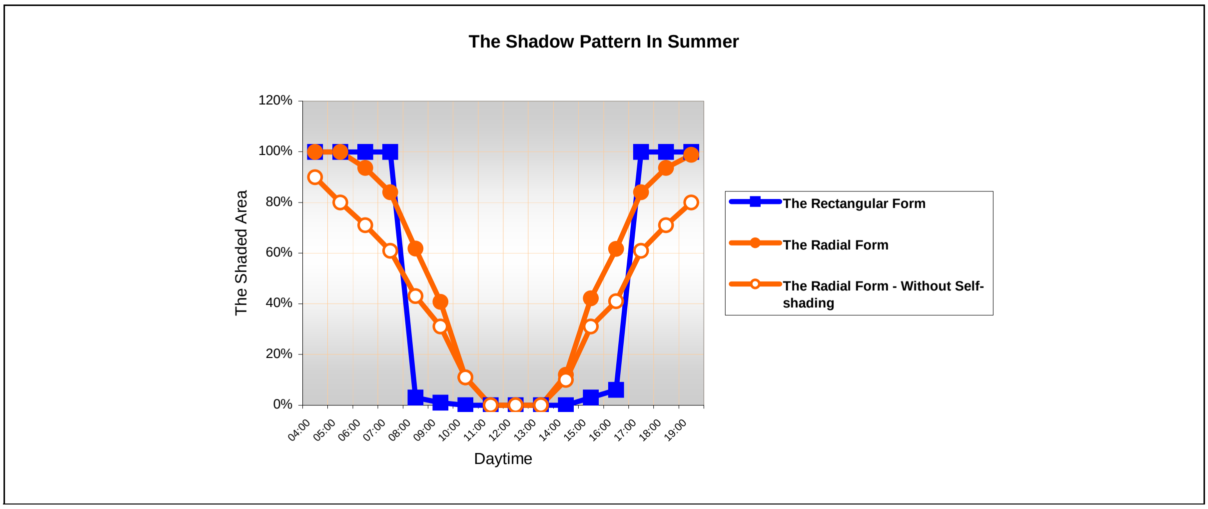


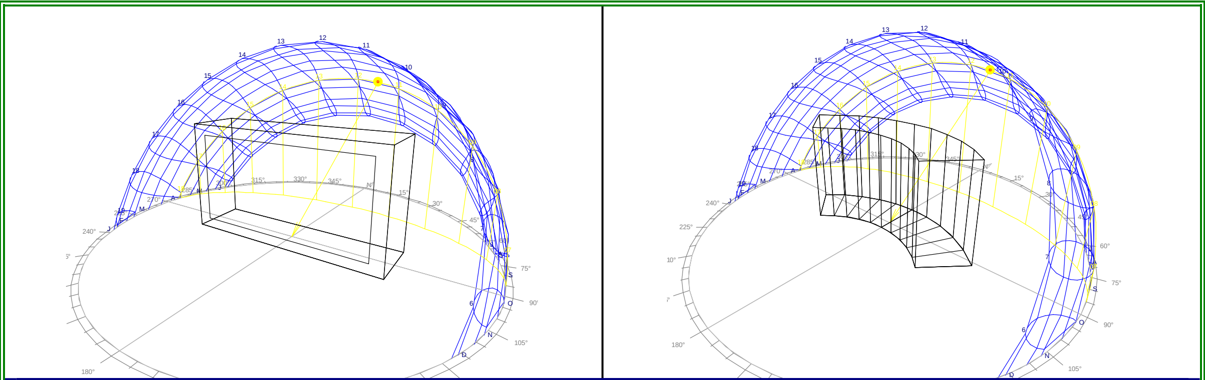
Figure 5.49: The Shaded Areas of the Radial and Rectangular Facades

It can be concluded that the self-shading effect is the factor that makes the rectangular facade collect more solar radiation than the radial one. In addition, the self-shading effect is the main cause of variation between the two facades with regard to the generated shaded area.

The Shaded Area and the Collected Solar Radiation in the Two Forms								
	Morning		Noon Period		Afternoon		Total Variation	
	Shade	(W)	Shade	(W)	Shade	(W)	Shade	(W)
The Rectangular Form	57.71%	31.83%	0%	40.34%	51.5%	27.83%	44.56%	100%
The Unconnected Radial Facade	55.29%	34.43%	0%	37.93%	49.0%	30.18%	42.44%	102.5%
The Variation	2.43%	-2.60%	0%	2.41%	2.5%	-2.35%	2.12%	-2.5%

Table 5.26: The Distribution of the Shaded Area and the Collected Solar Radiation During Daytime

5.8.2.2 Forms with Glazed-South Facades

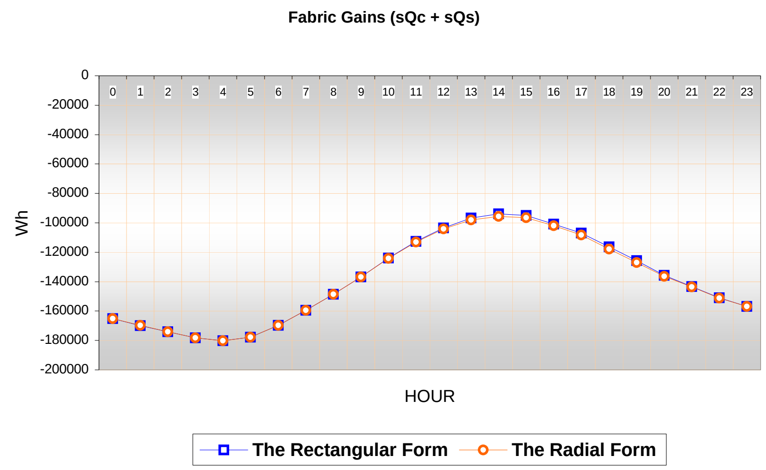


Fabric: CIBSE concrete block, South Facade: Double Glazing Panel, Environmental File: UK - London

Figure 5.50: Rectangular and Radial Forms with Glassed-South Facades

Because in northern latitudes the south facade is usually designed as the principal facade, rectangular and radial forms with glazed south facades will be examined (Figure 5.50). A comparison between the opaque and the glazed forms will be also conducted to clarify the variation between the two forms, with regard to their thermal performance.

5.8.2.2.1 Fabric Gains (sQc + sQs)
i. The Daily Fabric Gains Distribution



Annual Loads - Fabric Gains - sQc + sQs

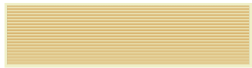
	
Annual Loads - Fabric Gains - sQc + sQs	
-3334.514 KWh	**-3322.753 KWh**
Admittance Factor - Fabric Gains - sQc + sQs	
17.883 KWh Less Fabric Gains (More Fabric Loss)	**23.256 KWh** More Fabric Gains (Less Fabric Loss)
More Suitable for Cooling Requirements	**More Suitable for Heating Requirements**

Figure 5.51: Fabric Gains (sQc + sQs) of the Two Forms

By studying this graph (Figure 5.51), it can be observed that heat gains from the building fabric, due to both external temperatures and incident solar radiation, are higher for the rectangular form. Therefore, it can be concluded that the rectangular form is more suitable for heating requirements, while the radial form is more suitable for cooling. This finding is consistent with the previously conducted shadow analysis, which indicated that the rectangular form generates less shaded area than the radial one over the year. Therefore, the rectangular form can receive more sunrays and consequently more heat gains. The greater heat gains during daytime period are maximised in the afternoon due to the thermal mass of the buildings. This is the period, when the variation between the two forms is the greatest, as well.

ii. A Comparison Between the Opaque and the Glazed Forms

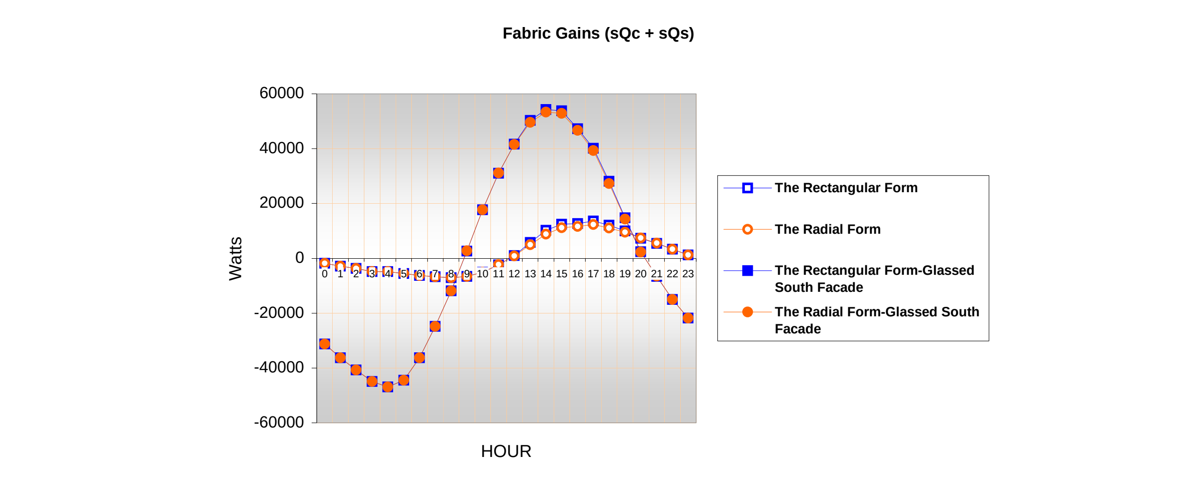
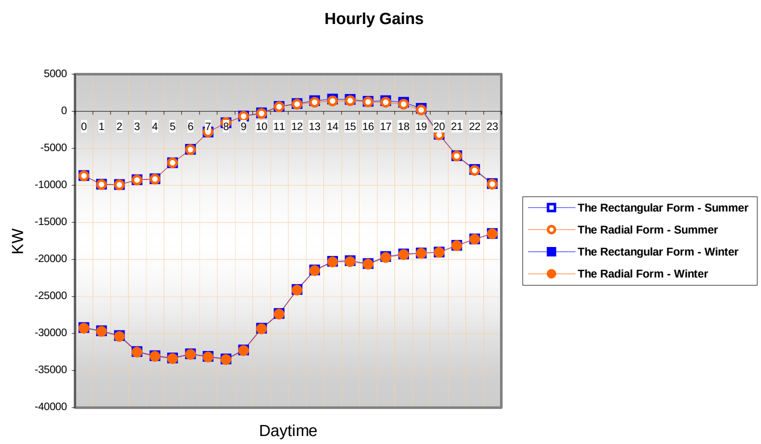


Figure 5.52: Admittance Factor - Fabric Gains - sQc + sQs

The above graph (Figure 5.52) shows the distribution of heat gains through the fabrics of the opaque and glazed forms. It can be observed that the opaque forms have less heat losses in general due to the higher thermal mass. Although in both cases the fabric load peaks take place in the afternoon period, due to the thermal lag of the building, the glazed forms demonstrate a fabric load peak closer to the noon period. Generally, large areas of glass make the fabric load peak during the middle of the day whereas a heavyweight building with lots of internal thermal mass may peak very late in the evening.

5.8.2.2.2 Hourly Heat Gains in the Two Seasons



	Summer		Winter	
	The Rectangular Form	The Radial Form	The Rectangular Form	The Radial Form
TOTAL	-80425 KWh	-82599 KWh	-611424 KWh	-613390 KWh
The Exposed Area	48.99 %	44.65 %	49.79 %	49.68 %

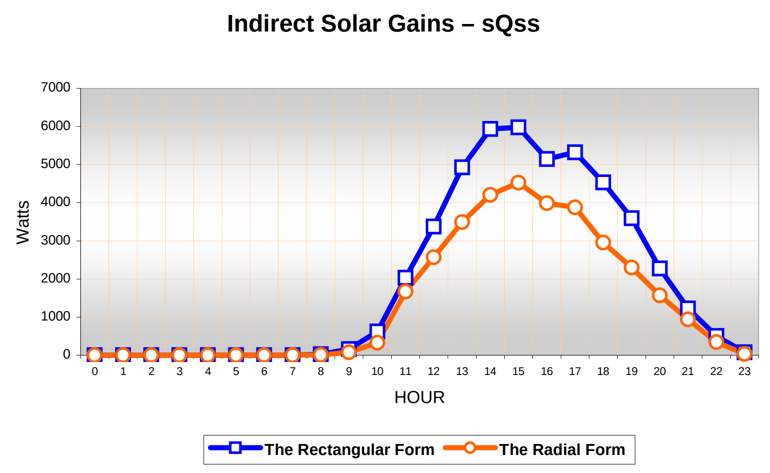
Figure 5.53: Hourly Heat Gains of the Rectangular and Radial Forms in Over and Underheated Periods

The graph (Figure 5.53) reveals that the rectangular form has less heat loss in both seasons; therefore it can be more suitable for heating requirements. The radial form, which experiences more heat loss, can be more suitable for cooling requirements. The main variation between the two forms takes place in summer period. The heat gains in summer are limited to the sunlit part of the day and occur mainly during the noon period. However, the forms experience greater heat loss during the rest of daytime period. Once these calculations are compared with the results obtained in the case of the opaque forms, it becomes clear that the glassed forms experience more heat loss due to the low insulation characteristics of the glassed area (Table 5.27).

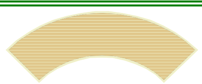
	Summer		Winter	
	The Rectangular Form	The Radial Form	The Rectangular Form	The Radial Form
The Opaque Forms	4784 KW	2218 KW	-88430 KW	-88901 KW
The Glassed Forms	-80425 KW	-82599 KW	-611424 KW	-613390 KW

Table 5.27: Hourly Heat Gains of the Rectangular and Radial Forms in the Two Cases

5.8.2.2.3 Indirect Solar Loads Through Solar Gains on Opaque Surfaces – sQss



Annual Loads - Indirect Solar Gains – sQss

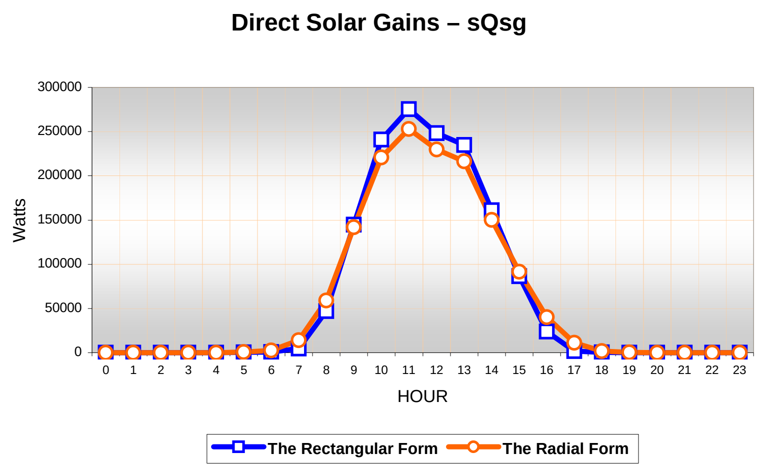


32882 Watts	45721 Watts
Annual Loads - Indirect Solar Gains – sQss	
21192 Watts	26567 Watts
Admittance Factor - Indirect Solar Gains – sQss	
Less Fabric Gains	More Fabric Gains
More Suitable for Cooling Requirements	**More Suitable for Heating Requirements**

Figure 5.54: Indirect Solar Gains – sQss of the Two Forms

The graph above (Figure 5.54) shows that the indirect solar gains from the building fabric due to the incident solar radiation are higher in the case of the rectangular form. The self-shading effect of the radial form decreases the indirect solar radiation received by the building's external walls, while the greater exposure of the rectangular form allows the building's envelope to collect more solar radiation which increases the obtained heat gains. The variation between the two forms increases gradually and reaches its maximum in the afternoon period. As a result of the thermal mass of the building, the fabric load peak is shifted to the afternoon period.

5.8.2.2.4 Direct Solar Gains – sQsg



Annual Loads - Direct Solar Gains – sQsg – in the Two Forms

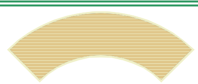
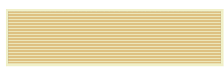
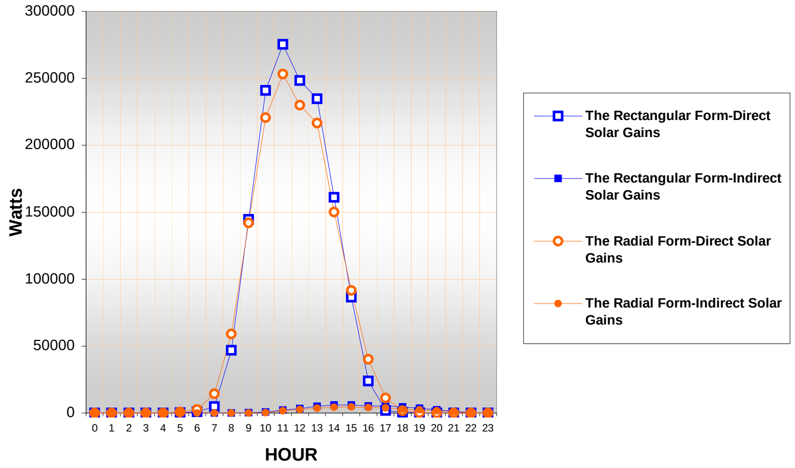
	
1434157 Watts	**1470632 Watts**
Annual Loads - Direct Solar Gains – sQsg	
Less Fabric Gains	More Fabric Gains
More Suitable for Cooling Requirements	**More Suitable for Heating Requirements**

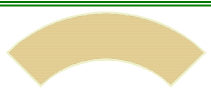
Figure 5.55: Direct Solar Gains – sQg of the two Forms

The measurements of the direct solar gains reveal that the rectangular form gains more heat than the radial one (Figure 5.55). This is mainly caused by the self-shading effect of the radial form, which minimises the exposed area and creates more shadow. As the thermal mass of the glazed area is relatively low, the fabric load peak takes place in the noon period. The greatest variation between the two forms, with regard to direct solar gains, takes place during this period, as well. The graph also illustrates the apparent association between the direct solar gains and both sunrise and sunset.

5.8.2.2.5 Direct and Indirect Solar Gains – sQsg + sQss
i. The Daily Direct and Indirect Solar Gains Distribution



Annual Loads - Direct and Indirect Solar Gains – sQsg + sQss



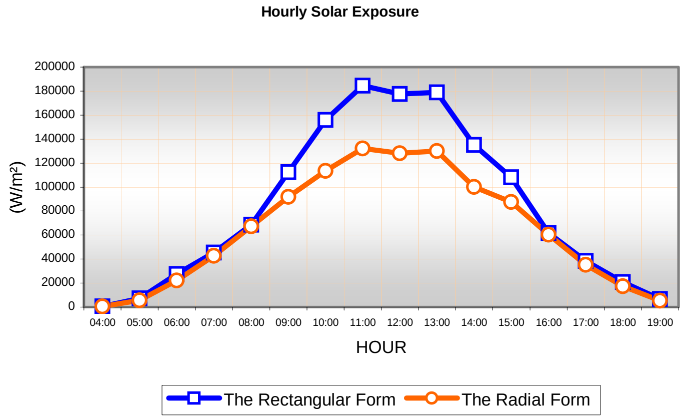
1467039 Watts	1516353 Watts
Annual Loads - Direct and Indirect Solar Gains – sQsg + sQss	
Less Fabric Gains	**More Fabric Gains**
More Suitable for Cooling Requirements	**More Suitable for Heating Requirements**

Figure 5.56: Direct and Indirect Solar Gains – sQsg + sQss of the Two Forms

The graph (Figure 5.56) illustrates the higher direct and indirect solar gains in the case of the rectangular form. Due to its greater exposure, the rectangular envelope collects more solar radiation which increases the obtained heat gains. The direct heat gains are linked to sunrise and sunset, and to fabric load peak during the middle of the day. On the other hand, the peak of the indirect solar loads, which is shifted to the right, indicates the use of materials with an average thermal lag of 4 hours. Generally, the glazed areas make the fabric load peak during the middle of the day whereas the opaque building's envelope, which have higher thermal mass, peaks late in the afternoon. The graph also reveals that most of the heat gains, due to the incidence of solar radiation, are produced by the direct solar gains through the transparent glazed area (sQsg).

5.8.2.2.6 The Incident Solar Radiation for the South Facades in Summer

i. Incident Solar Radiation (W/m^2)



The Collected Solar Radiation (W/m^2) for the South Facades in the Two Forms

Figure 5.57: The Collected Solar Radiation (W/m2) for the South Facades in Summer

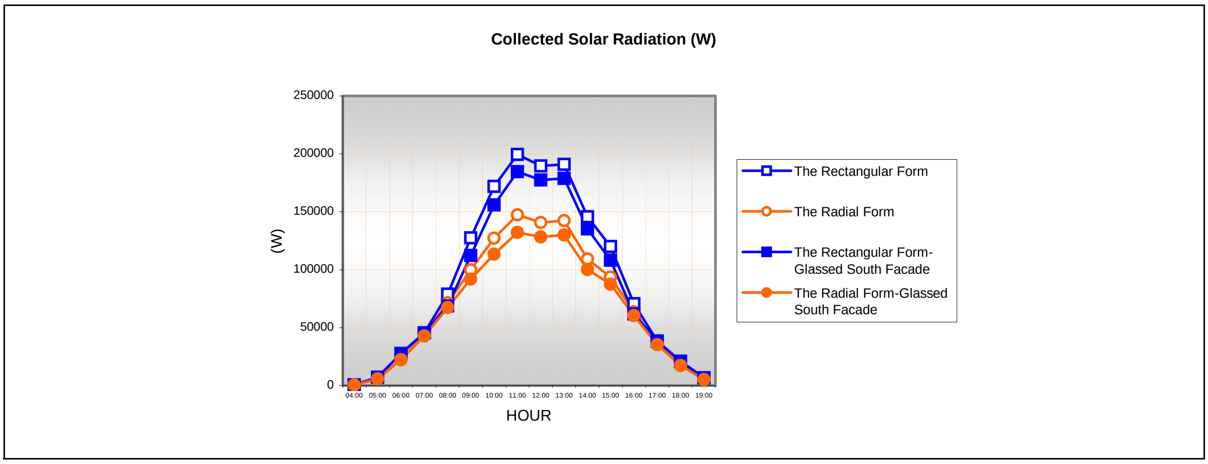
From studying this graph (Figure 5.57), it can be noted that the rectangular facade intercepts more solar radiation than the radial one. It can be also observed that the variation between the two facades increases with its closeness to the noon period. The calculations also reveal that the variation in the heat gains between the two facades is greater than the variation in the shaded area (Table 5.28). This is because the major differences between the shaded areas in the two facades occur during the noon period, when the incidence of solar radiation is maximised.

	The South Facades - Summer	
	The Shaded Area	**The Collected Solar Radiation (W)**
The Rectangular Form	**43.94 %**	**100 %**
The Radial Form	**55.22 %**	**78.20 %**
The Variation	**11.28 %**	**21.80 %**

Table 5.28: A Comparison between the Variation of the Shaded Areas and the Variation in the Heat Gains

iii. A Comparison Between the South Facades of the Opaque and the Glazed Forms

The comparison between the south facades of the forms (Figure 5.58) reveals that the rectangular facades in both cases can collect more solar radiation than the radial ones, as a result of their greater exposure to sunrays. The graph also illustrates the reduction of the collected solar radiation for the forms with glazed south facades due to the transparency of the material. In both cases, the greatest variation between the south facades of the two forms, with regard to the collected solar radiation, takes place during the noon period. The collected solar radiation is directly linked to sunrise and sunset and to the exposure of the facades to sunrays. For all facades, the collected solar radiation increases gradually and reaches its maximum during the noon period.



	Collected Solar Radiation (W) - Date: 15th June	
	The Rectangular Form	The Radial Form
The Opaque Forms	1441589	1127159
Forms with Glassed-south Facades	1329822	1039931

Figure 5.58: The Collected Solar Radiation (W) for the South Facades in Summer

5.9. Conclusion

One of the clear implications of this study is that the shaded and exposed periods for the rectangular facade begin and end sharply and the two periods exchange their influence on the facades. In the radial form, the shaded and exposed periods begin and end more gradually and the two opposite facades can be exposed to sun's rays 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.

By comparing the two radial forms, with respect to the generated annual shaded area, it can be observed that the north-facing form is more suitable for heating requirements, as it generates less shadow over the year. On the other hand, the south-facing form is more adequate for cooling requirements, as it generates more shadow over the period of a given year. The calculation also reveals that the north-facing form has the least amount of shaded area in winter and the biggest amount in summer, and is therefore more beneficial in a temperate climate, where it is preferable to receive more sunrays in winter and to avoid them in summer. The variation between the two opposite facades is less in the case of the south-facing form and therefore it is more suitable for bilateral types of building, where having a regular distribution of sunrays on both sides is crucial. Also, the south-facing form can be more suitable in unilateral types of building as it has better insolation efficiency for the south facade. In the coastal plain, (the Gaza Strip) in Palestine, where the major concern is to avoid summer heat, the south-facing form could be more suitable, as its south facade is more shaded in summer. In the mountain area (the West Bank), where the major concern is to receive winter sunrays, the north-facing form could be preferable, as its south facade is less shaded in winter.

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.

With regard to the comparison between the Jerusalem and London latitudes, it was proved that the effectiveness of bilateral buildings is greater in Jerusalem, where the variation in the shaded area between the two opposite facades is smaller. In London or more northerly latitudes, the tendency to have unilateral buildings will be preferable, as the exposed area is almost all concentrated on one facade (the southern one). Thermal calculations revealed that heat gains from building fabric, due to both external temperatures and incident solar radiation, is greater in the case of the rectangular form and therefore it is more suitable for heating requirements, while the radial form is more suitable for cooling demands. Hence, it can be observed that the gained heat increases where the shaded area is smaller (the rectangular form), and gained heat decreases where the shaded area is larger (the radial form). It can also be observed that the main variation between the two forms, with regard to both gained heat and shaded area, takes place in summer. Thus, greater variations in the shaded areas between the two forms result in greater variations in the obtained heat gains.

CHAPTER 6

PASSIVE SOLAR URBAN DESIGN:
Mutual Shading Of Different Urban Patterns

6. Passive Solar Urban Design: Mutual Shading of Different Urban Patterns
6.0 Overview

Although thermal comfort methods on an 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. Urban canyon configuration has a substantial impact on the passive solar design. If a building site is planned to utilise the sun for heating, it is necessary to ensure that the sun will not be blocked by structures on adjacent properties. Overshadowing by other buildings can make a passive solar design unsuccessful. Sunlight in urban areas can be significantly improved if the buildings are designed to overshadow each other as little as possible. This is an important issue to be considered by architects and planners. Much has been written about solar accessibility on unobstructed sites; however, little has been done to evaluate the mutual shading of buildings. Hence, quantitative guidelines are necessary to evaluate the relation between the geometric characteristics of the urban pattern and solar insolation, in particular the special needs of buildings, which rely on passive solar design principles. The experiment compares two urban patterns (radial and rectangular), in terms of the generated shadow pattern. The experiment aims to clarify the influence of the self-shading effect of the radial form and investigate the variation between the two patterns with respect to the distribution of the shaded area during the daytime period within the canyon facades in both seasons. Also, the experiment evaluates the two patterns with regard to of the amount of generated shadow in the overheated and underheated periods and over the whole year. 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 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. Therefore, the relation between solar insolation, orientation and building intensity will also be discussed.

6.1 Introduction

Urban form affects greatly the potentiality of using solar energy sources for lighting and the climatisation of building. Assis et al. (1999) considered the solar and wind orientation of the urban structure, and the height and gap relations between buildings as the parameters that define the geometry of an urban place. 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. 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. Capeluto et al. (2003) stressed that new buildings may create a different microclimate, like changing the wind regime and shading the existing urban structure. This is an important issue to be considered by architects and planners. However, little has been done to evaluate the mutual shading of buildings. While urban design guidelines have been developed to respond to climates in various regions, these recommendations are often based on experiences or observation more than on an integrated microclimatic analysis. Quantitative guidelines are therefore necessary to investigate the mutual shading of different urban patterns, in particular the special needs of buildings which rely on passive solar design principles.

Previous studies on passive solar design have concentrated on rural or suburban sites, where individual buildings are scattered on the green field. These are now increasingly scarce. To achieve major progress in the future, passive solar design has to move into more dense urban areas inside the city. 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. As the utilisation of solar technologies increases, this is likely to be more important. The form and the layout of buildings, as well as the urban canyon section and orientation, affect influentially the urban microclimate. Hence, more investigation is needed in this field in order to evaluate the interactions between the geometric characteristics of the urban form and the most important microclimate factor: solar insolation.

6.2 Passive Solar Urban Design

6.2.1 The Importance of Daylight

People evaluate natural lighting in their homes in a positive manner, because daylight makes the interior look more attractive and more interesting, as well as providing light for daily practices such as reading and working. Effective daylighting will reduce the need for electric light, while winter solar gain can reduce the heating requirements inside the building. Muneer (1997) reported that electrical lighting in the UK accounts for an estimated 5% of the total primary energy consumed. Therefore, considerable savings can be achieved by utilising daylight. Santamouris et al. (1999) emphasised the importance of sunlight in the design process because it can greatly affect thermal and visual comfort. Pereira et al. (2001) affirmed, "Planning for insolation and daylight is essential in establishing the benefits to be obtained from the sun in and around buildings (thermal and visual comfort and energy conservation)".

Tregenza (1992) pointed out that sunlight has to be controlled as it is sometimes needed in rooms and sometimes can lead to discomfort and overheating. Sunlight requirements vary according to climate. In cooler climates, sunlight is more valued and seen as a major necessity inside houses. The sun is the absolute provider of light and warmth, making interiors look bright and also having therapeutic, health-giving effects. However, simultaneously, it is an insufficient resource in such a climate, as sky is cloudier when sunlight is demanded and the sun is lower in the sky and hence more likely to be obstructed. The necessity for sunlight duration varies. In warmer climates, winter sunlight may be appreciated but in summer, sunlight may cause unpleasant overheating. In cooler areas, sunlight is much more likely to be welcomed through the year.

6.2.2 Mutual Shading of Buildings

Gupta (1984) has indicated that the mutual shadowing of buildings in urban layouts changes the rate of solar radiation around buildings. Solar shading has many important impacts on the building's energy consumption, the occupants' comfort, and the view outside. " The opaque shade produced by the projection of shadows of the buildings is the main factor of the lessening in illuminance in urban areas" (Mascaro et al., 1998). The attention of previous research 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. Mutual shading between buildings may determine if an outdoor space will be desirable or unpleasant during the different times of the day or throughout the year (Littlefair, 2001b; Shaviv et al., 1997). Littlefair (2001b) also highlighted the importance of placed windows and solar elements in an optimal location with regard to insolation.

Tregenza (1992) stated that "the amount of natural light entering a building depends on early decisions about block shape and orientation". Littlefair (2001b) has also reported that confinement and orientation are the two main factors for mutual shading. Therefore, sunlight in a new urban settlement can be significantly improved if buildings are designed to overshadow each other as little as possible. In cool and intermediate climates, a recommended strategy is usually to have buildings adequately separated for good lighting. Shaviv et al. (1997) asserted that insolation of windows in winter in cold climates and shading of windows in summer in hot climates are important design tools to reduce energy consumption and ameliorate the thermal indoor environment (Shaviv and Capeluto, 1992). In addition, overshadowing of the windows increases energy use for artificial lighting and internal heat gains (Shaviv, 1980).

Littlefair (2001a) described overshadowing as a key issue in daylight design, particularly the reduction of light to existing buildings. For example, good southerly orientation is of little benefit if adjacent buildings overshade the south windows for most of the winter (Pitts, 1989). The provision of daylight to nearby buildings is very important, as an unskilful planned development may make adjoining properties gloomy and unattractive. Tregenza (1992) stated that "a new development should not overshadow adjacent land in a way that would impair development on that land". He also mentioned that the sunlight on existing buildings is considered to be adversely affected if the hours of available sunlight are reduced by more than one-fifth as a result of a new development. In designing a new development or an extension to an existing building, care should be taken to maintain the access of sunlight to the existing nearby dwellings. Also, sunlight in the space between buildings has an important impact on the overall appearance of the development. In addition, access to skylight and sunlight helps to make an energy-efficient building.

6.2.3 Passive Solar Buildings

City layout, building forms, orientation and landscape elements are some of the major design factors that the urban designer can manipulate to control thermal comfort within the urban structure. Renewable forms of energy present an opportunity to make life in cities more attractive. The use of these kinds of energy should be maximized through the actual building form. Passive solar buildings can enhance recreation value, as occupants enjoy contact with the outside, with access to natural light and fresh air. Salleh (1994) illustrated the importance of the public outdoor spaces in cities, such as streets and squares, which have proved to be important social physical spaces. However, wherever such outdoor places exist, the range of possible activities depend partly on the microclimate. Human thermal comfort touches every aspect of man's activity in his environment, indoor and outdoor, and directly influences his well-being and productivity. The form of the built area and the human microclimate has the greatest influence on the level of thermal comfort experienced.

Good building design should attempt to make use of solar energy to reduce the consumption of conventional fuel. The energy crisis of 1973 accelerated attempts to find advanced tools for the design and evaluation of shading solutions and proper insolation (Shaviv, 1984ab; Arumi, 1979; McCluney et al., 1984) A passive solar design is produced once this approach becomes an important priority in arranging the form, fabric and systems of the building and the site layout. Tregenza (1992) referred to solar design as "the use of the sun as a source of direct energy". He also emphasised the necessity in this case to ensure that collecting surfaces have the maximum exposure. It is fundamental that access to the sun is not blocked by structures on adjacent properties if a building site is designed to utilise the sun for heating purposes. Similarly, to ensure the sun's access to adjacent buildings, the intended structure should be designed so that its shadow does not extend onto neighbouring sites during critical times of the day and year (Salleh, 1994). The geometry of the urban canyon and the building's structure and layout produces different shading patterns (Grosso, 1998). Thus, it is important to consider the possibility of future developments blocking solar access when designing a passive solar building. Larger spacing will be required where buildings are designed to make the most of solar heat gain. Tregenza (1992) in his description of the latest BRE (The Building Research Establishment) guide to site planning for good access to daylight reported that the ground-floor windows (and above) of a new building should have an adequate view of the sky. According to this guide, the skylight is adequate if the obstructions are all less than 25^0 above the horizon (measured on the face of the new building 2m above the ground) (Figure 6.1). The guide also suggests that the skylight on the existing building should not be reduced below 0.8 of its previous value, where the skylight falling on an existing building is reduced by a new development (Tregenza, 1992).

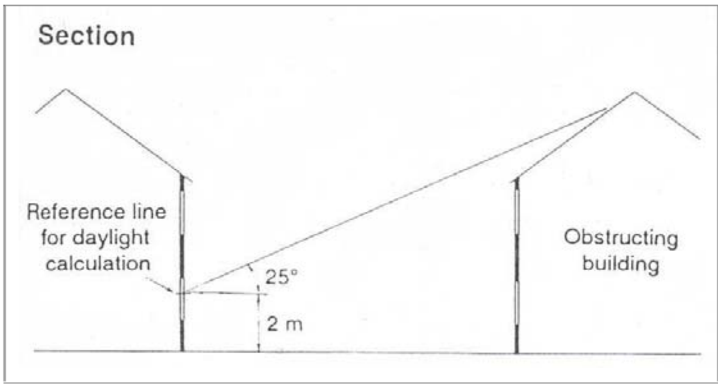


Figure 6.1: The Measure of Adequate Skylight (Tregenza, 1992)

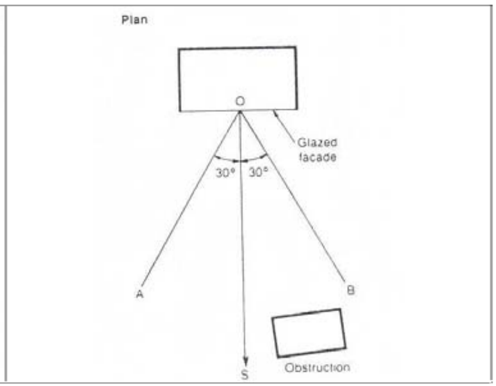


Figure 6.2: Solar Collecting Facade - within 30^0 of Due South (Tregenza, 1992)

Site layout has a major impact on the possibility of adopting passive solar heating in buildings, as high obstructions can block the incoming light, solar heat, and especially the low winter sun (Littlefair, 1998). A solar collection facade needs access to the low-angled sun in winter when its contribution will be most valuable (Littlefair, 2000). Therefore, it is necessary to ensure that overshadowing by other buildings does not reduce the effectiveness of a passive solar design. Tregenza (1992) mentioned that, for better passive solar design, obstructions to the south should be limited and the main solar collecting facade should face within 30^0 of due south (Figure 6.2). Site layout has a substantial impact on passive solar heating and overshadowing by other buildings can spoil a passive solar design. For instance, a south-facing window with a low opposite obstruction can receive sunlight nearly all winter. However, with large obstructions to the south, all the winter sun can be blocked and a glazed area may be in shadow all winter. In this case, the benefits of solar heat gain are lost but facades still receive much unwanted solar heat gain in summer (Littlefair, 2001a). Tregenza (1992) highlighted the difficulty to fix universal criteria for daylight as guidelines, which are appropriate for new housing on open sites, are not suitable for infill developments on city sites. Therefore, numerical values must be flexible and different standards may be used in special circumstances. He also emphasised the fact that natural lighting is only one of many aspects in site layout design such as view, privacy, security, enclosure and microclimate, etc.

In the case of Palestine, passive solar design has more benefits for the West Bank than for the Gaza Strip, mainly because the climate there is colder and heating is required more extensively. Also, the reasonable density of urban structures facilitates more the use of solar energy. At dense locations (as in some parts of Gaza), some houses may be seriously obstructed and on small sites it may be difficult to achieve the best orientation to avoid overshadowing by nearby buildings. In addition, the terrain in the West Bank (which is located in the mountain area) makes it possible to use a level or south-facing sloping site to reap the full benefits of passive solar design. Moreover, good natural ventilation in summer to avoid overheating in passive solar buildings could be more achievable in the West Bank due to the relatively low resident density which is less noisy and polluted.

6.2.4 Cross Section (Urban Canyon Ratio)

The major factors determining the character of the urban microclimate are the proportions of the space (the urban canyon ratio), and orientation. Bansal (1994) has pointed out that "in real situations the distance between buildings is usually related to the height in order to obtain sufficient daylight and ventilation indoors". Sakakibara (1996) reported that the urban thermal environment depends on the urban canyon configuration. Shashua et al. (2003) stressed, "Geometry and orientation play a major role in determining a street's climatic features". So, the issue that matters most in terms of climatic design and urban geometry is the "View Factor", (i.e. the proportion of the total spherical field of view from a subject taken up by surfaces). Thus, the urban canyon is a basic unit of urban space, which can be approximated by a two-dimensional cross-section comprising the average building height (H) and the distance between two adjacent buildings (W). The H/W ratio varies according to climatic, cultural and aesthetic needs. The cross section ratio of the canyon affects solar exposure to the surface of the canyon. Temperature at a surface point increases immediately when direct radiation falls upon it. The longer a point is exposed to solar radiation, the higher the temperature gets. The wider the canyon, the longer the duration of solar exposure time (El-Sioufi, 1987).

6.2.5 The Canyon Orientation

The orientation and width of the urban canyon affect the solar exposure of buildings. They are of greater importance in densely built urban areas (Santamouris et al., 1996). Orientation affects solar exposure as a result of the incidental shading of one building from another, thus reducing the period of its solar exposure. Kristl et al. (2001) pointed out that appropriate orientation of the building and a careful site layout can increase heat gains. Good orientation not only reduces heating costs, but living spaces exposed to sunlight provide high amenity value as well. Therefore, orientation is considered to be an important factor that affects substantially the energy performance of any residential building (Numan et al., 1999). The orientation of a building is influenced by the climatic factors of wind and solar radiation, as well as by view, noise and other requirements of privacy.

To make the most of solar gain, main roads, where possible, should run east-west, and the main solar-collecting facade should face within 30^0 of due south. Orientations further than this (east or west) will receive less solar gain, particularly in winter when it is of most use (Littlefair, 2001b). Access to sunlight can usually be improved by locating higher buildings to the north of the site and low-density housing in the area south of the building. Solar insolation can also be enhanced by creating courtyards in the southern part of the building area (Santamouris et al., 1999). A south-facing window will usually receive the most sunlight while a north-facing one will only receive it early in the mornings and in the late evenings in summer (Littlefair, 2001b). Optimum orientation would reduce radiation to a minimum in the overheated period, while at the same time allowing some radiation during the underheated period (Konya, 1980).

Canyons oriented to the north-south direction produce a dynamic and variable shading pattern; while the opposite variant (orienting the canyon axis east-west) makes one facade more shaded (the north facade), with the other one receiving solar radiation most of the time (the south one) (El-Sioufi, 1987). For the canyon which is oriented north-south, the maximum temperature is expected to occur at points on the west facade as these are expected to be warmer than their counterparts on the east side because they start warming up in the early morning due to the reflected radiation from the east facade. In addition, the warmer afternoon air temperature influences them when they receive direct solar radiation. In this case, the temperature and radiation peak are added together. This results in a heavy heat impact in the afternoon compared with the relatively low temperature in the forenoon

(Olgyay, 1992). The temperature is also expected to increase according to the height on each facade, as the upper points are exposed to solar radiation longer than the others.

6.2.6 Solar Right

Littlefair (1991) clarifies the two main factors on which the quality and quantity of natural light within an interior depend. First, the design of the interior environment is important, such as the size and the position of windows, the depth and shape of rooms, the colours of internal surfaces. The second important factor, which also plays a major role, is the design of the external environment. Site layout is the most important factor affecting the duration of sunlight inside buildings; so, good daylight design starts at the site layout stage. If obstructing buildings are large or close by, satisfactory daylighting will be difficult to obtain. This will affect the distribution of light inside the room, as well as the total amount received.

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”. However, Littlefair (2001a) advised that it would be incorrect to have obstruction angle as the only decisive factor, because a non-continuous obstruction could subtend a greater angle in section, but the window could still admit enough daylight around the sides of the obstruction.

6.3 A Comparison Between Radial and Rectangular Urban Patterns

6.3.1 The Urban Site

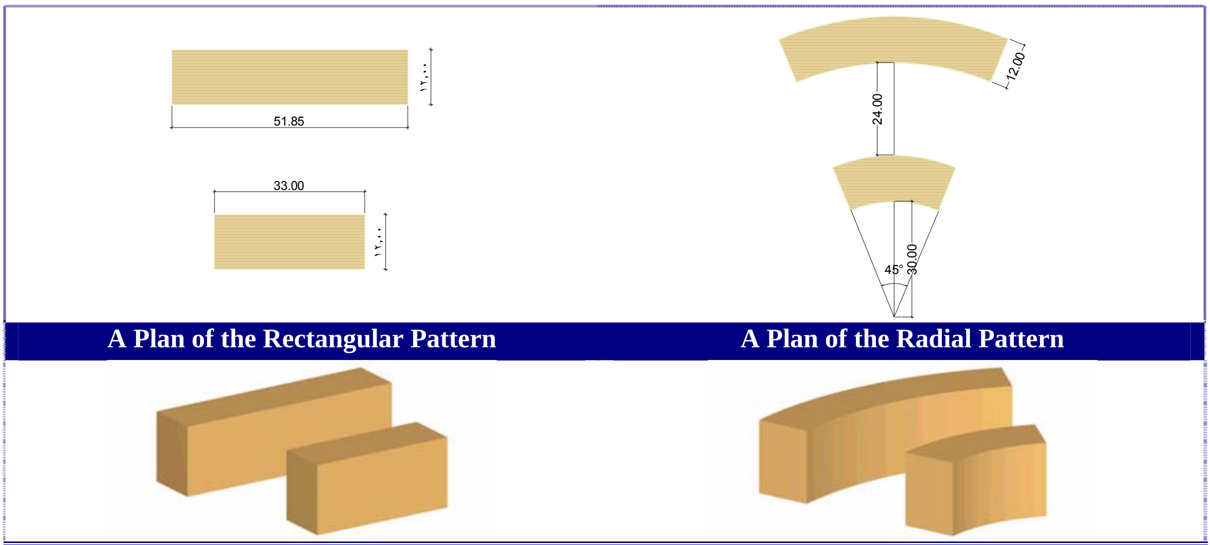
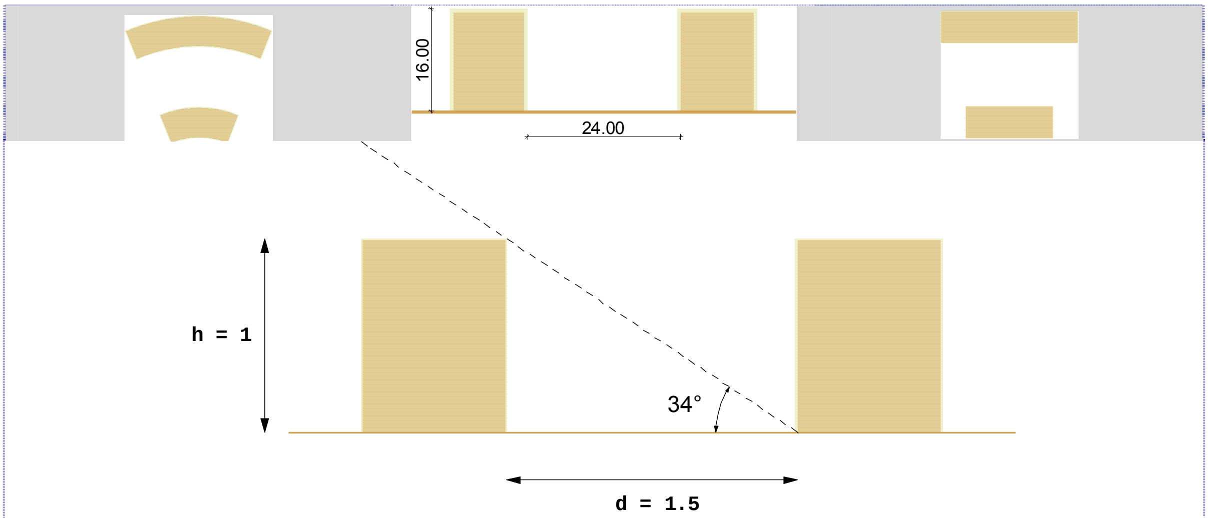


Figure 6.3: The Urban Site - East-West Pattern

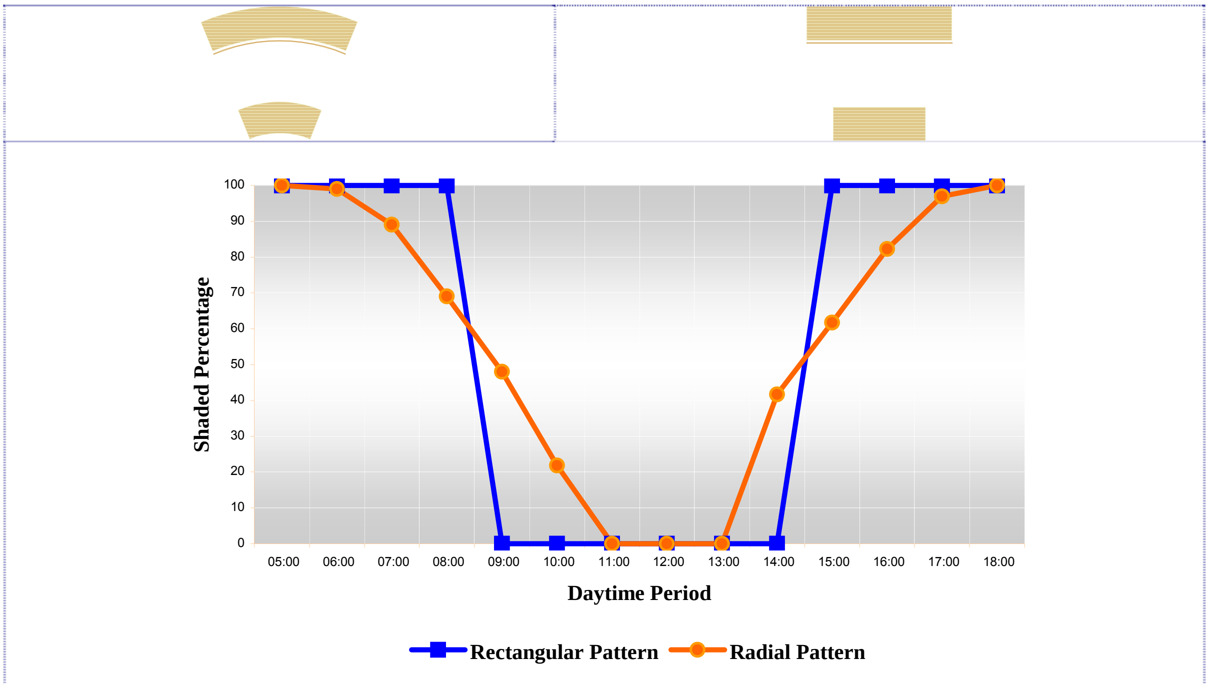
Two patterns of urban canyons are suggested (rectangular and radial). Both patterns consist of two blocks with the same separating distance (Figure 6.3). The two patterns have the same built volume and the same canyon facade area. In addition, the two patterns occupy the same floor area. The height is supposed to be 16 m and the depth of the blocks is 12 m. 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) (Figure 6.4). 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). As the two patterns have the same heights and the same perimeters, the external surface areas for the two patterns will be the same. 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. 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.



h = Roof height, d = Roof to face spacing to prevent overshading for a given sun angle, α = Solar Altitude
Example: {h = 1, midday solar altitude for latitude of Jerusalem (31° 47) on December 21st (α) = 34⁰}
No winter overshading will occur with roof to face distance of 1.5

Figure 6.4: The Urban Canyon Sections - Urban Canyon Ratio (H/W): 1: 1.5

6.3.2 The Shadow Analysis for the Canyon Located on the East-West Axis
6.3.2.1 Shadow Patterns in Summer
i. The South Facade - The North Block



The Rectangular Facade	The Radial Facade
57.14 %	57.83 %

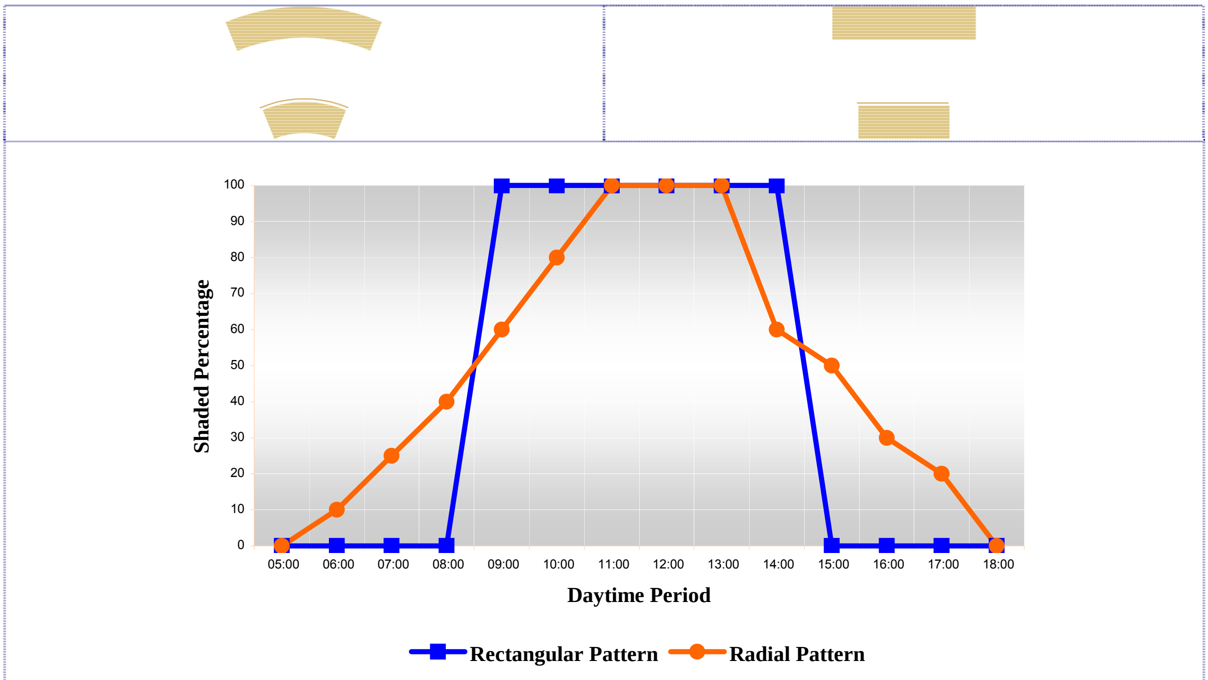
Figure 6.5: The Shadow Patterns in Summer (The South Facade - The North Block)

The graph (Figure 6.5) illustrates the generated shadow pattern in both facades in the summer period. The horizontal axis represents the daytime period within one-hour intervals. The vertical axis represents the percentage of the shaded area of the facade in units of 10%. The graph reveals that, in general, the rectangular facade is less shaded than the radial one over the daytime period. The rectangular facade is shaded for 8 hours and exposed for 6 hours during the daytime period. The facade is shaded in the forenoon and afternoon periods, as the facade is not exposed to sunrays. The radial facade is completely shaded for just one hour in the early morning and for one hour in the late afternoon. It is completely exposed for 2 hours in the noon period, while it is partially shaded during the rest of the daytime period. The radial facade is less shaded than the rectangular one in early morning and late afternoon. Then it becomes more shaded until one hour before and after noon. In the noon period, both facades are completely exposed.

The south block in this urban canyon ratio does not shade the north one, as the spacing between the two blocks is relatively large. Also, in summer, the angle of the south sun is quite high at midday, when the shadowing caused by the south block is expected to take place.

The radial facade is partially exposed most of the time. This clearly illustrates the importance of the self-shading effect of the radial form, as the facade can enjoy the sun during the whole daytime period. Due to the curvilinear character of the form, the western part of the radial facade is exposed earlier to sunrays in the morning, while the eastern part is exposed for a longer period in the afternoon. This variation between the two patterns is expected to increase with a larger extent of concavity.

ii. The North Facade - The South Block



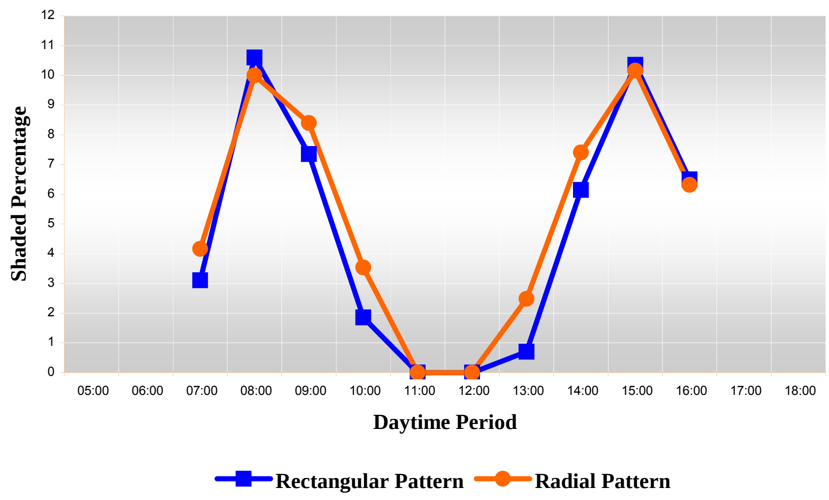
The Rectangular Facade	The Radial Facade
42.86 %	48.21%

Figure 6.6: The Shadow Patterns in Summer (The North Facade - The South Block)

The north facade is mainly exposed to sunrays just in the early morning and late afternoon (Figure 6.6). In general, the rectangular facade is less shaded than the radial one over the daytime period. The rectangular facade is shaded for 6 hours and exposed for 8 hours during the daytime. On the other hand, the radial facade is completely shaded for 3 hours in the noon period and completely exposed for one hour in both the morning and afternoon. For the rest of the time, the radial facade is partially shaded. Thus, the curved facade enjoys sun for a longer period of time than the rectangular one. Although the curved facade is a northern one, the facade still enjoys sun for most of the time, as the eastern part of the facade is exposed for a longer period of time than the rectangular one, and the western part of the facade is exposed earlier to sunrays.

The radial facade is more shaded than the rectangular one in the morning and the afternoon, and then it gradually becomes less shaded until one hour before and after noon. In the noontime both facades are completely shaded, as the direction of sunrays is approximately perpendicular to the centre of the shape. The north facades in both patterns (radial and rectangular) are more exposed in summer than the opposite south facades.

6.3.2.2 The Shadow Patterns in Winter
i. The South Facade - The North Block



The Rectangular Facade	The Radial Facade
4.66 %	5.25 %

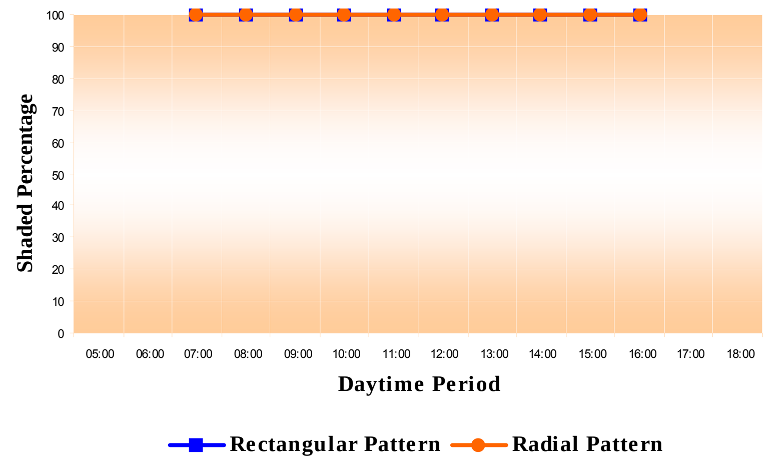
Figure 6.7: Shadow Patterns in Winter (The South Facade - The North Block)

The graph shows that the distribution of the shaded area in the two facades during the daytime period is approximately the same (Figure 6.7). For most of the time, the radial facade has a slightly higher shaded area. In the noon period the two facades are completely exposed. This shaded area is caused by the dappled shadow from the south block to the north one.

The north block is partly shadowed by the south block during the morning and afternoon, when the sun is closer to the horizon. On the other hand, the south block does not shadow the north one in the noon period as the sun is high in the sky. Therefore, the shadow starts gradually to decrease with the increase of the altitude angle of the sun until it vanishes completely during noon when the sun's altitude reaches its maximum.

The performance of the rectangular and radial facades is almost the same, as the self-shading effect of the radial facade does not occur in this case. This is because the sun's position in winter is more perpendicular to the south concave surfaces of the curve, as the sun in winter comes mainly from the south. The self-shading effect is mainly produced by sunrays coming from the east and west.

ii. The North Facade - The South Block



The Rectangular Facade	The Radial Facade
100 %	100 %

Figure 6.8: The Shadow Patterns in Winter (The North Facade - The South Block)

The two facades receive no sunrays at all (Figure 6.8) as a result of the fact that sunrays in winter come mainly from southern positions, while the facades are on the north sides. Although the end-parts of the curved facade partially take east and west directions, the extent of the concavity is not enough to receive any sunrays in the early morning or late afternoon, and the radial facade acts almost the same as the rectangular one. When comparing the shadow pattern generated in the facades of the two urban patterns (radial and rectangular) during daytime, more significant variation is found in the summer period than in winter.

6.3.2.3 The Annual Shaded Area Generated in the Two Patterns

	The Average Annual Shaded Area per Hour	
	The Rectangular Form	The Radial Form
The South Block-NF	80.56	79.13
The South Block-EF	51.04	42.71
The South Block-SF	19.79	28.85
The South Block-WF	49.31	44.44
The South Block	50.17	53.83
The North Block -NF	80.56	79.13
The North Block-EF	51.04	42.71
The North Block-SF	20.33	27.35
The North Block-WF	49.31	44.44
The North Block	50.39	53.33
Total Pattern	50.30	54.76

Table 6.1: 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 6.9). 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.

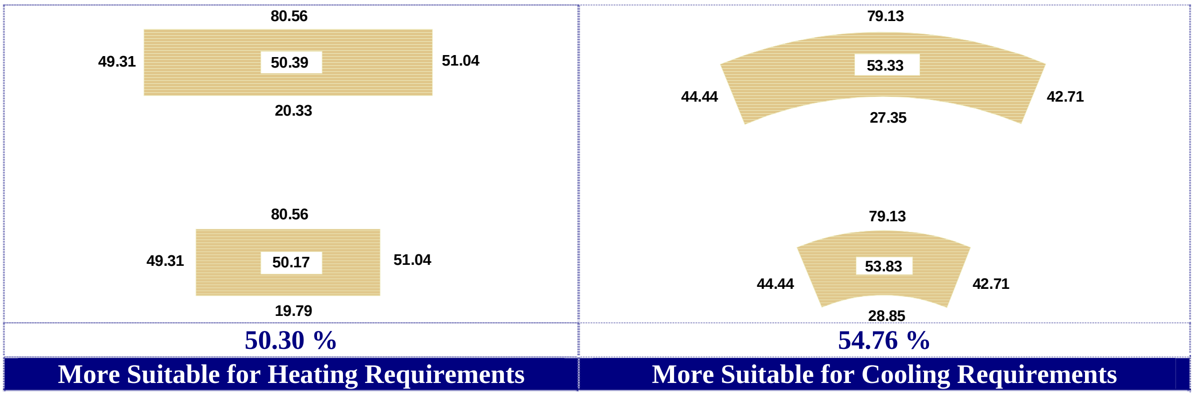


Figure 6.9: The Annual Shaded Area Generated in the Two Patterns

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 (Table 6.1).

6.3.2.3.1 The Calculation of the Shaded Area

i. The Rectangular Pattern

In the rectangular pattern, the shaded percentage caused by the south block to the north one can be calculated by subtracting the shaded area generated in the external south facade of the south block, which is not shadowed by any object, from the shaded area generated in the identical canyon facade of the north block.

The dappled shaded area in the south facade of the north block = 20.33 – 19.79 = 0.54

The dappled shadow from the south block to the north one occurs during the winter period in November, December and January (Table 6.2). The dappled shadow from the south block to the north one can be shown by comparing the shaded area in the two identical facades in the two blocks (Table 6.3).

Month	%
November	0.079 %
December	0.324 %
January	0.137%
Total Shadowed Area	0.540 %

Table 6.2: The Dappled Shadow from the South Block to the North One

The South Block-South Facade

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
01:00													
02:00													
03:00													
04:00													
05:00					100	100	100						300
06:00			0	100	100	100	100	100	0	0			500
07:00	0	0	0	0	100	100	100	100	0	0	0	0	400
08:00	0	0	0	0	0	100	100	0	0	0	0	0	200
09:00	0	0	0	0	0	0	0	0	0	0	0	0	0
10:00	0	0	0	0	0	0	0	0	0	0	0	0	0
11:00	0	0	0	0	0	0	0	0	0	0	0	0	0
12:00	0	0	0	0	0	0	0	0	0	0	0	0	0
13:00	0	0	0	0	0	0	0	0	0	0	0	0	0
14:00	0	0	0	0	0	0	0	0	0	0	0	0	0
15:00	0	0	0	0	0	100	0	0	0	0	0	0	100
16:00	0	0	0	0	100	100	100	0	0	0	0	0	300
17:00		0	0	100	100	100	100	100	0	0			500
18:00				100	100	100	100	100					500
19:00													
20:00													
21:00													
22:00													
23:00													
24:00													

The North Block-South Facade

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
01:00													
02:00													
03:00													
04:00													
05:00					100	100	100						300
06:00			0	100	100	100	100	100	0	0			500
07:00	0	0	0	0	100	100	100	100	0	0	0	3.4	403.4
08:00	7.1	0	0	0	0	100	100	0	0	0	3.9	10.5	221.5
09:00	4.5	0	0	0	0	0	0	0	0	0	0	7.1	11.6
10:00	0	0	0	0	0	0	0	0	0	0	0	1.6	1.6
11:00	0	0	0	0	0	0	0	0	0	0	0	0	0
12:00	0	0	0	0	0	0	0	0	0	0	0	0	0
13:00	0	0	0	0	0	0	0	0	0	0	0	0.7	0.7
14:00	0.6	0	0	0	0	0	0	0	0	0	0	6.2	6.8
15:00	6.3	0	0	0	0	100	0	0	0	0	4.2	10.3	120.8
16:00	5	0	0	0	100	100	100	0	0	0	0	6.1	311.1
17:00		0	0	100	100	100	100	100	0	0			500
18:00				100	100	100	100	100					500
19:00													
20:00													
21:00													
22:00													
23:00													
24:00													

Table 6.3: Comparing the Shaded Area Between the Two Identical Facades in the Two Blocks

ii. The Radial Pattern

In the radial pattern, the dappled shade of the south block to the south facade of the north one can be calculated by making a summation of the shaded areas during November, December and January, as this facade is supposed to be exposed in these months in case dappled shadow does not exist (Table 6.4).

Month	%
November	0.1317
December	0.3643
January	0.1817
Total Shadowed Area	0.6778

Table 6.4: The Dappled Shadow from the South Block to the North One

The genuine shaded area of the north block - south facade can be calculated by subtracting the shaded area caused by the dappled shadow from the south block, from the total area of shadow.

The genuine shaded area = 27.35 – 0.6778 = 26.67

Differences in the shaded percentages between the two south facades in the two blocks, due to the variation of the concavity of the forms, can be calculated by subtracting the shaded area of the south block - south facade from the shaded area of the north block - south facade.

The variation of shaded area due to the concavity = 28.85 – 26.67 = 2.18 %

The shaded area caused by the concavity (the self-shading effect) of the radial facade could be calculated by subtracting the shaded area of the south facade in the rectangular pattern from the shaded area of the south facade in the radial pattern.

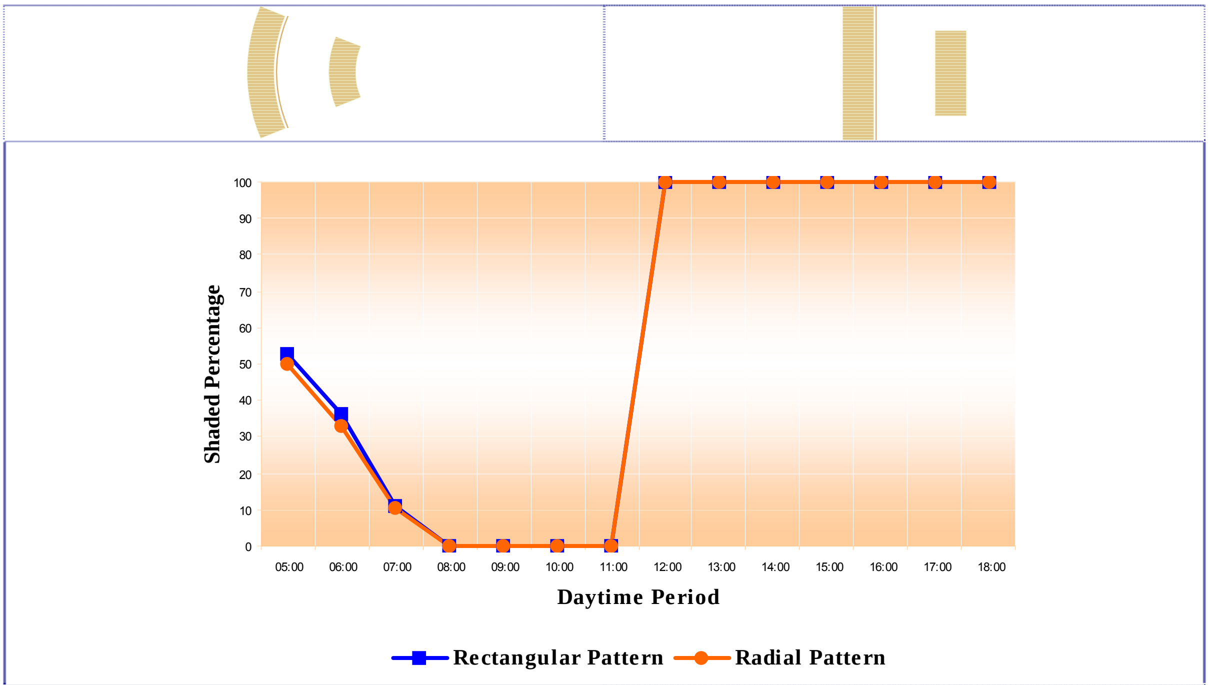
The shaded area caused by the concavity of the radial facade of the north block =
26.67 – 19.79 = 6.88 %
The shaded area caused by the concavity of the radial facade of the south block =
28.85 – 19.79 = 9.06 %

Thus, in the radial pattern, the generated shaded area of the south facade of the north block can be distributed as in the following table (6.5).

The Shaded Area of the South Facade of the North Block	
The Shaded Area (if Facade is not Concave - Flat Facade)	19.79
The Shaded Area Caused by the Self-shaded Effect of the Radial Facade	6.88 %
The Shaded Area Caused by the South Block	0.6778
Total Shaded Area	27.35 %

Table 6.5: The Distribution of the Shaded Area of the South Facade of the North Block

6.3.3 The Shadow Analysis for the Canyon Located on the North-South Axis
6.3.3.1 The Shadow Patterns in Summer
i. The East Facade - The West Block



The Rectangular Facade	The Radial Facade
57.17 %	56.67 %

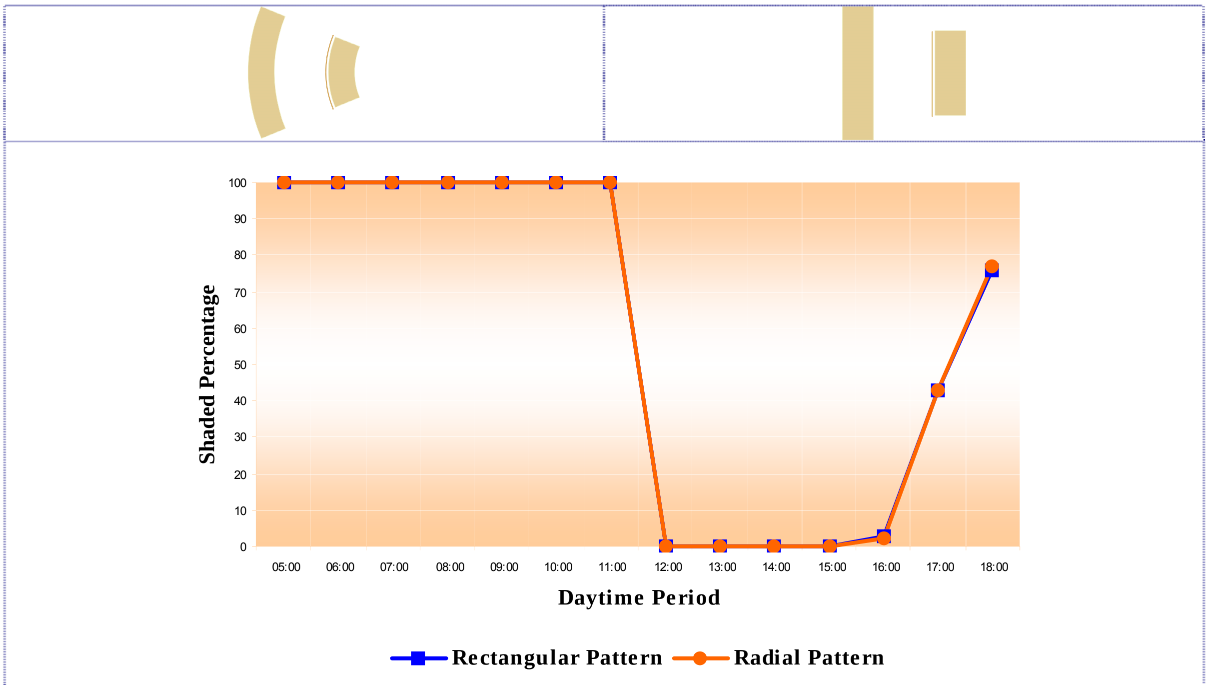
Figure 6.10: The Shadow Patterns in Summer (The East Facade - The West Block)

The shaded area in the facade, which is caused by the eastern block, comprises 11.77 % of the total shaded area in the case of the radial pattern and 12.54 % in the case of the rectangular pattern. The shadow effect caused by the eastern block occurs during the first 3 hours of daytime. Apart from the dappled shadow of the eastern block, the facade is exposed during the first half of daytime and shaded in the second half (Figure 6.10).

The southern part of the facade is partially shaded by the eastern block. This shadow covers a larger percentage of the facade in the early morning, and then it rapidly decreases with the increase of the altitude angle of the sun. As sunrays exceed the eastern block, the facade is exposed to the sun until the noon period, when sunrays are paralleling the facade at this time. Then, in the afternoon period, the whole facade is shaded as it is not exposed to the sun.

The performance of the radial pattern is similar to the rectangular one in this case. However, some parts of the radial form (the southern half) are shaded earlier due to the self-shading effect before noon, while the second half (the northern one) will remain exposed for a longer time after noon. In general, this period is very short, as sunrays in the noon period change direction very quickly. This variation also depends on the extent of the concavity of the form. The bigger the concavity of the form, the greater the range of this variation. However, the amount of generated shadow in the radial form will be approximately the same as in the rectangular one, as one half of the radial facade will be shaded earlier and the other one will be exposed for a longer duration.

ii. The West Facade - The East Block

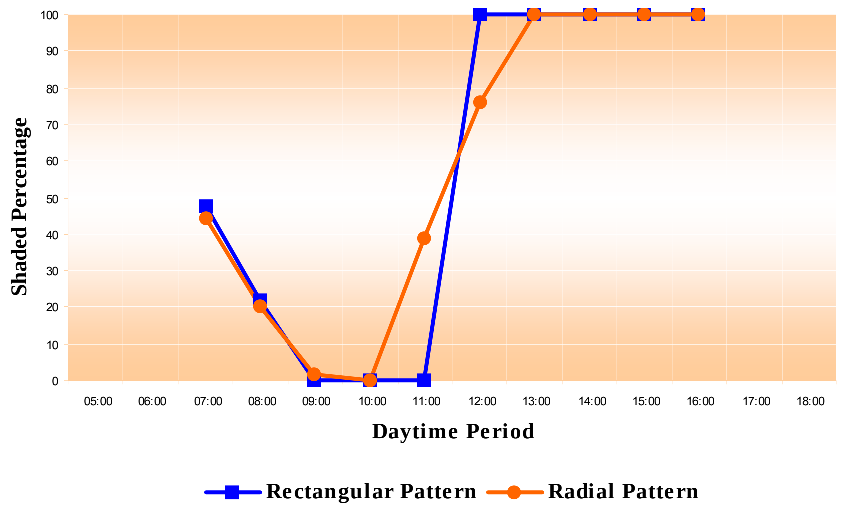


The Rectangular Facade	The Radial Facade
58.66 %	58.725 %

Figure 6.11: The Shadow Patterns in Summer (The West Facade - The East Block)

The dappled shade in the facade caused by the west block, comprises 14.857 % of the total shaded area in the case of the radial pattern and 14.76 % in the case of the rectangular one. The shadow caused by the west block occurs during the last 3 hours of daytime (Figure 6.11). The facade starts to be exposed to sunrays in the noon period. Then, in the afternoon it begins to be partially shaded by the effect of the west block. This shadow increases gradually with the decrease of the altitude angel of the sun and reaches its maximum when the sun starts to set. The shadow pattern generated by the radial facade in this case is very similar to that one generated from the rectangular facade. However, the radial facade starts to be exposed to the sun slightly earlier as its southern curved end will face the noon sunrays first.

6.3.3.2 Shadow Patterns in Winter
i. The East Facade - The West Block



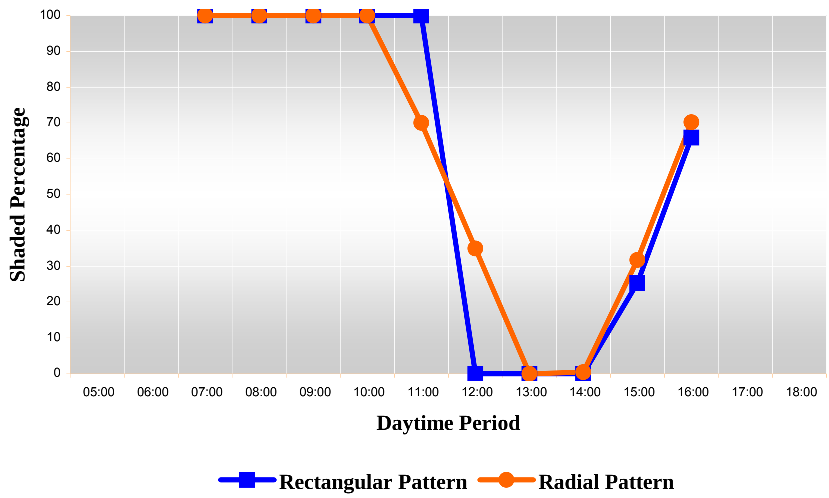
The Rectangular Facade	The Radial Facade
56.94 %	58.09 %

Figure 6.12: The Shadow Pattern in Winter (The East Facade - The West Block)

The dappled shade in the facade, which is caused by the east block, comprises 11.37 % of the total shaded area in the case of the radial facade and 12.188 % in the case of the rectangular one. The shadow caused by the east block occurs during the first 2 hours of daytime in the case of the rectangular pattern and during the first 3 hours in the case of the radial one (Figure 6.12). The north part of the facade is partially shaded by the east block. This shadow covers a larger percentage of the facade in the early morning, and then it rapidly decreases with the increase of the altitude angle of the sun. As sunrays exceed the eastern block, the facade becomes completely exposed to sunrays until the noon period. Then, in the afternoon the whole facade is shaded as it is not exposed to the sun. Compared to the rectangular facade, the radial facade is partially shaded one hour earlier and partially exposed one hour later. In the case of the rectangular pattern, and apart from the dappled shadow from the east block, the facade is exposed during the first half of the day and shaded in the second half.

Excluding the shaded area caused by the east block, the shaded area of the radial facade is bigger than the rectangular one due to the self-shading effect. The graph illustrates that some parts of the radial form (the southern half) are shaded earlier during the noon period due to the self-shading effect, while the other half (the northern one) remains exposed for a longer period. It is noted that this transition period is clearer and lasts for a longer time in winter than in summer, due to the fact that in winter, the sun is closer to the horizon and the azimuth of the sun changes at a slower rate.

ii. The West Facade - The East Block



The Rectangular Facade	The Radial Facade
59.12 %	60.75 %

Figure 6.13: The Shadow Pattern in Winter (The West Facade - The East Block)

The shaded area in the facade, which is caused by the western block, comprises 16.874 % of the total shaded area in the case of the radial facade and 15.426 % in the case of the rectangular one. The shadow caused by the west block occurs during the last 2 hours of the daytime period in the case of the rectangular pattern and during the last 3 hours in the case of the radial one. Compared to the rectangular facade, the radial facade is partially exposed one hour earlier and partially shaded one hour later.

Excluding the shaded area caused by the west block, the shaded percentage of the radial facade is bigger. The graph reveals that the radial facade starts being exposed to the sun a little earlier, as its southern curved end tends to face the noon sunrays first and then tends to be completely exposed gradually (Figure 6.13). This transition period in the wintertime is clearer and lasts for a longer time than the transition period in summer. In general, it is noted that the variation in the distribution of shadow during the daytime period is clearer and lasts for a longer time in winter than in summer. This is caused by the self-shading effect of the radial form which is more visible in wintertime. This can be attributed to the fact that the altitude angle of the sun is more vertical in summer. In addition, the direction of the sunrays change dynamically as the sun passes through a wider range than in wintertime. This results in a minimum self-shading effect in the summer period.

6.3.3.3 The Annual Shaded Area Generated in the Two Patterns over the Year

	The Average Annual Shaded Area per Hour	
	The Rectangular Form	The Radial Form
East Block-SF	21.92 %	23.61 %
East Block-WF	59.94 %	61.22 %
East Block-NF	83.43 %	76.39 %
East Block-EF	51.04 %	51.56 %
East Block	54.74 %	55.05 %
West Block-SF	19.79 %	23.61 %
West Block-WF	49.31 %	50.35 %
West Block-NF	80.56 %	76.39 %
West Block-EF	58.45 %	57.78 %
West Block	53.18 %	53.10 %
Total Average	53.825 %	53.822 %

Table 6.6: The Annual Shaded Area Generated in the Two Patterns

The calculations of the average annual shaded area in the two patterns (Table 6.6) 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 (Figure 6.14).

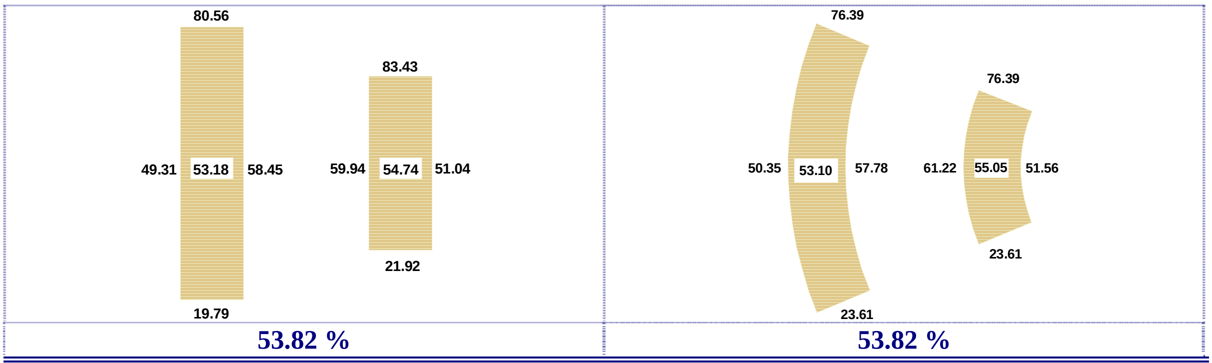


Figure 6.14: The Average Annual Shaded Area per Hour

The identical side facades in the two blocks within the radial pattern have the same shaded area, as there is no dappled shadow from the west block to the east one. The side facades of the east block in the rectangular pattern have more shaded area, as the west block casts a shadow on the east one. This dappled shadow in the southern facade of the eastern block occurs mainly in February, March, September and October, while the dappled shadow in the north side facade of the east block occurs in April, May, June, July and August.

The southeast side facades of the radial pattern are more shaded than the identical facades in the rectangular one due to their position, which is less turned towards the south. On the other hand, the northeast side facades of the radial pattern are less shaded than their counterparts in the rectangular one due to their position, which is less turned towards the north. The concave facade in the east block of the radial pattern is slightly more shaded than its counterpart in the rectangular one due to its concavity, which generates the self-shading effect.

6.3.3.3.1 The Shadow Area Calculation
i. The Rectangular Pattern

In the rectangular pattern, the shaded percentage dappled by one block on the other one can be calculated by subtracting the shaded area of the identical external facade from the internal canyon facade. So, the shaded percentage of the east block - west facade, which is caused by the west block could be calculated by subtracting the shaded area of the west block - west facade from the shaded area of the east block - west facade.

The dappled shadow in the west facade of the east block = 59.94 - 49.31 = 10.63 %

The shadow cast from the west block to the east one occurs during the afternoon period over the whole year (Table 6.7).

Month	%
January	0.489 %
February	0.947 %
March	0.7835 %
April	1.289 %
May	1.0405 %
June	0.8405 %
July	0.867 %
August	1.166 %
September	0.776 %
October	0.9685 %
November	0.712 %
December	0.63 %
Total Shaded Percentage	10.509 %

Table 6.7: The Dappled Shadow in the West Façade of the East Block over the Year

The dappled shadow from the west block to the east one can additionally be illustrated by comparing the shaded area in the two identical facades in the two blocks (Table 6.8).

West block-West Facade

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
01:00													0
02:00													0
03:00													0
04:00													0
05:00					100	100	100						300
06:00			100	100	100	100	100	100	100	100			800
07:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
08:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
09:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
10:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
11:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
12:00	0	0	0	0	0	0	0	0	0	0	0	0	0
13:00	0	0	0	0	0	0	0	0	0	0	0	0	0
14:00	0	0	0	0	0	0	0	0	0	0	0	0	0
15:00	0	0	0	0	0	0	0	0	0	0	0	0	0
16:00	0	0	0	0	0	0	0	0	0	0	0	0	0
17:00		0	0	0	0	0	0	0	0	0			0
18:00				0	0	0	0	0					0
19:00													0
20:00													0
21:00													0
22:00													0
23:00													0
24:00													0
Total	500	500	600	600	700	700	700	600	600	600	500	500	7100

East block-West Facade

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
01:00													0
02:00													0
03:00													0
04:00													0
05:00					100	100	100						300
06:00			100	100	100	100	100	100	100	100			800
07:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
08:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
09:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
10:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
11:00	100	100	100	100	100	100	100	100	100	100	100	100	1200
12:00	0	0	0	0	0	0	0	0	0	0	0	0	0
13:00	0	0	0	0	0	0	0	0	0	0	0	0	0
14:00	0	0	0	0	0	0	0	0	0	0	0	0	0
15:00	16.2	3.6	0	0	0	0	0	0	0	20.9	30.4	26.2	97.3
16:00	56.8	47.7	38.9	26.6	14.3	3.5	2.6	16.8	41.6	65.3	72.9	66.9	453.9
17:00		88.8	76.4	64.6	53	43.3	43	55.9	78.2	99.9			603.1
18:00				98.4	86.7	76	77.3	89.9					428.3
19:00													0
20:00													0
21:00													0
22:00													0
23:00													0
24:00													0
Total	573	640.1	715.3	789.6	854	822.8	822.9	762.6	719.8	786.1	603.3	593.1	8682.6

Table 6.8: A Comparison between the Shaded Area in the Two Identical Facades in the Two Blocks

If the following months are considered: November, December and January as representatives of the underheated period and May, June and July as representatives of the overheated period, it could be derived that the largest amount of shaded area takes place in the summer period. In this case, the dappled shaded area will be less in winter where it is crucial to gain an exposed area as much as possible (Table 6.9).

	Underheated Period			Overheated Period		
Month	**November**	**December**	**January**	**May**	**June**	**July**
Amount	**0.712**	**0.63**	**0.489**	**1.0405**	**0.8405**	**0.867**
Total	**1.831**			**2.748**		
Percentage	**40 %**			**60 %**		

Table 6.9: The Distribution of the Dappled Shaded Area in the West Facade in the Two Seasons

The shaded percentage of the west block - east facade, which is caused by the east block, can be calculated by subtracting the shaded area of the east block - east facade from the shaded area of the west block - east facade.

The dappled shaded area in the east facade of the west block = 58.45 – 51.04 = 7.41 %

Although, the two blocks are symmetrically arranged according to the sun's path, the shaded percentage of the west facade is bigger in the east block due to the larger size of the west block, which enlarges the dappled shadow to the east one. The dappled shadow from the east block to the west one occurs during the morning period over the whole year (Table 6.10).

Month	%
January	0.556 %
February	0.535 %
March	0.839 %
April	0.518 %
May	0.792 %
June	0.694 %
July	0.786 %
August	0.488 %
September	0.585 %
October	0.755 %
November	0.386 %
December	0.474 %
Total Shadowed Percentage	7.408 %

Table 6.10: The Dappled Shadow in the East Facade of the West Block over the Year

The calculations of the dappled shaded area in the two seasons reveal that the shaded area is less in winter when it is desirable to have as much exposed area as possible. This phenomenon is beneficial in temperate climates where it is preferable to have the least amount of shadow during wintertime and to have more shaded area in summer (Table 6.11).

	Underheated Period			Overheated Period		
Month	November	December	January	May	June	July
Amount	0.386	0.474	0.556	0.792	0.694	0.786
Total	1.416			2.272		
Percentage	38.40 %			61.60 %		

Table 6.11: The Distribution of the Dappled Shaded Area in the East Facade in the Two Seasons

Following the same principles, it is also possible to calculate the shaded area of the two side facades of the east block.

The shaded area in the south facade of the east block = 21.92 - 19.79 = 2.13 %

The shaded area in the north facade of the east block = 83.43 - 80.56 = 2.87 %

ii. The Radial Pattern

In the radial pattern, the shaded percentage of the east block - west facade, which is caused by the west block could be calculated by subtracting the shaded percentage of the west block - west facade from the shaded percentage of the east block - west facade. The shadow takes place in the afternoon period over the whole year.

= 61.22 - 50.35 = 10.87 %

The shaded percentage of the west block - east facade, which is caused by the east block can be calculated by subtracting the shaded percentage of the east block - east facade from the shaded percentage of the west block - east facade (after excluding the amount of shadow caused by the variation of the concavity between the two facades). The shadow takes place in the morning period over the whole year.

The total variation in the shaded percentage between the two facades:

57.78 – 51.56 = 6.22

The amount of shadow caused by the variation of concavity = 0.747 %
The genuine shaded percentage cast from the east block to the east facade of the west block = 6.22 + 0.747 = 6.97 %

Thus, the shaded area of the east facade of the west block (without the shadow cast by the east block)

= 57.78 – 6.97 = 50.81 %

The shaded area due to the concavity (the self shading effect of the form), when compared to the identical rectangular facade = 50.81 – 50.04 = 0.77

6.3.4 A Comparison between the Two Urban Patterns with Different Orientations
6.3.4.1 The Average Annual Shaded Area per Hour

The variation in the shaded percentage between the radial and the rectangular patterns is greater in the case of the canyons oriented east-west (Figure 6.15). 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 6.12).

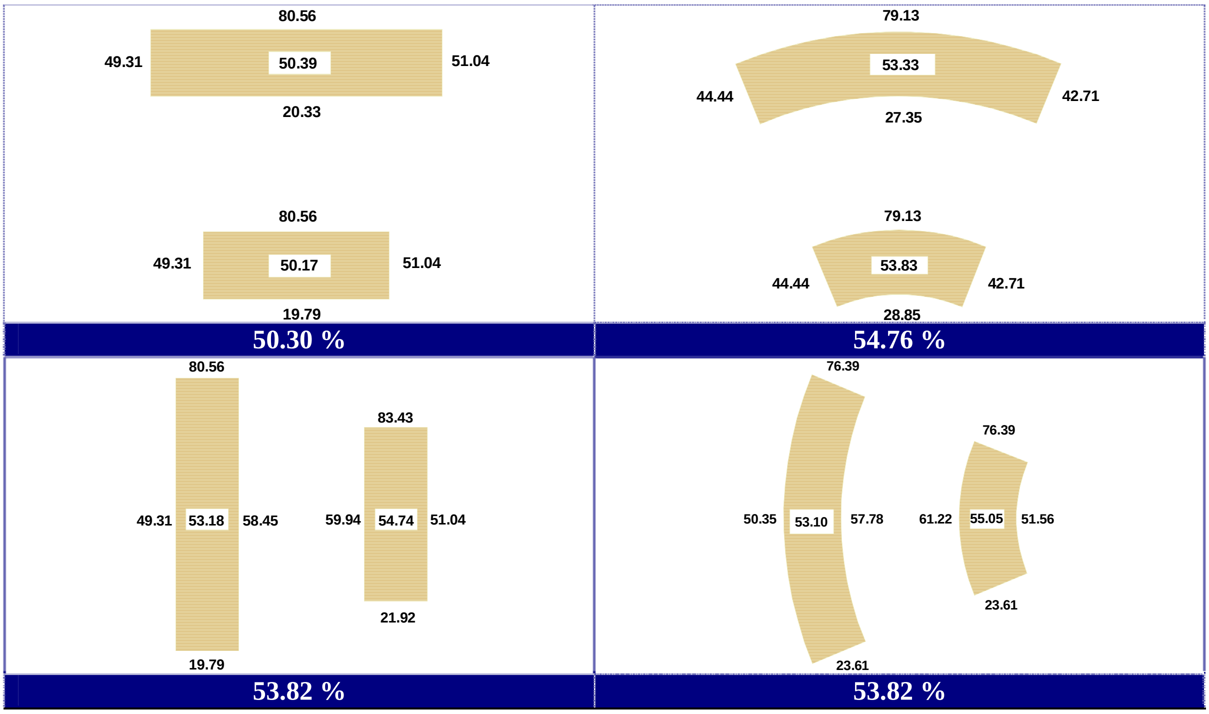


Figure 6.15: The Average Annual Shaded Area per Hour

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.

Canyon Oriented East-west		Canyon Oriented North-south	
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 %
The Variation		The Variation	
9.06 %		0.52 %	

Table 6.12: The Radial Forms in the East-west Canyon Generate more Self-shading Effect

With the urban canyon oriented east-west, just the south block casts shadow to the north block, while with the urban canyon oriented north-south, the impact from one over the other is almost the same, as the two blocks are located symmetrically relative to the path of the sun. 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 6.13).

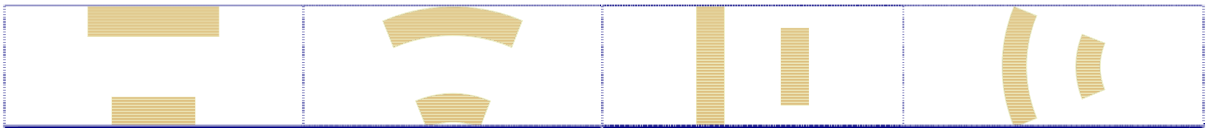
The East-west Pattern		The North-south Pattern	
The Shadow From the South Block to the North One		The Shadow From the East Block to the West One	
The Rectangular	The Radial Pattern	The Rectangular	The Radial Pattern
0.54 %	0.6778 %	7.41 %	6.97 %
		The Shadow From the West Block to the East One	
		The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

Table 6.13: The Shaded Percentage from one Block to the other in Both Patterns

By comparing the same configurations in the two orientations, it can be observed that the variation is more evident in the rectangular configurations, while there are no major differences in the generated shaded area between the two radial configurations. The comparison between the two orientations reveals that the rectangular pattern with the canyon located on the east-west axis has less shaded area than the rectangular pattern with the canyon located on the north-south axis (Figure 6.15). This is due to the minimised overshadowing from the south block to the north one. In the radial pattern with canyon oriented east-west, although the overshadowing from one block to another is minimised, there is an increase in the generated self-shading of the radial form.

By studying these results, it becomes evident that the main variations in the shadow patterns (both the amount of the generated shaded area and the distribution of the shaded area during daytime) 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.

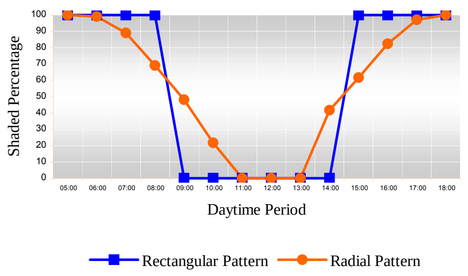
6.3.4.2 The Generated Shadow Patterns in the Two Patterns

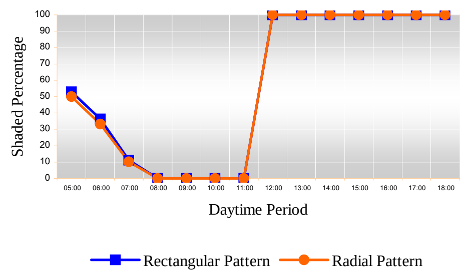


East-west Patterns	North-south Patterns

The Shadow Patterns in Summer

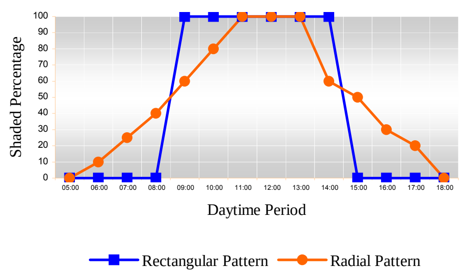
Long Canyon Facade - The South Facade - The Northern Block	Long Canyon Facade - The East Facade - The Western Block

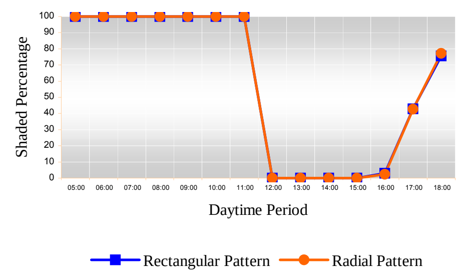




The Rectangular	57.14 %	The Radial	57.83 %	The Rectangular	57.17 %	The Radial	56.6675 %

Short Canyon Facade - The North Facade - The Southern Block	Short Canyon Facade - The West Facade - The Eastern Block

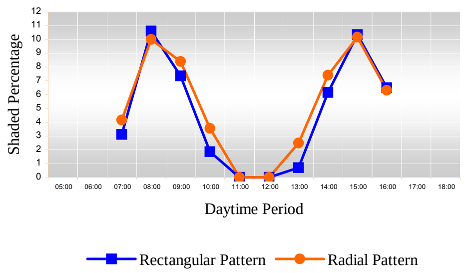


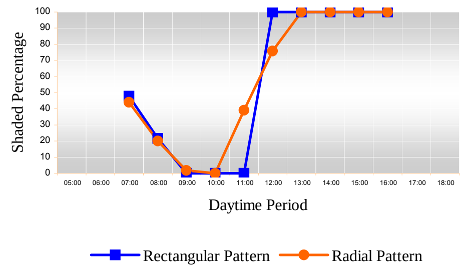


The Rectangular	42.86%	The Radial	48.21%	The Rectangular	58.66 %	The Radial	58.725 %

The Shadow Patterns in Winter

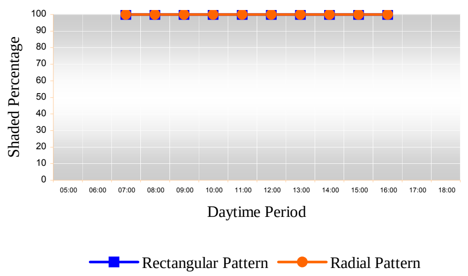
Long Canyon Facade - The South Facade - The Northern Block	Long Canyon Facade - The East Facade - The Western Block

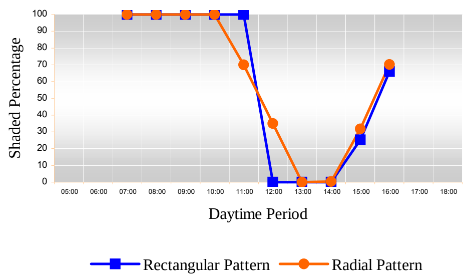




The Rectangular	4.66 %	The Radial	5.2465 %	The Rectangular	56.94 %	The Radial	58.09 %

Short Canyon Facade - The North Facade - The Southern Block	Short Canyon Facade - The West Facade - The Eastern Block





The Rectangular	100 %	The Radial	100 %	The Rectangular	59.12 %	The Radial	60.75 %

Figure 6.16: A Comparison between the Generated Shadow Patterns in the Studied Cases

As the concavity of the radial forms is relatively small, the variation in the amount of the generated shadow between the two patterns during the whole day is relatively small and the main differences are revealed in the distribution of the shaded area during the daytime period. In the rectangular forms, however, the shaded and exposed periods start and finish suddenly (if the form is not affected by the dappled shadow from the neighbouring block) and the two periods exchange their influence on the facade mutually. In the radial form, the shaded and exposed periods (especially for the pattern oriented east-west) start and finish gradually (Figure 6.16).

The variation in the distribution of the shaded area during the daytime period between the two patterns is more clear in the summer period in the case of the patterns with an urban canyon axis oriented east-west, while this variation is more evident in the winter period in the case of the patterns with an urban canyon oriented north-south (Figure 6.16). This refers to the self-shading effect of the radial form, which causes the main variations in the distribution of the shaded area during the daytime period in the two forms. The self-shading effect of the radial form always occurs when sunrays parallel more the concave facade, and when the sun is closer to the horizon.

The self shading character of the radial pattern with an urban canyon oriented east-west will be maximum in summer, especially in mornings and afternoons, because sunrays parallel more the long axis of the form and the sun's altitude is closer to the horizon. The self-shading effect also lasts for a longer time in these periods, as the sun's azimuth changes more slowly in the morning and afternoon. In contrast, this effect will be minimum during the noon period, as sunrays come directly from the south at a higher altitude. For the radial pattern with the urban canyon oriented north-south, the self-shading effect occurs in both summer and winter in the noon period, when sunrays parallel more the long axis of the form. In this case, the sun is higher in the sky and the period lasts for a shorter time which results in minimizing the self-shading effect of the radial facade. However, this effect is more notable in winter due to the relatively lower altitude angle of the sun.

In general, the self-shading effect, which occurs in the summer period for the pattern with the urban canyon oriented east-west, is more significant than the self-shading effect that occurs in the winter period for the patterns with the urban canyon oriented north-south. This is because the self-shading effect in the east-west pattern takes place in early morning and late afternoon, when the altitude angle of the sun is closer to the horizon and changes in the position of the sun occur less rapidly.

6.3.4.3 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 6.17).

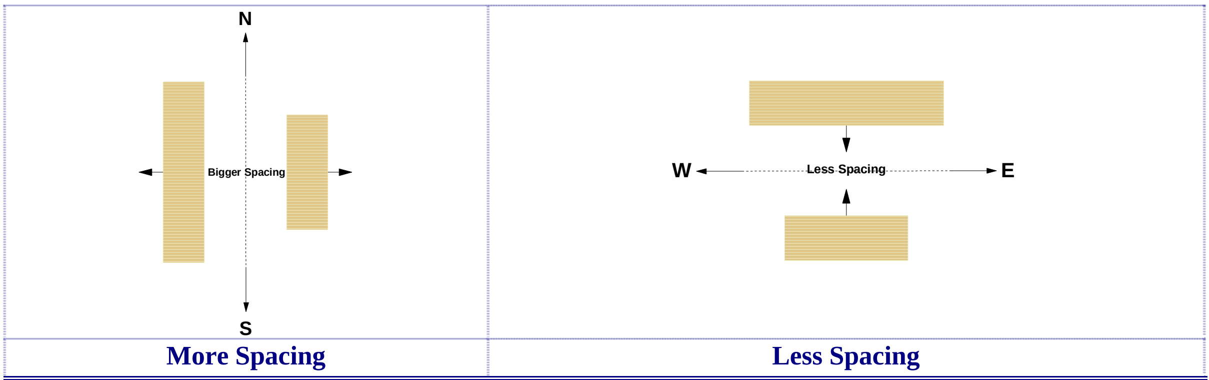
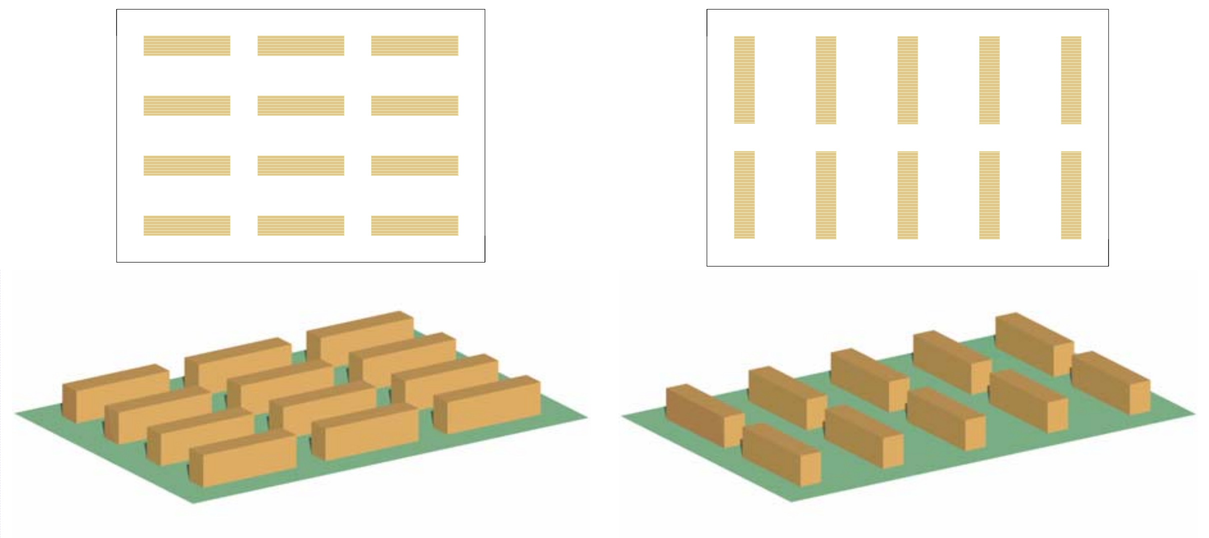


Figure 6.17: Solar Right: The Spacing between the Two Blocks

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, it can be concluded that 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, because the distance between the N-S oriented buildings in this canyon can be shorter compared to the distance between the E-W oriented buildings in the north-south canyon (Figure 6.18). 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.



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 6.18: The Relation between the Building Intensity and the Orientation of the Canyon

6.4 Conclusion

When comparing the shadow pattern generated during daytime in the facades of the two urban patterns with a canyon lying east-west, more significant variation is found in the summer period than in winter, as the sun's position in winter is more directed towards the south, while the self-shading effect generated in this pattern is mainly produced by sunrays coming from the east and west when sunrays match the long axis of the urban canyon. 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 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.

In patterns with the canyon lying south-north, it is observed that the variation between the two patterns, with regard to the distribution of shadow during daytime, is more notable in wintertime than in summer. This is caused by the self-shading effect of the radial form, which is more visible in winter due to the lower altitude angle of the sun. However, the variation between the generated shaded areas in the two patterns is insignificant, as the self-shading of the radial forms occurs during the noon period, which minimises the generated self-shading due to the high position of the sun in the sky at midday. In general, the self-shading effect of the radial form, which always occurs when sunrays parallel the canyon's long axis, is more prominent when the sun is closer to the horizon. Therefore, the self-shading effect produced in canyons with a long east-west axis in summer is more significant, as the self-shading in this case takes place in early morning and late afternoon, when the altitude angle of the sun is low.

The calculations of the average annual shaded area in the two patterns, with the canyon lying south-north, 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. The shadow caused by one block to another in this pattern is more significant, as the shadowing occurs early in the morning or late in the afternoon when sun is closer to the horizon. The shadow from the south block to the north one in patterns with the canyon lying east-west is limited, as the shadowing takes place during the noon period when the sun is high in the sky. By comparing the patterns in both positions, it becomes evident that the variation between the radial and the rectangular patterns within the same orientation is greater in the case of the canyons oriented east-west. Thus, it becomes apparent that the main variations in the generated shadow between the radial and rectangular patterns are created by the self-shading of the individual radial block, while the effect from one block to another is approximately the same in the two patterns.

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. A more significant increase of site size with a long south-north axis occurs due to longer morning and afternoon shadows during the year; this dictates a larger distance between the buildings. Thus, the most intensified use of the site can be achieved with canyons on the east-west axis.

CHAPTER 7

SOLAR INSOLATION ASPECTS IN BILATERAL TYPE OF BUILDINGS:
A Comparison between Radial Forms with Different Concavities

7. Solar Insolation Aspects in Bilateral Types of Building: A Comparison between Radial Forms with Different Concavities

7.0 Overview

Sunshine is one of the main factors which affects the quality of living spaces in residential buildings. Particularly in cold regions, sunshine is of special importance for the quality of environmental hygiene. Solar insolation of the urban form is similarly essential for buildings relying on passive solar design principles. Previous studies have mainly focused on investigating the optimum orientation of the buildings, in terms of solar radiation accessibility, regardless of the distribution of living spaces within the form. However, in many cases, the living areas of the building face an orientation other than the optimum. This occurs if a building is not of a unilateral type but where living areas are located in different directions. The most common type of building is the bilateral one where the living areas are located in opposite directions. In the bilateral design of buildings, the way in which the shaded area is distributed within the form becomes a fundamental issue. The insolation of opposite facades in a way that assures the access of sunrays to all residential units located in both sides of the form is crucial. As was proved by previous experiments, the north facade of the rectangular forms (elongated east-west) receives no sunrays at all in wintertime. This situation provides advantages to units located to the south side and undermines the northern ones. The radial form might be the solution to this problem because it receives winter sunrays on both facades (north and south). So, the radial form could distribute solar insolation in winter among all residential units in a more even manner. Having knowledge of such advantages of the radial forms, from the solar point of view, could encourage the use of these forms. This increase of utilising radial forms will also boost the aesthetic value and diversity of the urban structure. As the main feature that determines the shape of the radial form is the extension of the concavity, it was necessary to compare several types of radial form with various extents of concavity in order to find out which one could be more suitable for bilateral types of building. The most suitable form will be the one with the least differences of the shaded percentage between the two opposite facades during both the summer and winter periods, and also throughout the whole year. The study aims to focus on bilateral buildings, which is a very common urban pattern in Palestine. This pattern can allow for greater building intensity, which is a crucial aspect for urban design in Palestine due to the lack of land and the need to accommodate millions of refuges. The experiment aims also to establish a methodology by which the urban form can be evaluated with regard to the insolation efficiency of its different sides.

Thus, the determination of the optimum orientation for any building form can be always considered together with its suitability for unilateral or bilateral buildings in mind.

7.1 Background

"Sunshine is one of the key factors, which affects the environment quality of residential buildings" (Qian, 1995). Sunshine can improve indoor temperature, as well as generate vitamin D in the skin of the human body; this can protect children from rickets. Ultraviolet rays of sunshine can also kill pathogenic bacteria and prevent infection from respiratory tract diseases. In addition, sunshine keeps people happy, rouses them, makes them work more effectively, and enhances a human being's immunity. Particularly in cold regions, sunshine is of special importance for the quality of environmental hygiene (Qian, 1995).

Previous studies focused more attention on examining the optimum orientation of buildings in terms of solar radiation accessibility, regardless of the distribution of living spaces within the building. The underlying assumption for the best living conditions (i.e. warmth in winter, coolness in summer) is that the principal facades of buildings should face the south (the long axis of the building is oriented east-west) (Figure 7.1). Facades facing southeast and southwest are colder in winter and warmer in summer than facades facing the south. East and west exposures are warmer in summer and colder in winter than the south, southeast and southwest exposures.

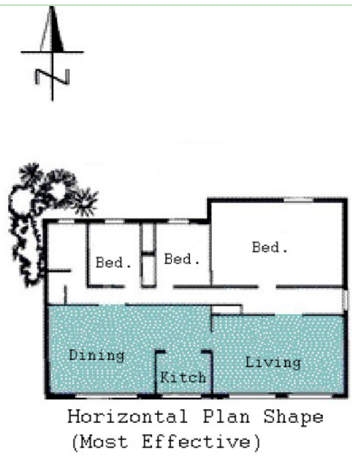


Figure 7.1: Principal South-Facing Facades of Buildings Offer Better Living Conditions (Murdoch University, 2001)

However, in many cases, the living areas of the building face an orientation other than the optimum one. This occurs if a building is not of a unilateral design but has the living areas located in different directions. The most common design is the bilateral type of building, where the living areas are located in opposite directions (Figure 7.2). This can be a back-to-back arrangement of residential units within the storey or through type in which the two sides belong to the same apartment. Olgyay (1992) has pointed out that, in such cases, the important side cannot be easily determined and each wall must be assigned a proportionate importance. He also mentioned that "two buildings with the same shape but differently arranged living areas will require different orientations to take the best advantage of the sun's impact". Therefore, determining the most suitable orientation in these cases is more complicated and depends more on individual design and the distribution of spaces within buildings.

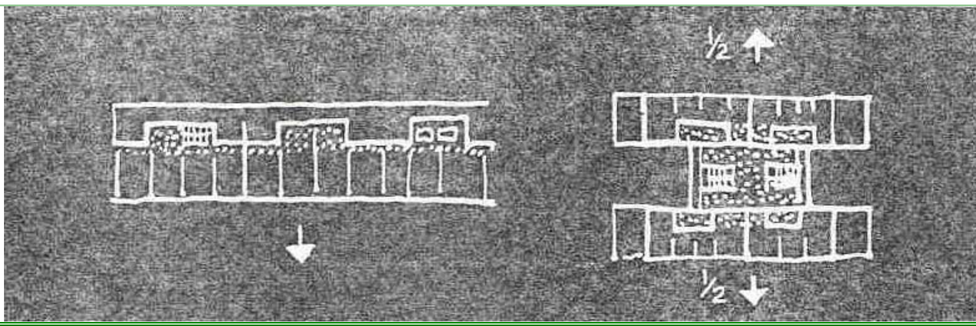


Figure 7.2: Unilateral and Bilateral Types of Building (Olgyay, 1992)

7.2 The Aim of the Experiment

As was proved by previous experiments, in the south-facing radial form, the north facade in winter will receive sunrays in the early morning and late afternoon. This curve can distribute solar insolation in winter among all residential units in a more even manner and therefore is more suitable for bilateral types of building. However, with an increase (or decrease) in the concavity of the form, the generated shadow pattern is expected to change slightly. The optimal radial form is expected to be the one with the least differences of shading percentage between the two opposite facades during over and underheated periods, and over the whole year in general. Such a form will enhance the unbiased distribution of solar insolation in buildings and will provide residential units with similar amounts of solar radiation as far as possible.

For the radial form, the main feature which determines the curvilinearity of the form, is the extent of the concavity. So, to find out the radial form which could be more suitable for bilateral types of building, it was necessary to examine different radial forms with different extents of concavity. To satisfy this goal, a comparison between different radial forms varying in the extension of concavity was conducted to find out the one with the minimum variation of the exposed areas in the two opposite facades in winter and summer periods, and also over the whole year. The experiment aimed also to establish a methodology by which the urban form can be evaluated, with regard to the insolation efficiency of its different sides. Thus, the optimum orientation for any building form can be always considered together with its suitability for unilateral or bilateral buildings.

7.3 A Comparison between Radial Forms with Different Concavities

The Urban Site: The urban site consists of five radial forms with different extents of concavity (Figure 7.3). The two opposite facades of the five forms will be analysed in terms of the generated shadow pattern.

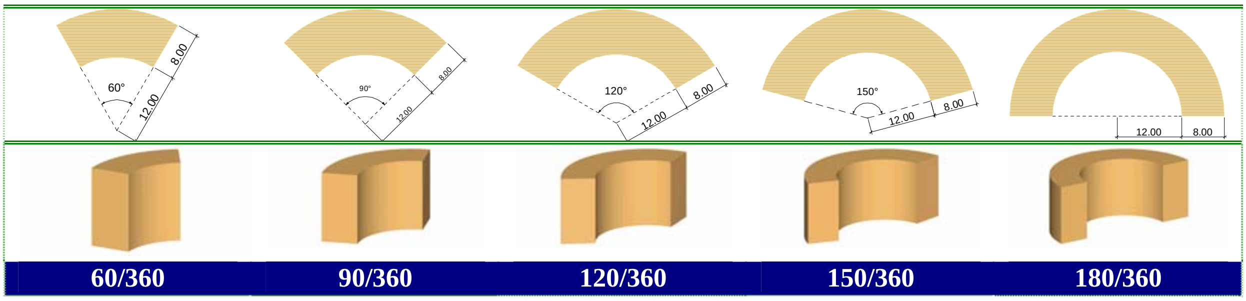
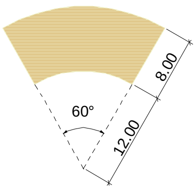


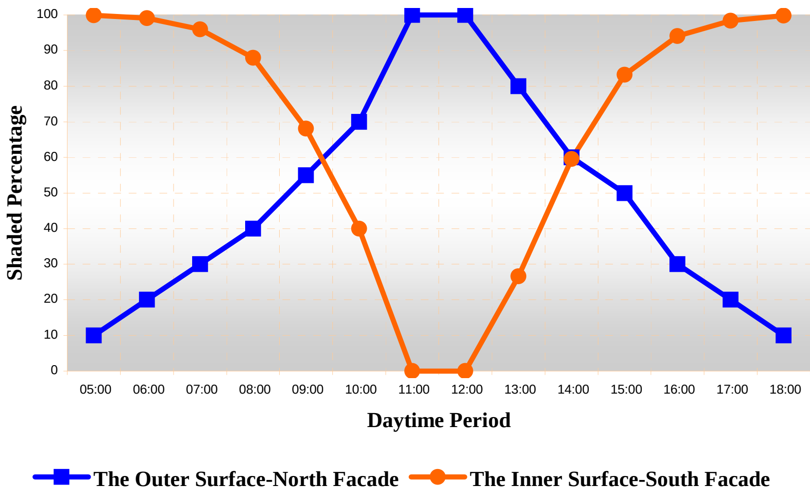
Figure 7.3: The Urban Site: Radial Forms with Different Concavities

7.3.1 The Radial Form 60/360



i. The Shadow Pattern in Summer

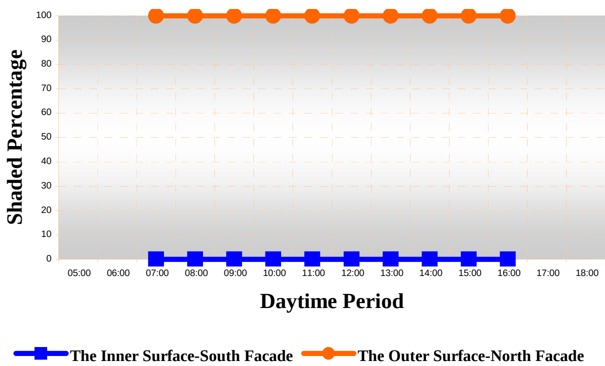
The graph (Figure 7.4) illustrates the generated shadow pattern in the two opposite facades in the summer period. The horizontal axis represents the daytime period within one-hour intervals. The vertical axis represents the percentage of the shaded area of the facade in units of 10%. The graph reveals that the north facade is less shaded in general, as the average of 48.21% of the facade is shaded during daytime, while 68.05 % of the south facade is shaded on average. The north facade is completely shaded for half an hour before and after noon, while the south facade is completely exposed at the same time. The two facades are partially exposed to sunrays for most of the daytime (just the north facade is completely shaded for a short time during the noon period, when sunrays become more perpendicular to the centre of the concave facade). The two facades receive the same amount of sunrays (the Balanced State) twice during the daytime: before and after noon.



The Inner Surface - South Facade	**68.05 %**
The Outer Surface - North Facade	**48.21 %**

Figure 7.4: The Radial Form-60/360: The Shadow Pattern in Summer

ii. The Shadow Pattern in Winter

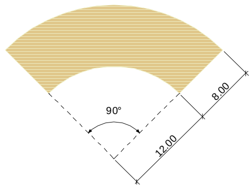


The Inner Surface - South Facade	**0 %**
The Outer Surface - North Facade	**100 %**

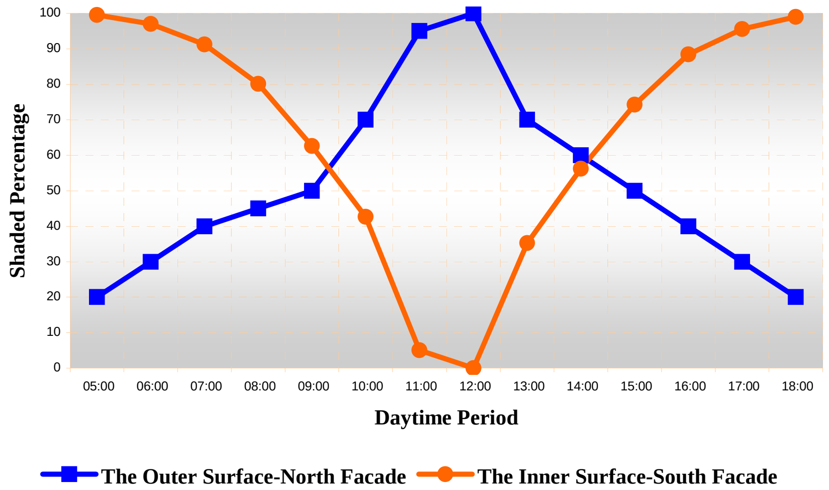
Figure 7.5: The Radial Form-60/360: The Shadow Pattern in Winter

By looking at this graph (Figure 7.5), it becomes evident that the north facade is completely shaded during daytime in winter, while the south facade is completely exposed simultaneously. This is attributed to the direction of the sun's rays in winter which come mainly from the south. Due to the small extent of the concavity of the radial form, the convexity of the north facade is not sufficient to catch sunrays in the early morning and the late afternoon. For the same reason, the south facade is not concaved enough to generate self-shading in the same periods. The behaviour of the radial form in this case, with regard to the generated shaded area, is the same as the rectangular one.

7.3.2 The Radial Form-90/360



i. The Shadow Pattern in Summer

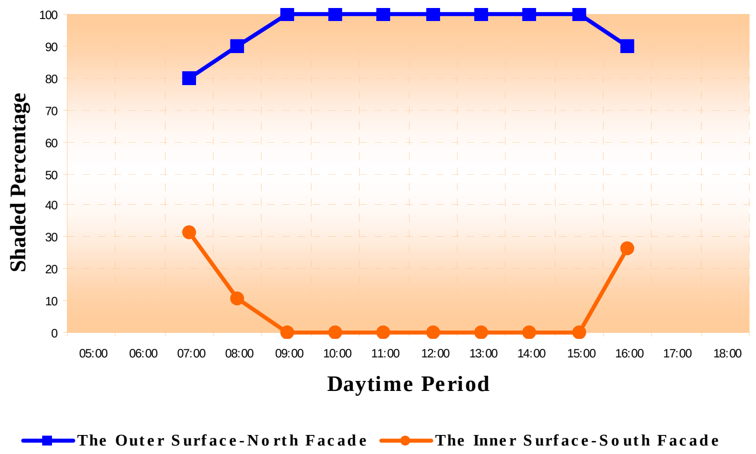


The Inner Surface - South Facade	**66.23 %**
The Outer Surface - North Facade	**51.43 %**

Figure 7.6: The Radial Form-90/360: The Average Daily Shaded Area per Hour in Summer

Graph (Figure 7.6) shows that the north facade is less shaded in general, as it generates approximately 51.43 % of the shaded area per hour on average, while the south facade generates 66.23 %. The north facade is completely shaded at noon, while the south facade is completely exposed at the same time. The balance in the shaded area generated by the two opposite facades occurs twice during the daytime: before and after noon. This takes place when sunrays are approximately parallel to the concave facade (when sunrays come directly from the east or the west direction). There is a greater variation between the two opposite facades in the early morning and the late afternoon. However, the greatest variation between the two facades takes place during the noon period.

ii. The Shadow Pattern in Winter

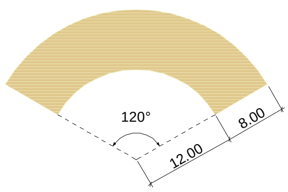


The Inner Surface - South Facade	**6.86 %**
The Outer Surface - North Facade	**96 %**

Figure 7.7: The Radial Form-90/360: The Average Daily Shaded Area per Hour in Winter

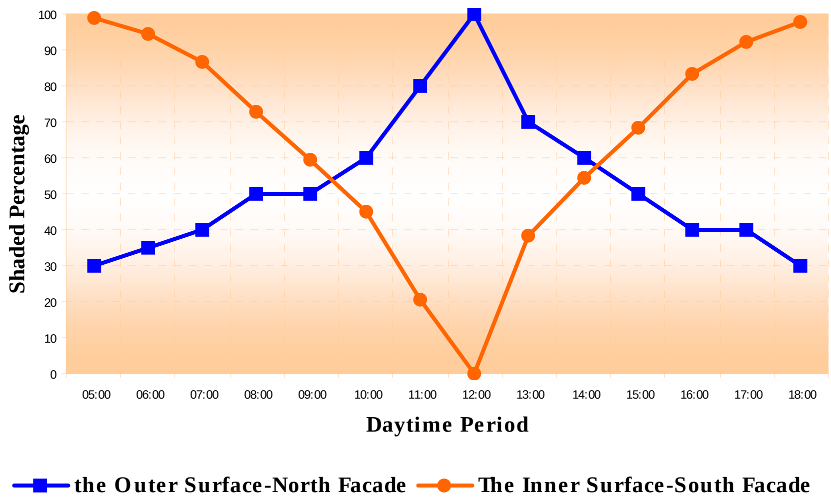
A limited part of the north facade is exposed in the early morning and late afternoon, while approximately a similarly limited part of the south facade is shaded at the same time (Figure 7.7). The increase of the convexity allows the north facade to receive sunrays in these periods, while the increase of the concavity reduces the exposure of the south facade. In general, the south facade is more exposed than the north one. The south facade is completely exposed for approximately 6 hours during the daytime period, while the north facade is completely shaded simultaneously. The least variation between the two opposite facades, with regard to the generated shaded area, occurs in the early morning and the late afternoon.

7.3.3 The Radial Form-120/360



i. The Shadow Pattern in Summer

By studying this graph, it can be viewed that the north facade is less shaded in general, as it produces roughly 52.5 % of the shaded area per hour on average, while the south facade produces 65.24 % (Figure 7.8).



The Inner Surface - South Facade	**65.24%**
The Outer Surface - North Facade	**52.5 %**

Figure 7.8: The Radial Form-120/360: The Average Daily Shaded Area per Hour in Summer

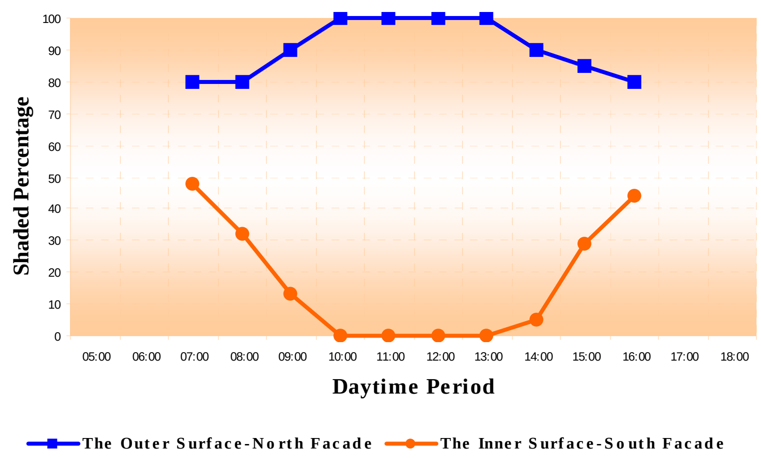
Also, it can be noted that the north facade is completely shaded at noon, while the south facade is completely exposed simultaneously. Therefore, the greatest variation between the two facades takes place during the noon period, approximately at 12:00 p.m., i.e. when solar azimuth angle equals 180^0 (Table 7.1). The graph also reveals that both the speed of the increase of the shaded area in the north facade and the speed of the decrease of the shaded area in the south facade increase with their closeness to the noon period. This is because the sun's azimuth in the noon period changes with higher rates than in the mornings or afternoons (Table 7.1).

Location: Jerusalem, Latitude: 31.8° N, Longitude: 35.2° E (Local Time Meridian: 30.0° E)		
Time	**Azimuth June (15)**	**The Increment**
01:00		
02:00		
03:00		
04:00		
05:00	65.65^0	
06:00	72.24^0	6.59^0
07:00	78.86^0	6.62^0
08:00	85.59^0	6.73^0
09:00	93.40^0	7.81^0
10:00	104.88^0	11.48^0
11:00	131.76^0	26.88^0
12:00	209.62^0	77.86^0
13:00	249.62^0	40.00^0
14:00	263.64^0	14.02^0
15:00	272.16^0	8.52^0
16:00	279.08^0	6.92^0
17:00	285.67^0	6.59^0
18:00	292.25^0	6.58^0
19:00		
20:00		
21:00		
22:00		
23:00		
24:00		

Table 7.1: Solar Azimuth Angle (α) in Jerusalem during Summer Period

The balance in the shaded area generated by the two opposite facades occurs twice before and after noon (approximately at 9:00 a.m. and 15:00 p.m.). This takes place mainly when sunrays come directly from the east or the west direction i.e. when solar azimuth angle equals 90^0 or 270^0 (Table 7.1).

ii. The Shadow Pattern in Winter

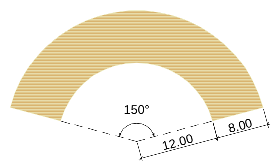


The Inner Surface - South Facade	17.16 %
The Outer Surface - North Facade	90.5 %

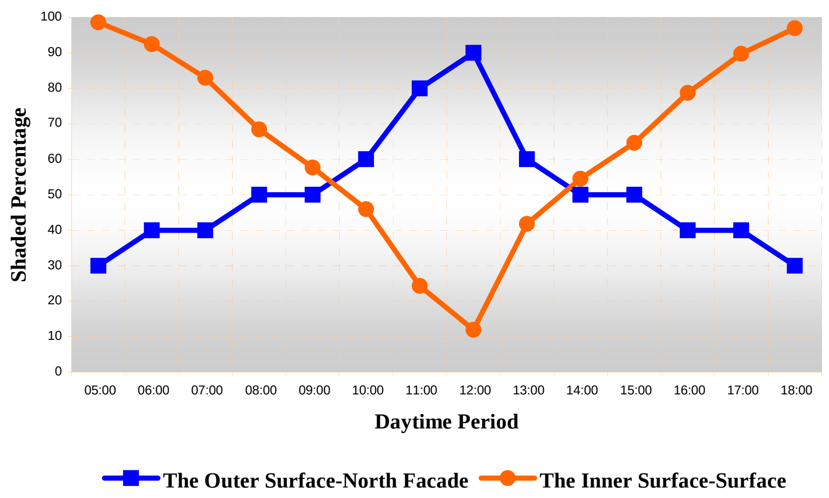
Figure 7.9: The Radial Form-120/360: The Average Daily Shaded Area per Hour in Winter

The two ends of the convex north facade still possess the potentiality to receive sunrays in the morning and afternoon periods, when sunrays are directed more towards the east and west, respectively. At the same time, greater parts of the south facade are shaded (Figure 7.9). Due to the increase of the concavity of the radial form, the convex north facade can catch more sunrays in the early morning and the late afternoon. For the same reason, the concave south facade generate more self-shading in the same periods. In general, the south facade is more exposed than the north one. The north facade is completely shaded for 3 hours during daytime, while the south facade is completely exposed simultaneously. The least variation between the two opposite facades, with regard to the generated shaded area, occurs in the early morning and the late afternoon.

7.3.4 The Radial Form-150/360



i. The Shadow Pattern in Summer



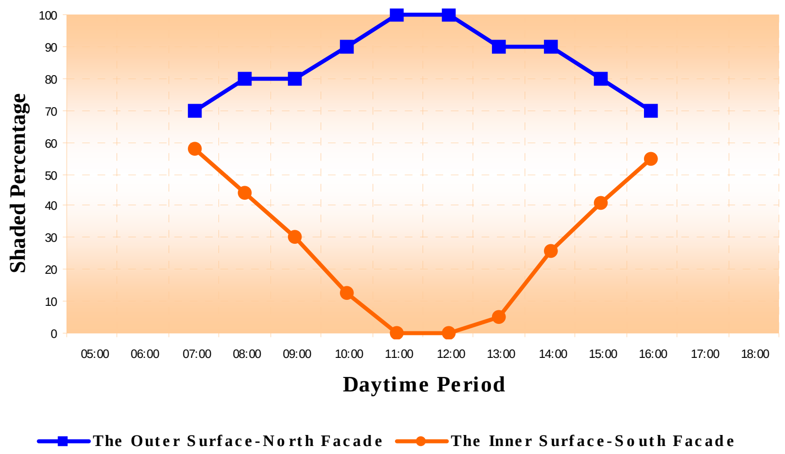
The Inner surface - South Facade	**64.88%**
The Outer Surface - North Facade	**50.71%**

Figure 7.10: The Radial Form-150/360: The Average Daily Shaded Area per Hour in Summer

In this curve, it can be noticed that the north facade maintains its trend to be more exposed and 50.71 % of the facade is shaded per hour on average, while 64.88 % of the south facade is shaded (Figure 7.10). Both north and south facades are partially exposed during the whole daytime period i.e. both facades could enjoy sunrays during the whole day. The major variation between the two facades occurs early in the morning, in the late afternoon, and at noon. However, the main variation takes place at noon. This because, at noon, the direction of the vertical plane of sunrays is more perpendicular to the centre of the curve where the maximum variation between the two opposite facades takes place.

ii. The Shadow Pattern in Winter

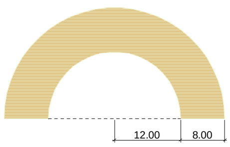
The limited part of the north facade, which has the possibility to receive sunrays, decreases with proximity to the noon period (Figure 7.11). A larger portion of the south facade is shaded simultaneously and the variation between the exposed area of the north facade and the shaded area of the south facade is of more significance in the early morning and late afternoon. In other words, both the exposed area of the north facade and the shaded area of the south facade decrease with proximity from the noon period and the crucial variation in the shaded percentage between the two opposite facades takes place at noon, as the north facade in this period is completely shaded, while the south one is completely exposed. The north facade is completely shaded for 1 hour during the noon period, while the south facade is simultaneously completely exposed. In general, the south facade is more exposed than the north one.



The Inner Surface - South Facade	**27.06%**
The Outer Surface - North Facade	**85.5 %**

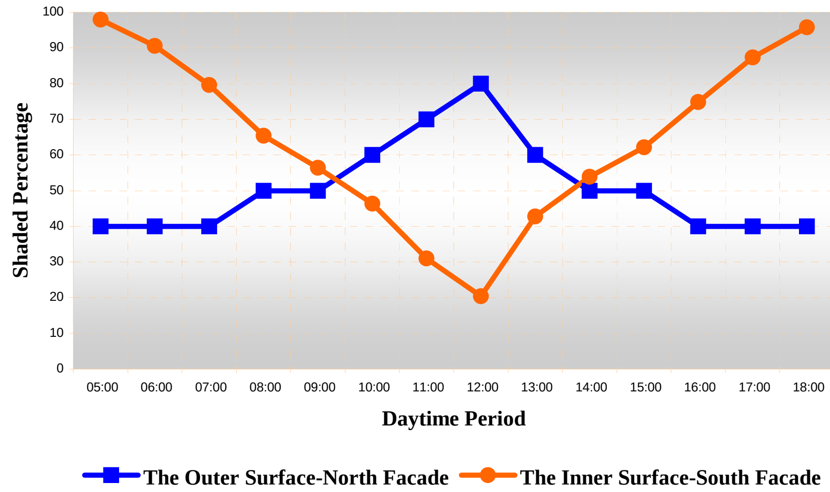
Figure 7.11: The Radial Form-150/360: The Average Daily Shaded Area per Hour in Winter

7.3.5 The Radial Form-180/360



i. The Shadow Pattern in Summer

The shaded area produced by the north facade here is roughly 50.71 % per hour on average, while the south facade is more shaded and produces approximately 64.61 % (Figure 7.12). Both north and south facades are partially exposed during the whole daytime period and can therefore enjoy sunrays during the whole day. In the north facade, the variation between the morning and noon periods, with regard to the generated shaded area, is less than the same variation in the south facade during the same periods. In other words, the distribution of the shaded area in the north facade is more regular during the daytime period than the shaded area generated in the south one.

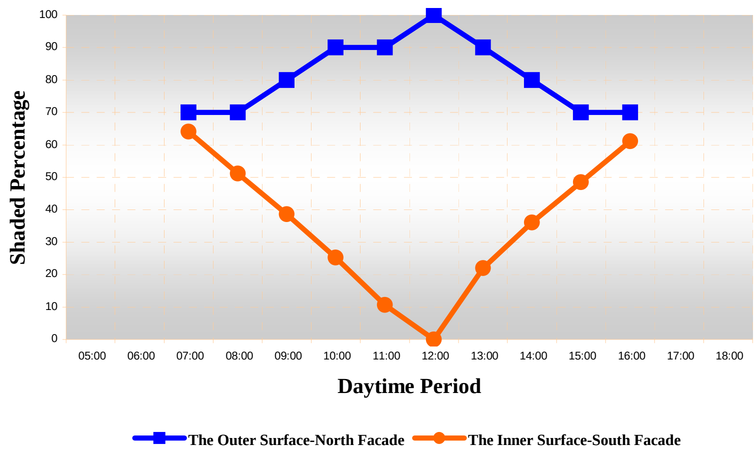


The Inner Surface - South Facade	**64.61%**
The Outer Surface - North Facade	**50.71%**

Figure 7.12: The Radial Form-180/360: The Average Daily Shaded Area per Hour in Summer

ii. The Shadow Pattern in Winter

The main exposure of the north facade to sunrays takes place in the morning and afternoon periods (Figure 7.13). A greater part of the south facade is shaded at the same time. The variation between the two opposite facades, with regard to the generated shadow, is the least in the morning and afternoon periods and the greatest at noon. In general, the south facade is more exposed than the north one. The trend revealed by this graph is that the exposed area of the north facade and the shaded area of the south facade decrease with proximity from the noon period. The two facades are partially exposed to sunrays most of the daytime (just the north facade is completely shaded for a short period at noon).



The Inner surface - South Facade	**35.76 %**
The Outer Surface - North Facade	**81%**

Figure 7.13: The Radial Form-180/360: The Average Daily Shaded Area per Hour in Winter

7.3.6 A Comparison between the Forms: The Generated Shadow Pattern

i. The Shadow Pattern in Summer

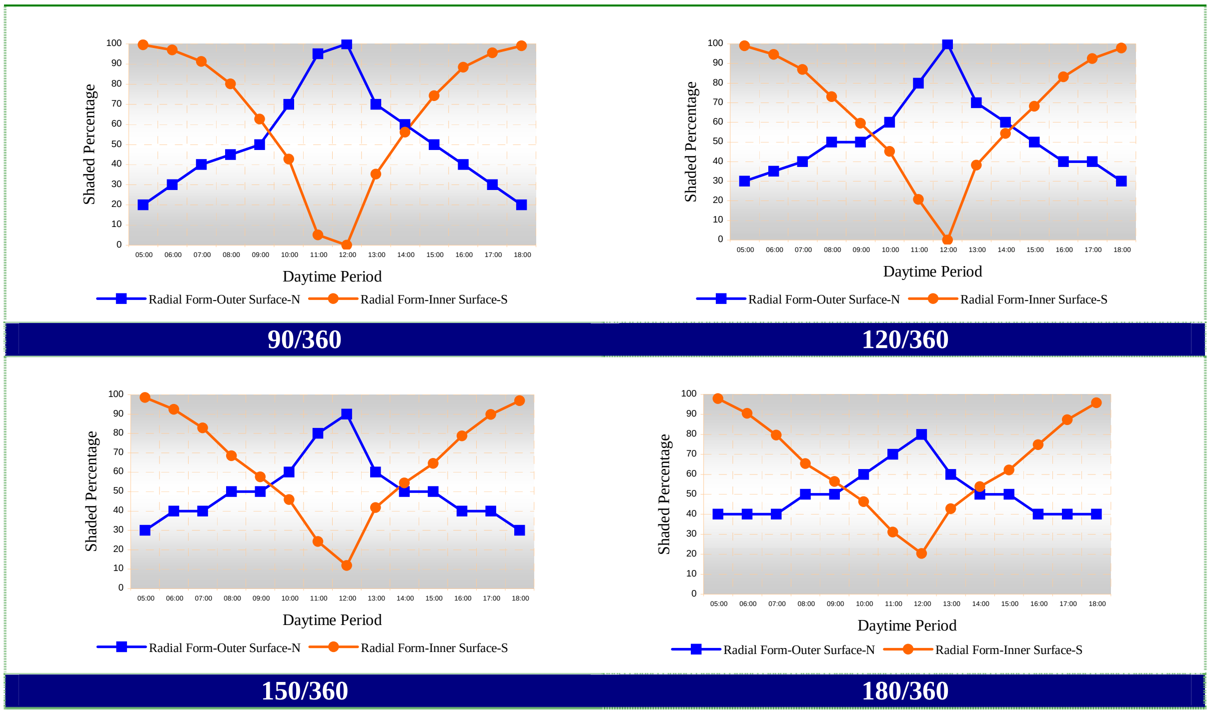


Figure 7.14: The Shadow Pattern in Summer

The trend illustrated by these graphs (Figure 7.14) is that both the speed of the increase of the shaded area in the north facade and the speed of the decrease of the shaded area in the south facade increase with their closeness to the noon period. This is because the sun's azimuth in the noon period changes with higher rates than in the mornings or afternoons. The supreme variation between the two facades occurs early in the morning, in the late afternoon, and at noon. However, the main variation takes place at noon, especially for curves with less concavity. This because, at noon, the direction of sunrays is more perpendicular to the centre of the curve where the maximum variation occurs. In general, the north facade is better exposed to sunrays than the south one. With the increase of the concavity of the form, the distribution of the shadow pattern during the daytime period in the two opposite facades becomes more regular. However, the amount of the generated shadow in each group of facades (north and south) does not change in any significant manner.

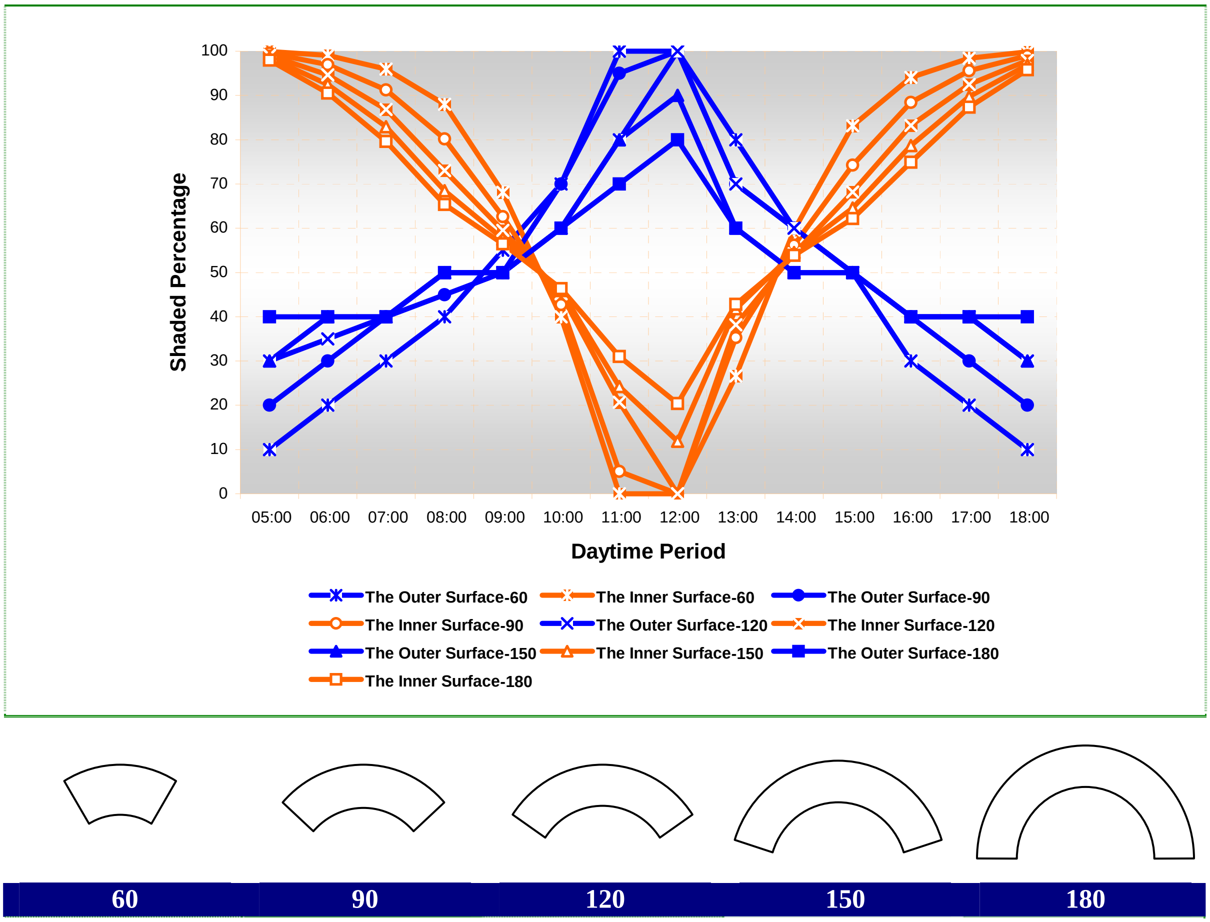


Figure 7.15: A Comparison between the Forms: The Shadow Pattern in Summer

By examining this graph (Figure 7.15), it becomes apparent that the shaded area of the north facade increases with the increase of the concavity of the form in the morning and afternoon periods, and decreases with the increase of the concavity of the form in the noon period. Conversely, the shaded area of the southern facade decreases with the increase of the concavity of the form in the morning and afternoon periods and increases with the increase of the concavity of the form in the noon period.

Thus, with the increase of the form's concavity, the distribution of the shadow in both facades during the daytime period tends to be more regular. So, radial forms with more concavity distribute insolation in such a manner that residential units in both facades can enjoy more homogenous solar accessibility during the daytime. Also, the variation between the two opposite facades with regard to the generated shaded area, in the early morning, late afternoon and during the noon period, decreases with an increase of the form's concavity. The balance in the shaded area generated by the two opposite facades occurs twice before and after noon (approximately at 9:00 a.m. and 15:00 p.m.). This takes place when sunrays are approximately parallel to the concaved facade (when sunrays come directly from the east or the west direction).

The north facade in all patterns is more exposed than the south one. However, the amount of generated shadow in identical facades in all the forms is approximately the same. Thus, the main variation between the forms is related to the distribution of the shaded area during the daytime, while the amount of generated shadow in identical facades remains approximately the same regardless of their various concavities.

ii. The Shadow Pattern in Winter

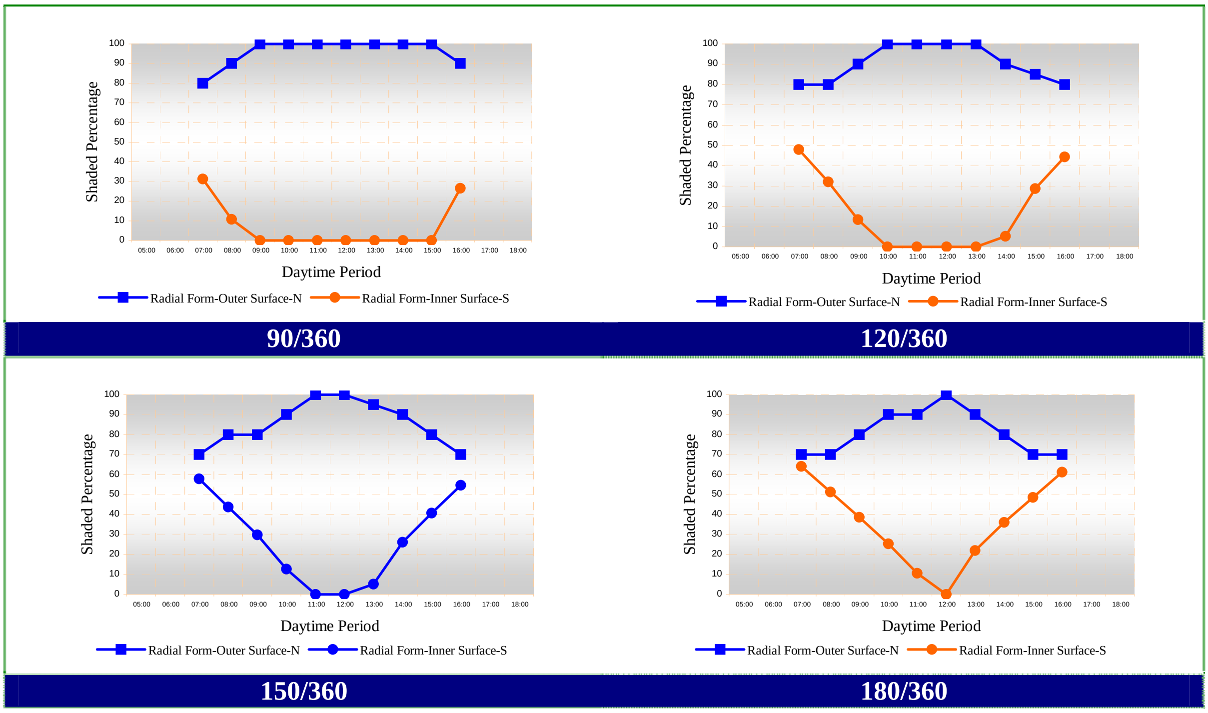


Figure 7.16: The Shadow Pattern in Winter

The trend revealed by this graph (Figure 7.16) is that, with an increase of the form's concavity, a larger percentage of the south facade is shaded in the morning and afternoon, and also a larger percentage of the north facade is exposed at the same periods. However, the gradual increase of the shaded area of the south facade is intensified at a higher rate than the gradual increase of the exposed area in the north facade. The north facade is wholly shaded during noon, while the south one is completely exposed. However, the duration of the periods when the north facade is completely shaded and the south facade is completely exposed becomes less significant with increases in the concavity of the form. Consequently, with an increase of the concavity of the radial form, the distribution of the shaded area during daytime becomes more regular. In general, the south facade is better exposed to sunrays than the north one.

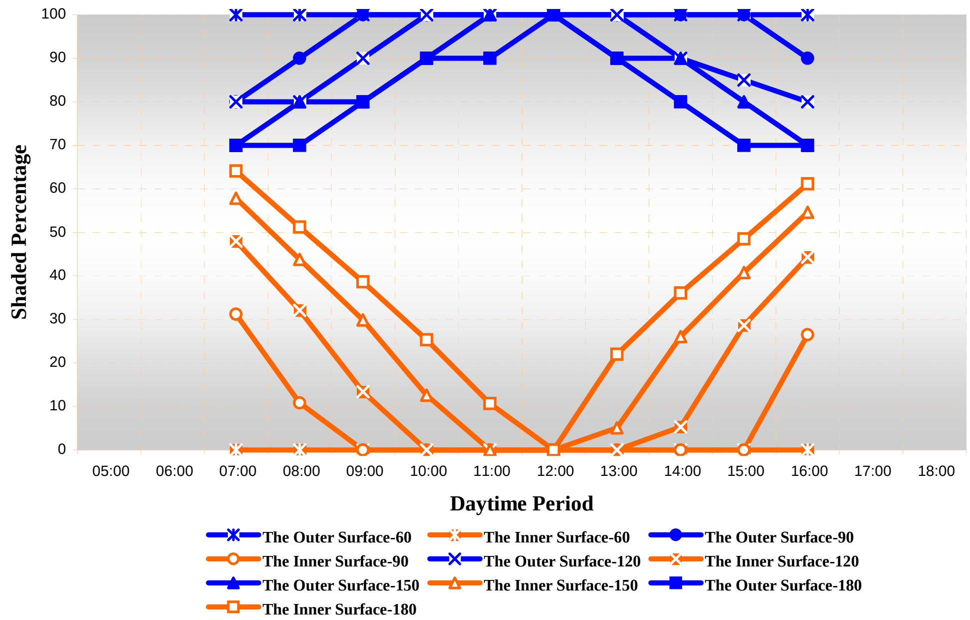


Figure 7.17: A Comparison between the Forms: The Shadow Pattern in Winter

The trend concluded from this graph (Figure 7.17) is that the variation between the two opposite facades increases with proximity from the noon period, where the two opposite facades either are completely shaded (the north one) or completely exposed (the south one). In wintertime, this balance does not exist as sunrays will never parallel the concave facade since sunrays in the winter period are derived mainly from the south. However, the curve with the biggest concavity (180/360) is very close to reaching two points of balance at sunrise and sunset. The two opposite facades have approximately the same amount of shaded areas in these periods, as sunrays are more closed from being parallel to the concave facades.

	The Shaded Percentage	
	The Inner Surface (South Facade)	The Outer Surface (North Facade)
The Radial Form 60/360	0 %	100 %
The Radial Form 90/360	6.86 %	96 %
The Radial Form 120/360	17.16 %	90.5 %
The Radial Form 150/360	27.06%	85.5 %
The Radial Form 180/360	35.76 %	81%

Table 7.2: The Generated Shaded Area in Winter Period

By comparing the shadow patterns of the radial forms, it can be observed that the exposed area of the north facade increases with the increase of the form's concavity (Table 7.2).

Conversely, and in the case of the south facade, the shaded area increases with the increase of the form's concavity. Therefore, the variation between the exposed area generated in the north facade and the exposed area generated in the south facade decreases with the increase of the concavity.

One of the trends that has become evident by studying the previous graphs is that both opposite facades in the radial form with greater concavity can enjoy sunrays for most of the daytime periods in both seasons, as they are partially exposed during the whole day. This illustrates the suitability of radial forms with more concavity characteristics for bilateral buildings.

The graph (Figure 7.18) reveals that the differences between the amount of the shaded area of the south facade and the amount of the exposed area of the north facade increase with an increase in the form's concavity. However, the increment of the shaded area in the south facade is greater than the increment of the exposed area in the north facade.

The Radial Form	60/360	90/360	120/360	150/360	180/360
The Amount of the Shaded Area in the South Facade	0	6.86 %	17.16 %	27.06 %	35.76 %
The Increment		6.86 %	10.3 %	9.9 %	8.7 %
The Amount of the Exposed Area in the North Facade	0	4 %	9.5 %	14.5 %	19 %
The Increment		4 %	5.5 %	5 %	4.5 %
The Variation between the Shaded Area of the South Facade and the Exposed Area of the North Facade	0	2.86 %	7.66 %	12.56 %	16.76 %

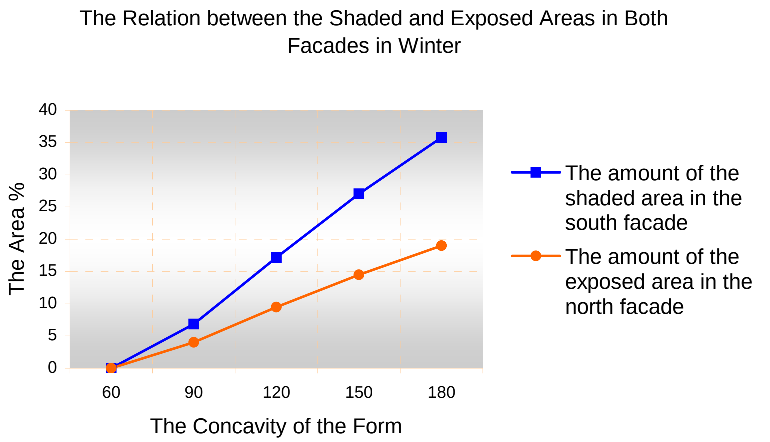


Figure 7.18: The Variation between the Shaded Area in the South Facade and the Exposed Area in the North Facade

The Radial Form	60/360	90/360	120/360	150/360	180/360
The Exposed Area in the South Facade	100	93.14	82.84	72.94	64.24
The Exposed Area in the North Facade	0	4	9.5	14.5	19
The Variation	100	89.14	73.34	58.44	45.24

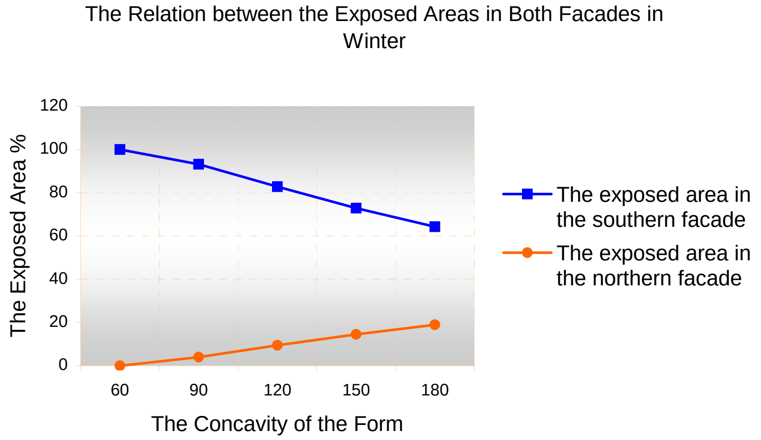


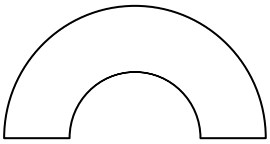
Figure 7.19: The Differences in the Exposed Area between the Two Facades

As a result of the reduction of the exposed area in the south facade and the increase of the exposed area in the north one, the variation between the exposed areas in the two facades decreases with the increase of the form's concavity (Figure 7.19). Thus, the bigger the concavity of the form, the higher the level of the unbiased distribution of insolation in the two opposite facades, and consequently the higher its suitability for bilateral buildings.

Summer			
	The South Facade	The North Facade	The Variation
The Radial Form: 60/360	68.05 %	48.21 %	19.84 %
The Radial Form: 90/360	66.23 %	51.43 %	14.8 %
The Radial Form: 120/360	65.24 %	52.5 %	12.74 %
The Radial Form: 150/360	64.88 %	50.71 %	14.17 %
The Radial Form: 180/360	64.61 %	50.71 %	13.9 %
Winter			
	The South Facade	The North Facade	The Variation
The Radial Form: 60/360	0 %	100 %	100 %
The Radial Form: 90/360	6.86 %	96 %	89.14 %
The Radial Form: 120/360	17.16 %	90.5 %	73.34 %
The Radial Form: 150/360	27.06 %	85.5 %	58.44 %
The Radial Form: 180/360	35.76 %	81 %	45.24 %

Table 7.3: The Shaded Area Generated in the Forms During Summer and Winter

The variation in the exposed area between the two opposite facades in the two seasons becomes minimum with more concave characteristics (Table 7.3). So, the radial form with the biggest concavity has the least variation of sun exposure between the two opposite facades. This makes the curve with more concave characteristics more beneficial in bilateral buildings (Figure 7.20). The variation between the two opposite facades, with regard to solar insolation, is less in the summer period in general. However, the gradual reduction of this variation with the increase of the concavity of the form is more obvious in winter. This trend is welcomed, as the variation between the two facades, with regard to the exposed area, is more crucial in wintertime than in summer.



More Advantageous for Bilateral Types of Building

Figure 7.20: The Form (180/360) has the Least Variation in the Exposed Areas between the Two Opposite Facades

	The South Facade		**The North Facade**	
	Summer	**Winter**	**Summer**	**Winter**
	Exposed Area	Exposed Area	Exposed Area	Exposed Area
The Radial Form: 60/360	**31.95 %**	**100 %**	**51.79 %**	**0 %**
The Radial Form: 90/360	**33.77 %**	**93.14 %**	**48.57 %**	**4 %**
The Radial Form: 120/360	**34.76 %**	**82.94 %**	**47.5 %**	**9.5 %**
The Radial Form: 150/360	**35.12 %**	**72.94 %**	**49.29 %**	**14.5 %**
The Radial Form: 180/360	**35.39 %**	**64.24 %**	**49.29 %**	**19 %**

Ew			
	South Facade	North Facade	The Variation
The Radial Form: 60/360	**312.99 %**	**0 %**	**312.99 %**
The Radial Form: 90/360	**275.81 %**	**8.24 %**	**267.57 %**
The Radial Form: 120/360	**238.61 %**	**20 %**	**218.61 %**
The Radial Form: 150/360	**207.69 %**	**29.42 %**	**178.27 %**
The Radial Form: 180/360	**181.52 %**	**38.55 %**	**142.97 %**

Table 7.4: The Variation in the Insolation Efficiency between the Two Opposite Facades in the Radial Forms

The above calculations (Table 7.4) show that the insolation efficiency for the south facades decreases with the increase of the form's concavity. This is caused mainly by the increase of the shaded area in wintertime, as the shaded area in the summer period for all south facades is approximately the same. On the other hand, the insolation efficiency for the north facades increases with the increase of the form's concavity. This is also due to the decrease of the shaded area in wintertime, as the shaded areas for all north facades are approximately the same in the summer period. So, in both cases, winter is the season which creates the major differences in the insolation efficiency between the opposite facades. In addition, the major variations between the two opposite facades in the same form are always evident in winter.

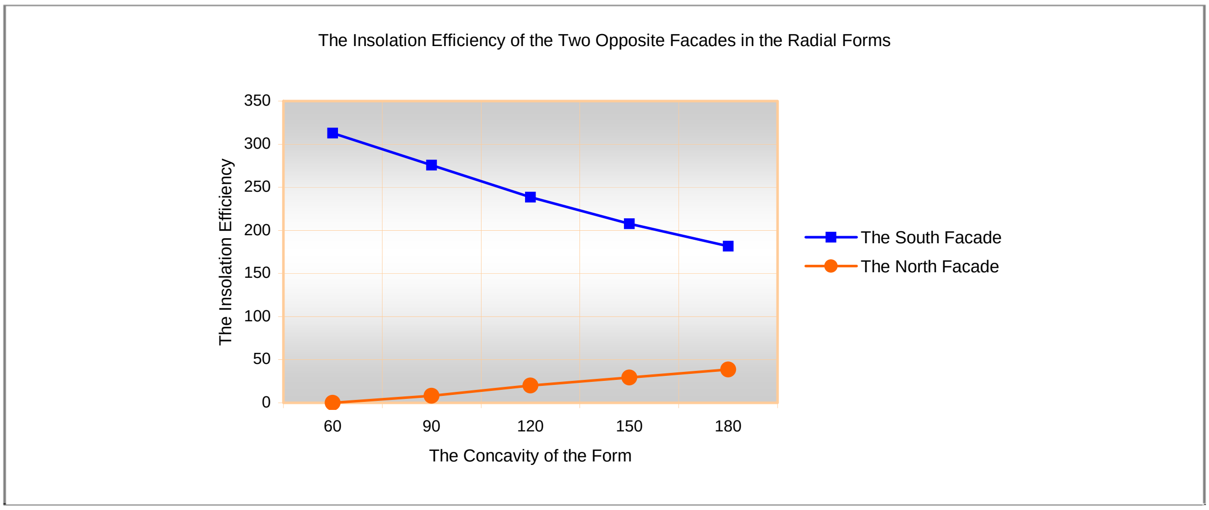
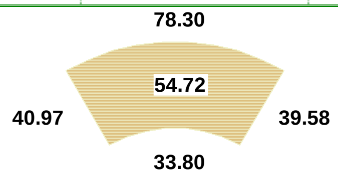


Figure 7.21: The relation between Ew of the Two Opposite Facades and the concavity of the Forms

By studying the above graph (Figure 7.21), it becomes evident that the variation in the insolation efficiency between the two opposite facades decreases with the increase of the form concavity. This finding confirms the result, previously concluded, that the radial form with more concave characteristics is more suitable for bilateral buildings, as the two opposite facades have the closest insolation efficiency. In unilateral buildings, where the south facade is the principal facade, the radial form with less concavity will be more suitable, as the insolation efficiency of the south facades increases with the decrease of the form's concavity.

7.3.7 The Annual Shaded Area Generated in the Patterns

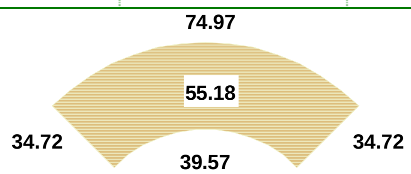
The Average Annual Shaded Area per Hour				
The Side-west Facade	The North-facing Facade	The Side-east Facade	The South-facing Facade	Total Average
40.97 %	78.30 %	39.58 %	33.80 %	54.72 %



The North Facade has a Bigger Shaded Percentage than the South One

Figure 7.22: The Radial Form-60/360: The Annual Shaded Area

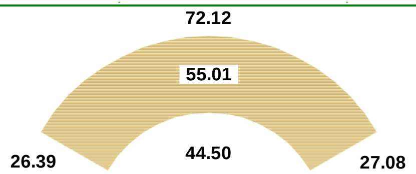
The Average Annual Shaded Area per Hour				
The Side-west Façade	The North-facing Facade	The Side-east Facade	The South-facing Facade	Total Average
34.72 %	74.97 %	34.72 %	39.57 %	55.18 %



The North Facade is More Shaded than the South One

Figure 7.23: The Radial Form-90/360: The Annual Shaded Area

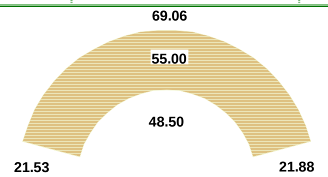
The Average Annual Shaded Area per Hour				
The Side-west Facade	The North-facing Facade	The Side-east Facade	The South-facing Facade	Total Average
26.39 %	72.12 %	27.08 %	44.50 %	55.01 %



The South Facade is Less Shaded than the North One

Figure 7.24: The Radial Form-120/360: The Annual Shaded Area

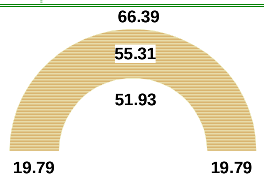
The Average Annual Shaded Area per Hour				
The Side-west Facade	The North-facing Facade	The Side-east Facade	The South-facing Facade	Total Average
21.53 %	69.06 %	21.88 %	48.50 %	55.00 %



The South Facade is more Exposed than the North One

Figure 7.25: The Radial Form-150/360: The Annual Shaded Area

The Average Annual Shaded Area per Hour				
The Side-west Facade	The North-facing Facade	The Side-east Facade	The South-facing Facade	Total Average
19.79 %	66.39 %	19.79 %	51.93 %	55.31 %



The North Facade Receives Fewer Sunrays

Figure 7.26: The Radial Form-180/360: The Annual Shaded Area

By studying the amount of generated shaded area in the forms (Figure 7.27), it can be observed that with the increase of the concavity of the radial from, the shaded area in the south facade increases, while the shaded area in the north facade decreases. This is due to the fact that with the increase of the form's concavity, the self-shading effect of the south facade increases and the facade also becomes less oriented to the south; simultaneously the north facade gets more parts oriented to directions other than the north. Therefore, with the increase of the concavity of the radial form, the differences between the two opposite facades (northern and southern) decrease. Thus, the suitability of the radial form for bilateral buildings increases with the increase of the form's concavity. Radial forms with greater concavity are also more advantageous in terms of urban space design, as they are able to create more defined outdoor space which can be utilized for social and living activities.

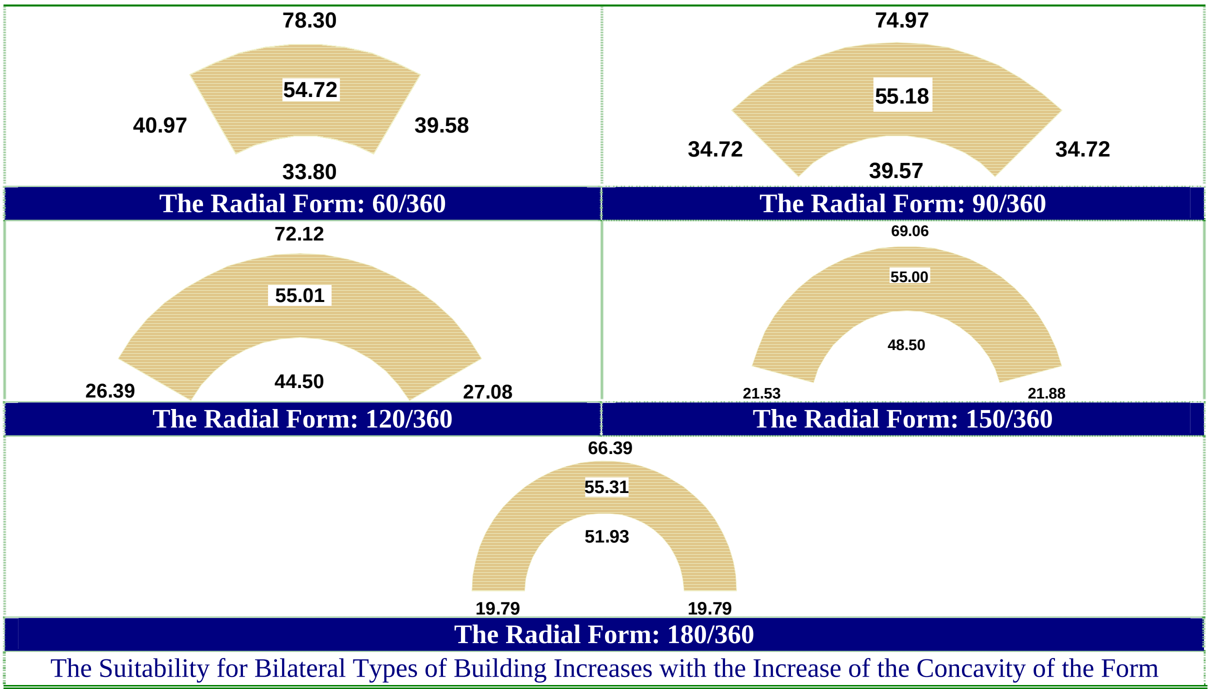


Figure 7.27: The Annual Shaded Area Generated in the Forms

The comparison between the forms also reveals that there is no major variation in the total shaded area generated in the forms during the whole year (Table 7.5), but the main difference is in the distribution of the shaded area in the facades of the forms. As regards the amount of shadow, it is clearly illustrated that it is enough to curve the form slightly to have the variations in the amount of the generated shaded areas between the radial form and the rectangular one, as further increases in concavity did not make any significant variation to the generated shaded area. However, further increase in the concavity of the form affects the distribution of the shaded area in both facades during the daytime period. The side facades of the radial form became more exposed with increases in concavity, as the sides became more oriented to the south.

Radial Form Concavity	The Shaded Percentage
60/360	54.72 %
90/360	55.18 %
120/360	55.01 %
150/360	55.00 %
180/360	55.31 %

Table 7.5: The Annual Shaded Area Generated in the Patterns

The trend revealed by this table (7.6) is that with the increase in concavity, the increment in the shaded area in the south facade is bigger than the decline of the shaded area in the north facade.

Radial Form Concavity	The North Facade		The South Facade	
	The Shaded Percentage	The Variation	The Shaded Percentage	The Variation
60/360	78.30 %		33.80 %	
90/360	74.97 %	-3.33	39.57 %	5.77
120/360	72.12 %	-2.85	44.50 %	4.93
150/360	69.06 %	-3.06	48.50 %	4.00
180/360	66.39 %	-2.67	51.93 %	3.43

Table 7.6: The Annual Shaded Area Generated in the Patterns over the Year in the Two Opposite Facades

Table 7.7 illustrates the fact that the variation in the shaded area between the two opposite facades (south and north) becomes lower with the increase in concavity. Thus, forms with more concavity characteristics are more suitable for bilateral buildings. Another trend revealed by this table is that the decline of the variation in the shaded area between the two opposite facades decreases with the increase of the concavity of the radial form.

Radial Form Concavity	The Shaded Percentage			
	The North Facade	The South Facade	The Variation	The Increment
60/360	78.30 %	33.80 %	44.5	
90/360	74.97 %	39.57 %	35.4	9.1
120/360	72.12 %	44.50 %	27.62	7.78
150/360	69.06 %	48.50 %	20.56	7.06
180/360	66.39 %	51.93 %	14.46	6.1

Table 7.7: The Variation in the Annual Shaded Area Generated in the Two Opposite Facades

7.4 The Relation between the Bilateral Radial Form and Orientation: A Comparison between Radial Forms with Different Orientations

Olgyay (1992) pointed out that, in order to achieve the best living conditions (i.e. warmth in winter, coolness in summer), the building's principal facades should face the south. He also reported that the optimal orientation of the long axis of the building is east-west. This design concept was also supported by many other researchers. For example, Fathi (1973) also confirmed that the best orientation for sun would be with the long axis of the building lying east-west. According to these previous researches, a form which is elongated east-west is more suitable in terms of saving energy. However, when attempting to maintain this concept in the case of a rectangular form with a bilateral distribution of residential units, this will be disadvantageous as the north facade will receive no sunrays at all during winter. In bilateral buildings, it is also important to have a homogeneous distribution of sunrays for all residential units on both sides of the form. The radial form with a principal concave facade facing the south still has the most advantages. This is derived from the fact that the form is more elongated east-west than in other directions, especially when a deviation of 20^0 off a recommended east-west orientation does not produce a major variation (Danby, 1973). In addition, the form can overcome the shortcomings of the rectangular form, as the north facade of the radial form still has the possibility to gather some sunrays in winter. However, if the regular distribution of the shaded area in the two long opposite facades of the form was taken as the main criterion to determine the suitability of the form for bilateral buildings, other orientations for the radial form can be more suitable.

So, the experiment aims to find out which form has the smallest differences in the exposed areas between the two opposite facades. To satisfy this goal, the experiment compares several radial forms varying in their orientation with regard to the generated shadow pattern in both the over and underheated periods, and over the whole year. The most suitable orientation will be found when differences between the exposed areas in the two opposite facades is minimal. Such a form will be more suitable for bilateral buildings, as it enables all residential units in the two opposite facades to receive similar amounts of sunrays.

The Urban Site: The site consists of three radial forms with different orientations (Figure 7.28). The form (180/360) which has been proved as the most suitable radial form for bilateral buildings in terms of concavity (in the case of an east-west elongation) was chosen for this experiment. The three basic forms that will be examined are south-facing, east-facing and southwest-facing forms.

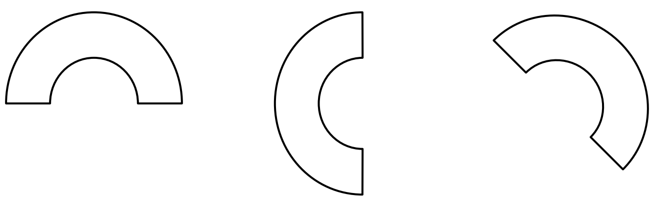
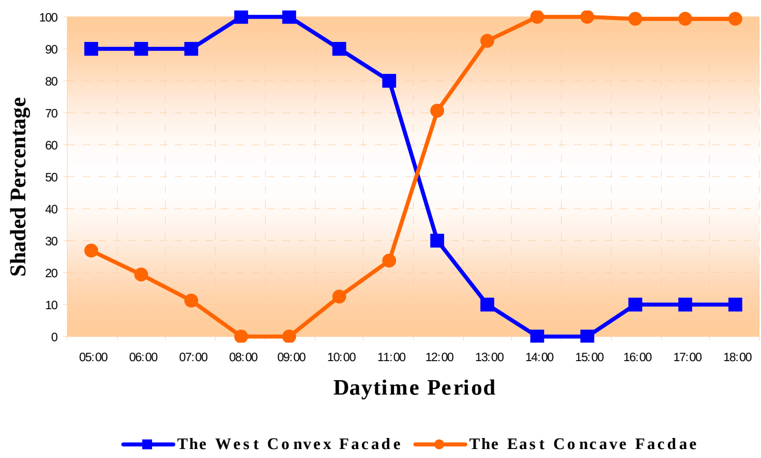


Figure 7.28: A Comparison between Radial Forms with Different Orientations

7.4.1 The East-facing Radial Form 180/360
i. The Shadow Pattern in Summer



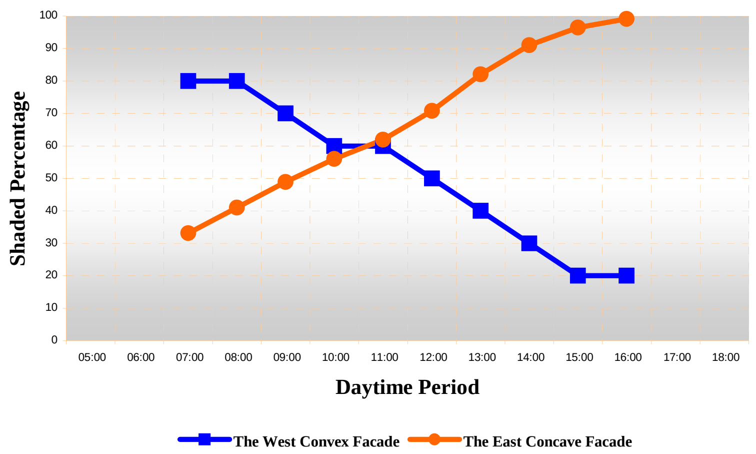
The Average Shaded Area per Hour During Daytime in Summer	
The East Concave Facade	53.92 %
The West Convex Facade	50.71 %

Figure 7.29: The East-facing Radial Form: The Shadow Pattern in Summer

The graph (Figure 7.29) shows that the west convex facade is partially exposed in the morning period and, at the same time, the east concave facade is partially shaded. The west convex facade is completely shaded for one hour approximately in the middle of the first half of the day and the east concave facade is completely exposed simultaneously. This occurs when sunrays are perpendicular to the centre of the curve. At noon, both facades have approximately the same shaded area, with each facade being approximately half shaded and half exposed at this time. This occurs when sunrays are approximately parallel to the side facades of the radial form. The west convex facade is less shaded in general, as it generates about 50.71 % of shaded area per hour on average, while the east facade generates about 53.92 %.

With the exception of short periods in the early morning and late afternoon, the trend in the west facade is to be gradually exposed while, at the same time, the trend in the east facade is to be gradually shaded. Both the rates of increase of the shaded area in the east facade and decrease of the shaded area in the west facade increase with closeness to the noon period. This is because the sun’s azimuth at the noon period changes at a higher rate than in the morning or afternoon.

ii. The Shadow Pattern in Winter



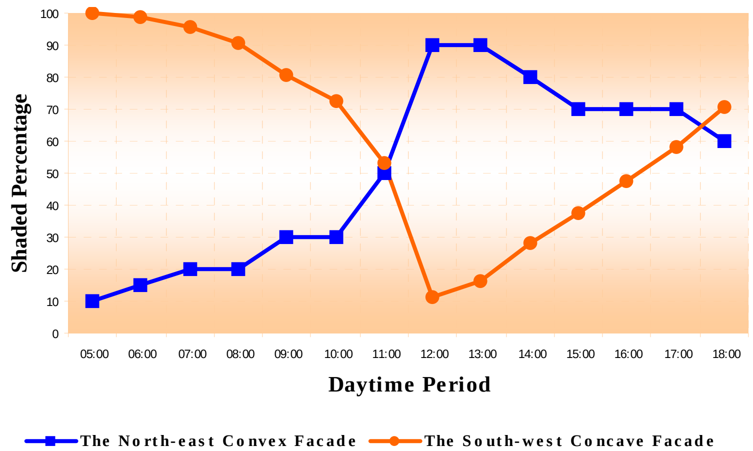
The Average Shaded Area per Hour During Daytime in Winter	
The East Concave Facade	**68.06 %**
The West Convex Facade	**51%**

Figure 7.30: The East-facing Radial Form: The Shadow Pattern in Winter

The graph (Figure 7.30) shows that both facades have approximately the same shaded areas for the short period before noon. This occurs when the sunrays are approximately parallel to the side facades of the radial form. The state of balance in this case takes place with a higher shaded percentage in both facades than the balanced state in summer, because the sun in winter is at a lower altitude. The trend in the west facade is to be gradually exposed while, at the same time, the trend in the east facade is to be gradually shaded. Although the two facades are approximately symmetrically arranged according to the sun's path, the east concave facade is more shaded in general, as it generates about 68.06 % of shaded area per hour on average, while the west facade generates about 51%. This clearly illustrates the significance of the self-shading effects of the concave facade. The self-shading effect of the concave facade here is greater than in summer, as the sun is closer to the horizon in winter.

7.4.2 The Southwest-facing Radial Form 180/360
i. The Shadow Pattern in Summer

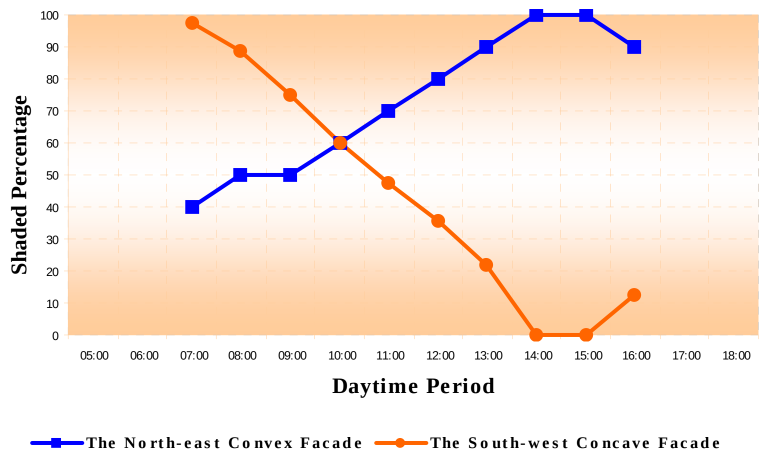
The graph (Figure 7.31) reveals that both facades have approximately the same shaded area for a short period before noon, and that each facade is approximately half shaded and half exposed at this time. This occurs when sunrays are approximately parallel to the side facades of the radial form. Both facades are partially shaded or exposed during the whole daytime period, i.e. both facades could enjoy sunrays during the whole day. The distribution of the shaded area in both facades is more dynamic, as the shadow pattern for both facades changes its trend during the daytime period. The north-east convex facade is less shaded in general, as it generates only 50.36 % of shaded area per hour on average, while the south-west concave facade generates 61.49 % per hour on average.



The Average Shaded Area per Hour During Daytime in Summer	
The South-west Concave Facade	**61.49 %**
The North-east Convex Facade	**50.36 %**

Figure 7.31: The South-west facing Radial Form: The Shadow Pattern in Summer

ii. The Shadow Pattern in Winter



The Average Shaded Area per Hour During Daytime in Winter	
The South-west Concave Facade	**43.94 %**
The North-east Convex Facade	**73 %**

Figure 7.32: The South-west Facing Radial Form: The Shadow Pattern in Winter

The north-east convex facade is more shaded in general, as it produces about 73 % of shaded area per hour on average, while the south-west concave facade produces only 43.94 % (Figure 7.32). In the forenoon period, both facades have approximately the same shaded area. This occurs when sunrays are approximately parallel to the side facades of the radial form. This balance occurs with more shaded area than the balanced state in the summer period, as the altitude angle of the sun is lower in winter. Except for a short period in the late afternoon, the trend in the south-west concave facade is to be gradually exposed while, at the same time, the trend in the north-east convex facade is to be gradually shaded.

7.4.3 The Shaded Area Generated by the two Opposite Facades in Over and Underheated Periods

South-facing Radial Form			
	Summer	Winter	Average
The South Concave Facade	64.61%	35.76 %	
The North Convex Facade	50.71%	81 %	
The Variation	13.9 %	45.24 %	
Total	55.92	64.04 %	59.98 %
East-facing Radial Form			
	Summer	Winter	Average
The East Concave Facade	53.92 %	68.06 %	
The West Convex Facade	50.71 %	51 %	
The Variation	3.21 %	17.06 %	
Total	51.91	57.40 %	54.66 %
	Southwest-facing Radial Form		
	Summer	Winter	Average
The South-west Concave Facade	61.49 %	43.94 %	
The North-east Convex Facade	50.36 %	73 %	
The Variation	11.13 %	29.06 %	
Total	54.53 %	62.10 %	58.32 %
	The Variation Between the Two Opposite Facades		
	Summer	Winter	
The South-facing Radial Form	13.9 %	45.24 %	
The East-facing Radial Form	3.21 %	17.06 %	
The Southwest-facing Radial Form	11.13 %	29.06 %	

Table 7.8: A Comparison Between the Shaded Area Generated by the Radial Forms in the Two Seasons

By studying the comparison between the three forms, it can be observed that the curve with the open space oriented east is more suitable for bilateral buildings (Figure 7.33), as it has the least variation between the two opposite facades in both seasons (Table 7.8).

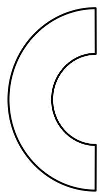


Figure 7.33: The East-Facing Radial Form is More Suitable for Bilateral Types of Building

	The Exposed Area		
The South-facing Radial Form			
	Summer	Winter	Solar Insolation (Ew)
The South Concave Facade	35.39 %	64.24 %	181.52 %
The North Convex Facade	49.29 %	19 %	38.55 %
The Variation			142.97 %
The East-facing Radial Form			
	Summer	Winter	Solar Insolation (Ew)
The East Concave Facade	46.08 %	31.94 %	69.31 %
The West Convex Facade	49.29 %	49 %	99.41 %
The Variation			30.1 %
The Southwest-facing Radial Form			
	Summer	Winter	Solar Insolation (Ew)
The South-west Concave Facade	38.51 %	56.06 %	145.57 %
The North-east Convex Facade	49.64 %	27 %	54.39 %
The Variation			91.18 %

Table 7.9: A Comparison Between the Solar Insolation of the Two Opposite Facades

By calculating the insolation efficiency (Ew) for the two opposite facades in all forms, it can be observed that the south facade in the radial form oriented south has the best insolation efficiency, while the lowest insolation efficiency is seen in the north facade for the same form (Table 7.9). The radial form with the open space facing east has the least variation in the insolation efficiency of the two opposite facades. Thus, the form is more suitable for bilateral buildings. In unilateral buildings, where the living spaces are concentrated in one side of the form, the best orientation is the long principal facade facing south (Figure 7.34), as the facade in this position has the best insolation efficiency.

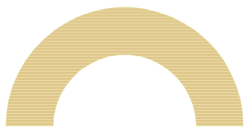


Figure 7.34: The Radial Form with the Principal Facade Facing South is more Suitable in Unilateral Types of Building

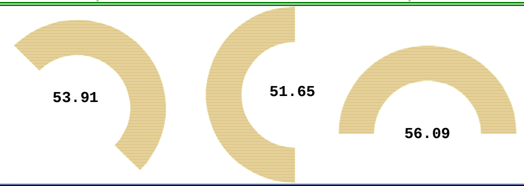
7.4.4 The Average Shaded Area for the Radial Forms in the Two Seasons

In order to calculate the average shaded area for the whole form in both seasons, it is necessary to calculate the shaded area for the side facades in each form (Table 7.10).

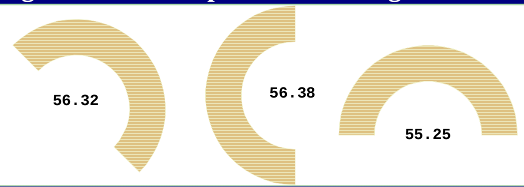
	The Shaded Area for the Side Facades		
	The South-Facing Radial Form	The East-Facing Radial Form	The Southwest-Facing Radial Form
Winter	0 %	50 %	20 %
Summer	57.14 %	50 %	50 %

Table 7.10: The Shaded Area for the Side Facades of the Radial Forms

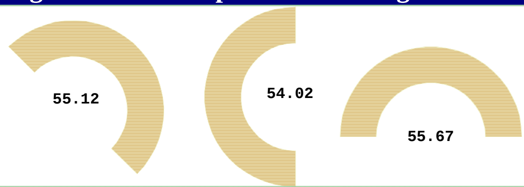
	Summer	Winter	Average
The South-facing Radial Form	56.09 %	55.25 %	55.67 %
The East-facing Radial Form	51.65 %	56.38 %	54.02 %
The Southwest-facing Radial Form	53.91 %	56.32 %	55.12 %



The Average Shaded Area per Hour During the Summer Period



The Average Shaded Area per Hour During the Winter Period



The Average Shaded Area per Hour in the Two Seasons

Figure 7.35: A Comparison Between the Shaded Area Generated by the Radial Forms in the Two Seasons

The comparison between the forms with regard to the shaded area in the two seasons reveals that the curve with its pen space facing south has the biggest shaded percentage in summer and the least shaded percentage in winter (Figure 7.35). Therefore, it can be concluded that this form would be preferable in Palestine and in other temperate climates (Figure 7.36) where avoiding summer heat and receiving sunrays in winter is a requirement. This is based on the fact that under cold conditions, radiation will be welcomed and the building should receive as much radiation as possible, while under conditions of excessive heat, the same building should decrease undesirable solar impact. Therefore, an optimum form for a given site would provide the maximum radiation during the underheated period while, at the same time, reducing insolation to a minimum in the overheated period.

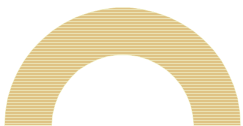


Figure 7.36: The Radial Form with its Open Space Facing South is Preferable in Palestine and Temperate Climates

However, because the form has the largest average of shaded percentage of the two seasons, the form facing south could be more advantageous in the summer period or in places where the major concern is to satisfy cooling requirements. The comparison also shows that the largest variation between the south-facing curve and other radial forms also occurs in the summer period. This makes the form even more advantageous in areas where the major concern is to avoid sunrays in summer (the coastal plain in the case of Palestine). For qualitative indicators to compare the relative performance of the forms, the efficiency factor E_W (a measure of building performance in temperate climates and for those regions where winter heating is a necessity) can be used. The insulation efficiency of a building form can be measured by comparing the summer solar exposure with the winter solar exposure. As is indicated in Table 7.11, the south-facing radial form has the best insolation efficiency and the table also establishes the ratio between the forms with regard to their insolation efficiency in temperate climates.

E_W = Winter Solar Exposure/Summer Solar Exposure * 100	
The South-facing Radial Form	E_W = 44.75/ 43.91* 100 = 101.91%
The East-facing Radial Form	E_W = 43.62/ 48.35* 100 = 90.22%
The Southwest-facing Radial Form	E_W = 43.68/ 46.09* 100 = 94.77%

Table 7.11: The Insulation Efficiency of the Radial Form

7.4.5 A Comparison between the Forms: The Generated Shadow Pattern
i. The Shadow Pattern in Summer

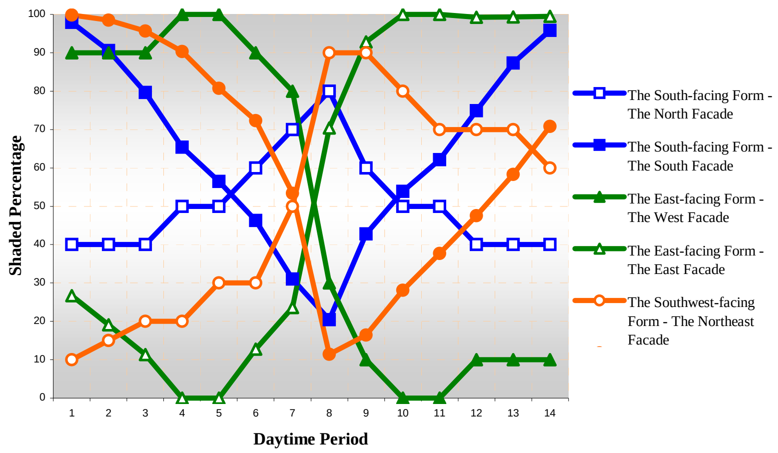
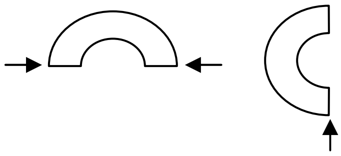


Figure 7.37: The Generated Shadow Patterns in Summer

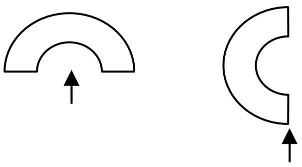
The comparison of the radial forms with regard to shadow patterns during daytime in summer shows that the balanced state (both facades have the same shaded percentage) in the south-facing radial form occurs twice during daytime (before and after noon). On the other hand, the balanced state in the east-facing radial form occurs just once, at approximately noon (Figure 7.37). This refers to the fact that the balanced state always happens when sunrays are parallel to the side facades of the form (Figure 7.38). The shadow pattern of the forms in summer shows that both facades in the east-facing radial form have approximately the same percentage of exposure.



Balance State always Happens when Sunrays are Parallel to the Side Facades of the Form

Figure 7.38: The Balance State in the Radial Forms

The biggest variation between the two facades of the south-facing radial form occur at noon, when sunrays are perpendicular to the centre of the concave facade. At the same period, the east-facing radial form has the least variation between the two opposite facades, as sunrays are parallel to the side facades of the form. In general, the greatest differences between the two opposite facades occur when sunrays are perpendicular to the centre of the concaved facade and the smallest differences occur when sunrays are parallel to the side facades of the form (Figure 7.39). The north facade of the south-facing form is more exposed to sunrays than the south one, while both facades in the east-facing form are approximately exposed to sunrays equally, as they are arranged symmetrically in relation to the sunpath.



The greatest differences between the two opposite facades occur when sunrays are perpendicular to the centre of the curve and the smallest differences occur when sunrays are parallel to the side facades of the form

Figure 7.39: The Greatest and Smallest Differences between the Two Opposite Facades

ii. The Shadow Pattern in Winter

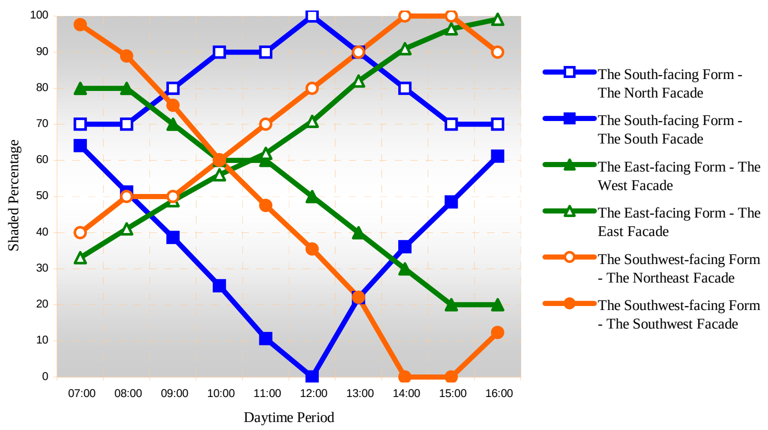


Figure 7.40: The Generated Shadow Patterns in Winter

The Balance Condition for the east-facing radial form occurs once during daytime in each season, while the State of Balance for the south-facing radial form occurs twice during daytime, but only during the summer period (Figure 7.40). As the east-facing radial form has the smallest differences in exposed areas between the two opposite facades in both the summer and winter periods, the form will be more suitable for bilateral buildings. In this case, the residential units in the two opposite facades will receive approximately the same amount of solar insolation in all periods.

7.4.6 The Annual Shaded Area Generated in the Forms

The Average Annual Shaded Area per Hour				
The East Side Facade-North	The West Facade – Outer Surface	The East Side Facade-South	The East Facade – Inner Surface	Total Average
51.04 %	50.38 %	51.04 %	58.65 %	53.15 %

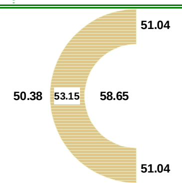


Figure 7.41: The Annual Shaded Area for the East-facing Form

The Average Annual Shaded Area per Hour				
The Southwest Side Facade – North	The Northeast Facade – Outer Surface	The Southwest Side Facade – South	The Southwest Facade-Inner Surface	Total Average
34.72 %	62.74 %	34.72 %	51.35 %	55.21 %

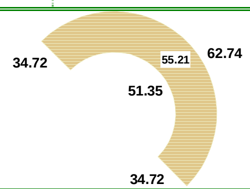
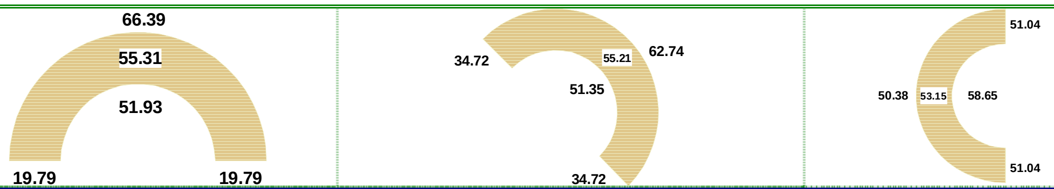


Figure 7.42: The Annual Shaded Area for the Southwest-facing Form



The Variation between the Two Opposite Facades		
14.46 %	11.39 %	8.27 %
More Suitable for Cooling Requirements		More Suitable for Heating

Figure 7.43: A Comparison between the Forms: The Average Annual Shaded Area per Hour

When comparing the average annual shaded area in the forms, it can be observed that the south-facing radial form generates more shadow than others. Thus, it is more suitable for cooling requirements, while the form with its open space oriented east is more suitable for heating requirements as it generates the least amount of shadow (Figure 7.43). Also, the curve with the open space facing east (Figure 7.44) is more suitable for bilateral buildings, as it has the least variation in the shaded percentage generated in the two opposite facades.

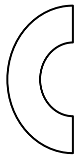


Figure 7.44: The East-Facing Radial Form is more Suitable for Bilateral Types of Building

7.5 Conclusions

By reviewing the generated shadow patterns in the opposite facades of the radial forms (with different concavities) in the summer period, it can be observed that the supreme variation between the two facades occurs early in the morning, in the late afternoon, and at noon. However, this variation decreases with the increase of the form's concavity. Therefore, the distribution of the shadow pattern in the two opposite facades during daytime becomes more regular with increases of concavity. So, both facades in radial forms with more concavity can enjoy more homogenous solar accessibility during daytime.

In wintertime, the variation between the two opposite facades within the same form is more evident. However, the variation between the two facades decreases with an increase of the form's concavity, as a larger percentage of the south facade becomes shaded in the morning and afternoon and a larger percentage of the north facade becomes exposed simultaneously. It is also observed that the gradual increase of the shaded area in the south facade is intensified at a higher rate than the exposed area in the north facade.

One of the trends that has become evident by studying the previous graphs is that the two opposite facades in radial forms with more concave characteristics have the least variation of sun exposure and can enjoy sunrays most of the daytime in both seasons, as they are approximately partially exposed throughout the whole day. This illustrates the suitability of radial forms with more concavity for bilateral buildings. The comparison between the forms, with regard to the total generated shaded area in the whole form over the year, reveals that there is no major variation between the forms; the main variation is in the distribution of the shaded area within the facades of these forms.

As regards insolation efficiency, winter is the season which creates major differences in insolation efficiency between the two opposite facades, as the shaded area for the two facades is approximately the same in the summer period. Insolation efficiency decreases with the increase of the form's concavity in the case of the south facade and increases in the case of the north facade. Consequently, the variation in the insolation efficiency between the two opposite facades decreases with the increase of the form's concavity. This finding confirms the suitability of the radial form with more concave characteristics for bilateral buildings. In unilateral buildings, where the south facade is the principal facade, the radial form with less concavity will be more suitable, as the insolation efficiency of the south facade increases with a decrease of the form's concavity.

By studying the comparison between the radial forms facing south, east, and west-south, it can be observed that the curve with the open space oriented east is more suitable for bilateral buildings as it has the least variation between the two opposite facades in both seasons, with regard to the shaded area. In unilateral buildings, where the living spaces are concentrated on one side of the form, the best orientation is to have the long principal facade facing south, as the facade in this position has the best insolation efficiency.

The comparison between the three forms, with regard to the shaded area in the two seasons, also reveals that the curve with the pen space facing south has the biggest shaded percentage in summer and the least shaded percentage in winter and consequently the best insolation efficiency. So, it can be concluded that this form is preferable in Palestine and other temperate climates, where avoiding summer heat and receiving sunrays in winter are important requirements. When comparing the average annual shaded areas generated in the forms, it can be observed that the south-facing radial form generates more shadow than the others and thus is more suitable for cooling requirements, while the form with its open space oriented east is more suitable for heating requirements, as it generates the least amount of shadow. Also, the calculations confirm the suitability of the east-facing form for bilateral buildings, as it has the least variation between the two opposite facades with regard to the shaded area.

CHAPTER 8

SOLAR ANALYSIS OF COMPLEX FORMS:
A Comparison Between The Radial Form And The Rectangular U-Shape

8. Solar Analysis Of Complex Forms: A Comparison between the Radial Form and the Rectangular U-Shape

8.0 Overview

It seems evident that the geometry of the urban form as an urban design tool is crucial. Different urban forms result in differing microclimates, offering more or less comfort. The layout of the structure can modify the urban climate through proper design, thus improving thermal comfort both outside and inside buildings and even reducing energy demands for heating and cooling requirements. Some forms, which can create a space surrounded and defined by walls, can offer self-protection against unfavourable weather and create their own microclimate. Such forms are very common within the urban structure and this principle is adequate in residential areas, since such spaces can be used as playgrounds for children and can enhance social activities and human contact. These forms are also characterised by their ability to generate a self-shading effect. The previous studies were mainly concerned to examine simple shapes and less care was given to examine such forms. The forms considered in this experiment are radial forms and the rectangular U-Shape. These forms could be considered as intermediate types between closed and open layouts. In Palestine and other temperate climates, a layout which is semi-closed could be more beneficial, as completely closed or completely open layouts are preferable in arid zones and cold climates respectively. This experiment also aims to prove that the methodology which was developed in this research can also be used to evaluate such complex forms. Studies in this case cover the three basic classified types of urban forms: pavilions, urban canyons and complex forms (or forms that can create open spaces). Therefore, the experiment proves the capability and universality of this comprehensive approach which includes all the points that should be examined in order that the maximum benefit can be derived. In addition, the method illustrates how these analyses could be related to aspects of design and energy. The research finally facilitates and accelerates further research in this field, as this approach can be applicable for different kinds of urban forms.

8.1 Background

It seems clear that the geometry of the urban form as an urban design tool is more crucial in urban climate amelioration than other factors, at least in the small-to-medium scale. Hence, explicit considerations of urban geometry are very important. The great variation of urban forms produces various kinds of microclimates inside the settlements. Different layouts result in differing microclimates, with more or less comfort. Mascaro et al. (1998) stated that each built site interacts with the physical environment and produces particular microclimate conditions. The layout and structure of a settlement affect the climate of the area and can even modify it through a proper design, thus enhancing thermal comfort both outside and inside the buildings, and even reducing energy demands for heating and cooling. Thus, the geometry of the urban form is a variable that may be controlled for the amelioration of bioclimatic conditions. To make a successful integration of renewable energies in established urban structures, the actual performance and the generated shadow pattern of the urban forms have to be precisely defined. Depending on requirements, urban and building forms might be modelled for solar access or shade.

The forms of Buildings can be classified into three basic types (Martin & March, 1972). The first consists of pavilions or isolated buildings, single or in a cluster, surrounded by large open spaces. The second type is the street urban canyon, which comprises long building blocks arranged in parallel rows and separated by actual streets or open spaces. The third one is a type where the forms can create an open space surrounded by walls, such as U-shapes (Figure 8.1), courts, etc. Previous experiments on parametric studies have dealt with the first two kinds, i.e. individual buildings and the urban canyon. This section of the study is devoted to covering the third kind of building form: forms creating an open space surrounded by walls. The examined forms are the radial form and the rectangular U-shape. These forms could be midway between the closed and open layouts. Such semi-closed layouts could be more beneficial in Palestine and other temperate climates than completely closed or completely open layouts, which are preferable in arid zones and cold climates respectively.

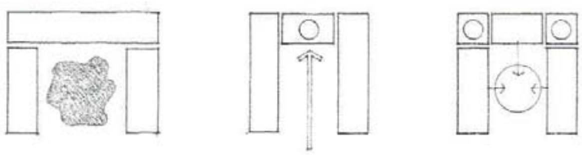


Figure 8.1: U-shaped Configurations of Building Forms (Ching, 1996)

Courtyards appear in different forms, dimensions and architectural treatments, but all create open space adjacent to buildings. Meir et al. (1995) pointed out that such a space can provide climatic, visual and acoustic protection, as well as the possibility of spending time in the outdoor living space. Ratti et al. (2003) considered the primary characteristic of courts as the ability to create a microclimate that is quieter, cleaner and more private than the street, and where the surrounding interior spaces can interact positively with this improved microclimate. Such characteristics of courts make them a form of building that makes desirable use of land, particularly in an urban context. To improve the thermal behaviour of these forms, the courtyard's geometry, as well as the orientation of the semi-enclosed open spaces, should be designed to provide the highest level of comfort possible.

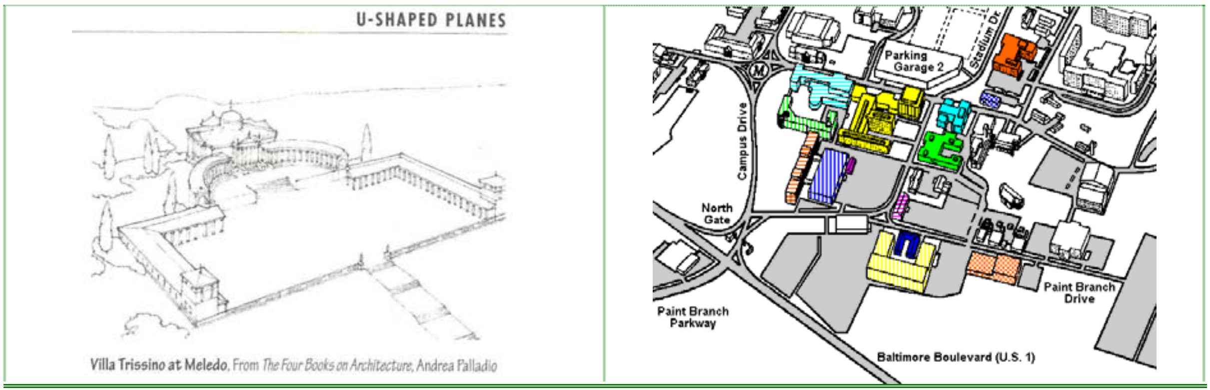


Figure 8.2: U-shaped Plans within Urban Structure (Ching, 1996, UOM, 2001)

Ching (1996) referred to the U-shape as a configuration which defines a field of space that has an inward focus as well as an outward orientation. U-shapes and semi-enclosed courtyards are popular, as such forms have a high inherent potential for outdoor activities in different climatic regions (Figure 8.2). "Semi-enclosed forms are part of an architectural language common throughout the history of many regions" (Meir et al., 1995). Semi-courtyards have been incorporated as part of single houses, multi-family complexes and public buildings (Figure 8.3). Cook (1991) stressed the social and functional aspects of these patterns, such as privacy and security in an open space, or daylighting and ventilation for the surrounding volumes, as well as the importance of microclimate moderation. While the actual insolation performance of the semi-enclosed forms has not been very well investigated through documentation, even less work has been undertaken on understanding the behaviour of the radial semi-enclosed ones.

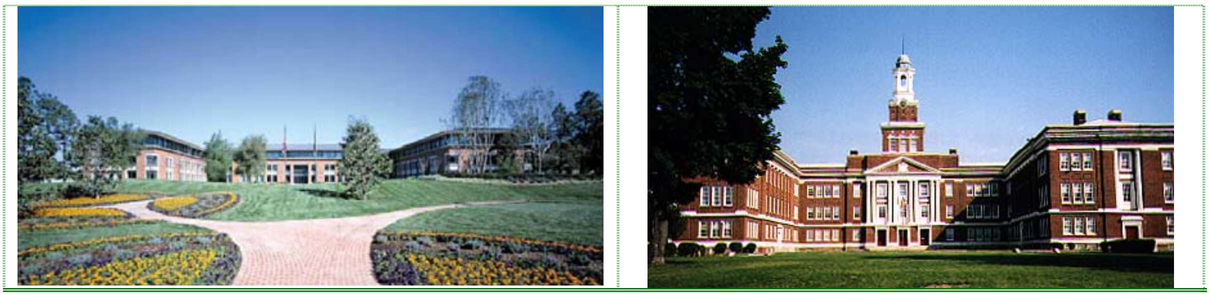


Figure 8.3: U-shaped Buildings (Matt Construction, 2001, BAH, 2001)

8.2 A Comparison between the Radial Form and the Rectangular U-Shape
8.2.1 South-facing Patterns

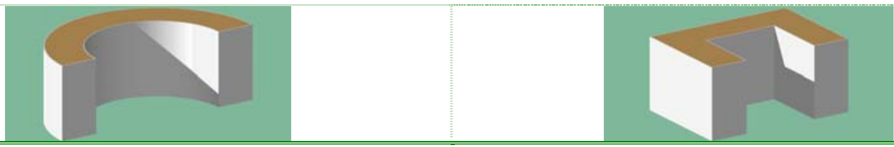


Figure 8.4: The Radial Form and the U-Shape

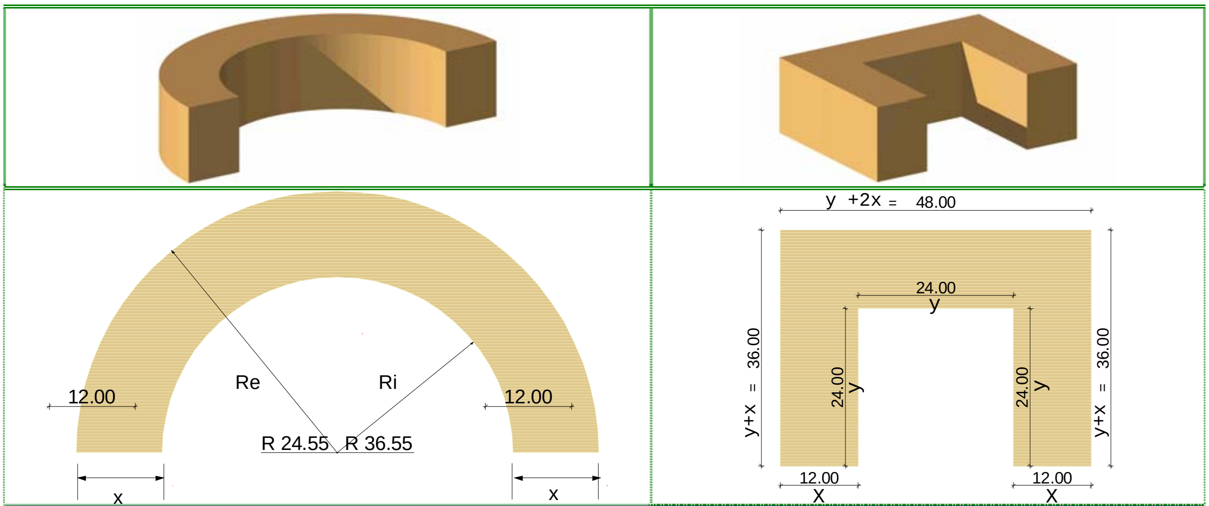
The dominant common characteristic of both forms (the radial and the U-shape) is that they can create space which is surrounded and defined by walls (Figure 8.4). This principle is very useful in residential areas, as these spaces can be used as the main outdoor living space for the children's playgrounds, as well as for some social activities that enhance human contact within the neighbourhood. While the open rectangular layout makes the most of radiation reflected far away from the exposed surface, the rectangular U-shape enhances some concentration of the reflected radiation. However, the radial form enhances maximum concentration of the reflected radiation from the curvilinear surfaces, as the curved spaces absorb and focus solar heat. This could be beneficial during winter, as it can improve thermal comfort outdoors and encourage the occupants to practice some activities outside during the cold period.

Although the rectangular U-shape is more common than the radial one in the current urban structure (mainly for constructional and compositional reasons), discovering some advantages of the radial form (from the solar point of view) could provide the radial form with the opportunity to be used more. The investigation considered that, in the hot season the objective is to minimize heat load on buildings, and in the cold period the objective is to maximise it.

The goal of this experiment is to investigate the main characteristics of the curvilinear form regarding thermal performance and solar insulation as opposed to the rectangular U-shape. The experiment also aims to clarify the methodology by which the complex forms can be evaluated with regard to the generated shadow pattern. This methodology aims, not only to offer information about the variation of the annual shaded area generated in the two forms, but also to determine the period when this variation is maximal. In addition, it aims to find out the sides where this variation is greater. Moreover, the experiment intends to indicate the specific time during the day where this variation is more significant. This comprehensive approach gives a full explanation of the status of the generated shadow;

this allows the best interpretation of the results and the derivation of the maximum benefit from it.

The Urban Site: The two forms have the same built volume and the same floor area. The height of the two blocks is 16 m and the depth of the two forms is 12 m. The urban canyon section (H/W) for the U-shape is 1:1.5. As the two forms have the same height and perimeter, the external surface areas of the two forms are the same (Figure 8.5). The experiment will apply patterns with open spaces oriented towards the south.



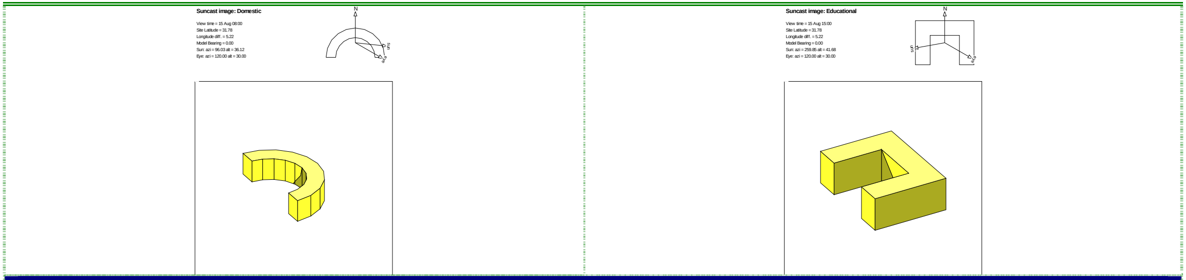
The Relation between the Dimensions of the Two Forms	
The Two Forms have the Same Built Volume =	$X(y+2x) + 2xy = ½(\Pi r_e^2 - \Pi r_i^2)$
The Perimeter of the Rectangular Form =	$2x + 3y + 2(x+y) + y+2x = 216m$
The Perimeter of the Radial Form =	$½(2\Pi r_e) + ½(2\Pi r_i) + 2x = 216m$
The External Surfaces Area =	$216m*16 = 3456\ m^2$
The Floor Area of the Forms =	$1152\ m^2$
The Built Volume of the Forms =	$18432\ m^3$

Figure 8.5: The Dimensions of the Radial Form and the Rectangular U-shape

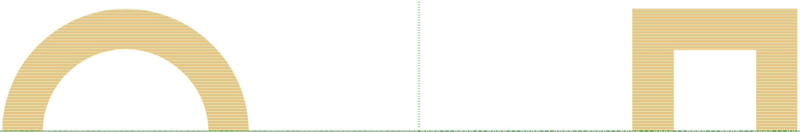
A comparison between the two forms with regard to the generated shadow in both winter, summer and for the whole year, was conducted to find out which form is more suitable for heating requirements and the one that is more suitable for cooling. Consequently, the generated shaded area in the two forms each hour during daytime was summed over the whole year and then for the overheated and underheated periods. This summation was computed firstly for the whole form and secondly for both the inner and outer surfaces separately. Furthermore, a comparison between the two forms was conducted to illustrate the daytime hours that result in more significant variation between the two forms with regard to the generated shaded area.

December was considered as representative of the underheated period, while June was considered as representative for the overheated period. 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 two forms is expected to be relatively small.

8.2.1.1 The Evaluation of the Generated Shaded Area in the Two Forms
8.2.1.1.1 The Annual Shaded Area Generated by the Two Forms



The Average Annual Shaded Percentage per Hour During Daytime			
The Radial Form	53.82 %	The Rectangular U-Shape	55.62 %



53.82%	55.62%
The Radial Form: Less Shaded Area	The Rectangular U-Shape: More Shaded Area
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure 8.6: The Average Annual Shaded Area Generated by the Two Forms

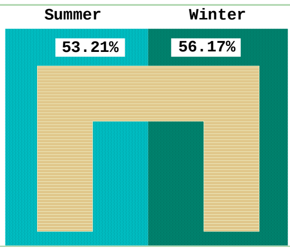
Calculating the annual shaded area generated in the two forms shows that the annual shaded area is greater in the case of the rectangular form and smaller in the case of the radial one (Figure 8.6). Thus, it can be derived that the rectangular U-shape is more suitable for cooling requirements, while the radial form is more suitable for heating.

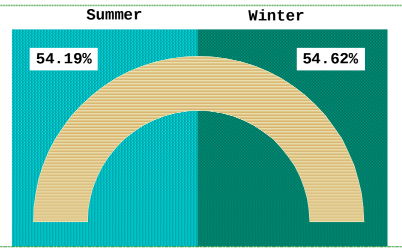
As the rectangular U-shape enhances some concentration of reflected radiation, while the curvilinear form enhances maximum concentration of reflected radiation, the suitability of the radial form for heating requirements will be enhanced by the fact that the radial form generates more heat in the outdoor space. Thus, the radial form can also contribute in the heating requirements of the outdoor living space.

8.2.1.1.2 The Distribution of the Shaded Area during Over and Underheated Periods

The Average Daily Shaded Percentage per Hour		
	Summer Period	Winter Period
The Rectangular U-Shape	53.21%	56.17%
The Radial Form	54.19%	54.62%

The Shaded Area in the Two forms in Both Overheated and Underheated Periods





The South-Facing Radial Form is Preferable in Temperate Climates

Figure 8.7: The Average Daily Shaded Area in Over and Underheated Periods

The south-facing radial form has the least amount of shadow in winter when sun exposure is desirable, and the greatest amount of shadow in summer when sheltering the building from sunrays is required (Figure 8.7). Thus, in Palestine and other temperate climates, the radial form is preferable. Measuring the shaded area generated in both seasons also reveals that the shaded percentage in both forms is slightly higher in wintertime, this especially applies to the rectangular form. When comparing the shaded area generated in the two forms during the two seasons, it can be observed that the shaded percentage of the radial form is higher in summer, while it is higher with more extension in winter in the case of the rectangular U-shape. Therefore, the greatest variation between the two forms, with regard to the generated shaded area, occurs in wintertime.

For qualitative indicators to compare the relative performance of both forms, the efficiency factor E_W can be used. The insolation efficiency (Ew) is a measurement of a building's performance in temperate climates and for those regions where winter heating is a necessity. The insulation efficiency of a building form can be measured by comparing the summer solar exposure with the winter solar exposure (Table 8.1).

E_W = Winter Solar Exposure/Summer Solar Exposure * 100	
The Rectangular U-Shape	**E_W = 43.83/ 46.79* 100 = 93.67%**
The Radial Form	**E_W = 45.38/ 45.81* 100 = 99.06%**

Table 8.1: Solar Insolation Efficiency of the Radial and Rectangular U-shape

8.2.1.1.3 The Shaded Area Generated by the Outer and the Inner Surfaces Over the Year

The Shaded Area Generated by the Outer and the Inner Surfaces Over the Year		
	The Outer Surfaces	**The Inner Surfaces**
The Rectangular U-Shape	**62.33 %**	**47.25 %**
The Radial Form	**66.09 %**	**39.90 %**

Figure 8.8: The Average Annual Shaded Percentage per Hour for the Outer and the Inner Surfaces

Figure (8.8) shows that outer surfaces in both forms have more annual shaded percentage per hour and the inner parts are less shaded, as they are oriented more toward the south in general. Although outer surfaces of the radial form are more shaded than their counterparts in the rectangular one, the inner surfaces of the rectangular form are more shaded, and with greater extension, than their counterparts in the radial one. Consequently, the main variation between the two forms, with regard to the annual generated shaded area, is caused by the inner surfaces.

	The Outer Surfaces (N)	The Inner Surfaces (S)	The Variation
The Rectangular Form	**62.33%**	**47.25%**	**15.08 %**
The Radial Form	**66.09%**	**39.90%**	**26.19 %**
The Rectangular U-Shape is More Suitable for Bilateral Type of Buildings			

Table 8.2: The Variation Between the Outer and the Inner Surfaces of the Two Forms

As the variation between the outer and the inner surfaces, with regard to the annual generated shaded area, is less in the case of the rectangular U-shape (Table 8.2), this form is more suitable for bilateral buildings. On the other hand, the radial form is more beneficial for unilateral buildings, as its south facade (the inner surfaces) is less shaded than the south facade of the rectangular U-shape over the year.

8.2.1.1.4 The Shaded Area Generated by the Outer and the Inner Surfaces in the Two Seasons

i. The Shaded Area of the Outer Surfaces

	The Average Daily Shaded Percentage per Hour	
	Summer Period	**Winter Period**
The Rectangular U-Shape	**47.14 %**	**70 %**
The Radial Form	**50.49 %**	**80.63 %**

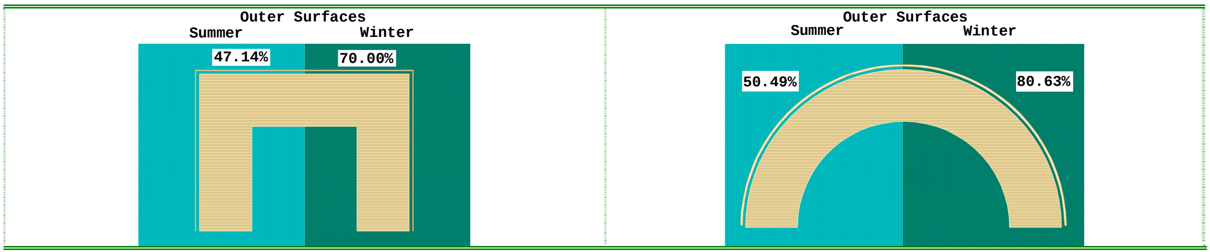


Figure 8.9: The Shaded Area Generated by the Outer Surfaces in the Two Seasons

Comparing the two forms regarding the generated shaded area in the outer surfaces in the two seasons, reveals that the outer surfaces of the rectangular U-shape are less shaded than the outer surfaces of the radial form in both seasons (Figure 8.9). However, the variation between the two forms is more evident during winter. It can also be observed that for the same form the variation between the two seasons, regarding the annual shaded area of the outer surfaces, is greater in the case of the radial form.

E_W = Winter Solar Exposure/Summer Solar Exposure * 100	
The Rectangular form	E_W = 30/ 52.8 6* 100 = 56.75 %
The Radial form	E_W = 19.37/ 49.51* 100 = 39.12 %

Table 8.3: Solar Insolation Efficiency of the Outer Surfaces in the Two Forms

The calculations of insolation efficiency show that Ew for the outer surfaces is relatively low in both cases (Table 8.3). This reflects the fact that the outer surfaces here are more oriented towards the north; however, the efficiency of the outer surfaces of the rectangular form is higher than the efficiency of the outer surfaces in the case of the radial one.

ii. The Shaded Area of the Inner Surfaces

	The Average Daily Shaded Percentage per Hour	
	Summer Period	**Winter Period**
The Rectangular U-Shape	60.78 %	38.88 %
The Radial Form	58.40 %	25.07 %

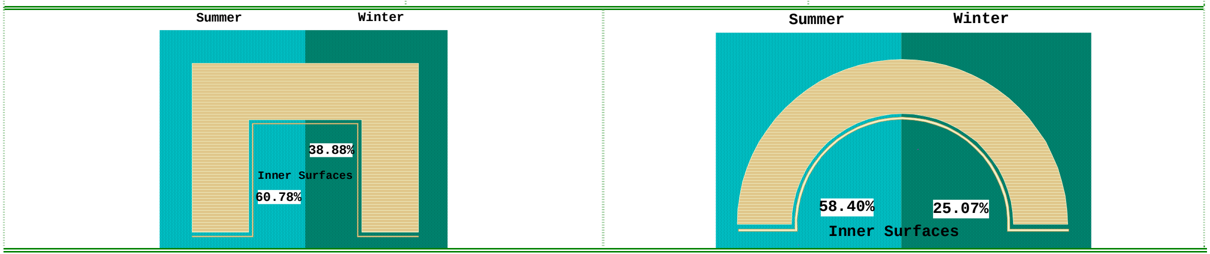


Figure 8.10: The Shaded Area Generated by the Inner Surfaces in the Two Seasons

Studying the shaded area of the inner surfaces in the two forms, it can be observed that these surfaces in the rectangular U-shape have a greater shaded percentage in both seasons; however, the variation between the two forms is bigger in winter (Figure 8.10). Also, it can be observed that the variation between the two seasons for the same form is greater in the case of the radial form.

E_W = Winter Solar Exposure/Summer Solar Exposure * 100	
The Rectangular Form	EW = 61.12/ 39.22* 100 = 155.84 %
The Radial Form	EW = 74.93/ 41.6* 100 = 180.12 %

Table 8.4: Solar Insolation Efficiency of the Inner Surfaces in the Two Forms

It can also be noted that the insulation efficiency of the inner surfaces is relatively high in general (Table 8.4). This reflects the fact that the inner surfaces here are more oriented towards the south, when the insolation in winter is very well presented, as sunrays come almost from the southern positions. However, the efficiency of the inner surfaces of the radial form is higher than the efficiency of the inner surfaces in the case of the rectangular one.

	The Rectangular Form	The Radial Form
The Outer Surfaces (North)	56.75 %	39.12 %
The Inner Surfaces (South)	155.84 %	180.12 %
The Variation	99.09 %	141 %
Average	106.295 %	109.62 %

Table 8.5: The Insolation Efficiency of the Outer and the Inner Surfaces in the Two Forms

The average insolation efficiency of the two groups of surfaces (outer and inner) is slightly higher in the case of the radial from (Table 8.5). However, the insolation efficiency factor here also confirms the suitability of the rectangular form for bilateral buildings, as the variation between the two opposite surfaces of the form is less than the same variation in the radial form. The results confirm similarly the common design concept used by architects to adopt the south facade as the principal one in unilateral buildings, as it has better solar insolation than the north facade. However, the calculations reveal that the radial form is more suitable in unilateral types of building, as it has better insolation efficiency for the south facade. These calculations also give a qualitative value for the variation between the two facades with regard to the efficiency of solar insulation.

The Average Daily Shaded Percentage per Hour	The Outer Surfaces		The Inner Surfaces	
	Summer	Winter	Summer	Winter
The Rectangular U-shape	47.14 %	70 %	60.78 %	38.88 %
The Radial Form	50.49 %	80.63 %	58.40 %	25.07 %

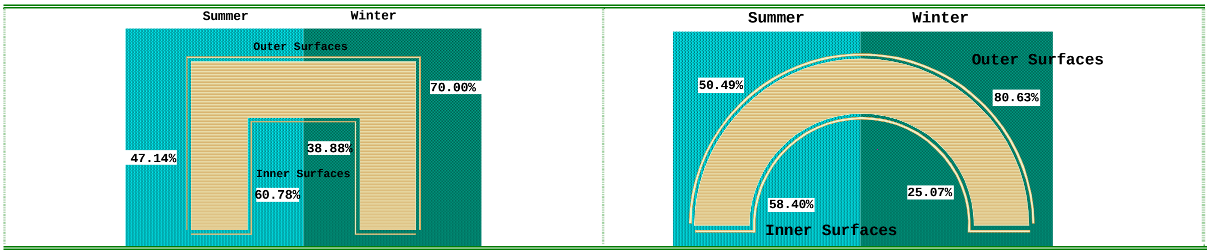


Figure 8.11: The Shaded Area Generated by the Outer and the Inner Surfaces in the Two Seasons

Once the shaded areas generated by the inner and the outer surfaces in the two forms are compared, it can be observed that in summer period the identical sides of both forms receive approximately the same shaded percentage per hour and that the biggest variation always occurs during the winter period (Table 8.6), especially for inner surfaces. Figure 8.11 also shows that in the summer period, the outer surfaces in both forms are better exposed to sunrays than the inner surfaces. On the other hand, the inner surfaces in both forms are better exposed to sunrays, and with higher extensions, in wintertime. By studying these results, it can be concluded that the most significant variation of the generated shaded percentage between the outer and inner surfaces for the same form occurs in the case of the radial form in the winter period (Table 8.6). Also, the biggest variation between the two seasons for the same group of surfaces within the same form takes place in the radial form and especially within its inner surfaces (Figure 8.11). In addition, it can be noted that the biggest shaded percentage occurs in the outer surfaces of the radial form in the winter period and the smallest shaded percentage occurs in the inner surfaces of the radial form, also during winter.

	Summer Period			**Winter Period**		
	The Outer Surfaces	The Inner Surfaces	The Variation	The Outer Surfaces	The Inner Surfaces	The Variation
The Rectangular U-Shape	**47.14 %**	**60.78 %**	**13.64 %**	**70 %**	**38.88 %**	**31.12 %**
The Radial Form	**50.49 %**	**58.40 %**	**7.91 %**	**80.63 %**	**25.07 %**	**55.56 %**
The Variation	**3.35 %**	**2.38 %**		**10.63 %**	**13.81 %**	

Table 8.6: The Variation between the Outer and the Inner Surfaces in the Two Forms

8.2.1.2 The Evaluation of the Shadow Pattern During the Daytime Period

8.2.1.2.1 The Annual Distribution of the Shaded Area in the Two Forms

The annual distribution of the shaded area of the radial form during daytime reveals that the form has a greater amount of shadow in the early morning, late afternoon and in the noon period; it is also more exposed in the middle of the first and second halves of daytime (Figure 8.12). However, the maximum shaded area is reached early in the morning and late in the afternoon. The rectangular form starts to be more exposed gradually in the morning and reaches its maximum exposure at noon. The rectangular U-shape is more shaded than the radial one before and after noon. In the noon period, the radial form is more shaded, but to a lesser extent. Therefore, the rectangular U-shape is more shaded in general. The balanced state, when both forms have the same percentage of shaded area, takes place approximately one hour before and after noon.

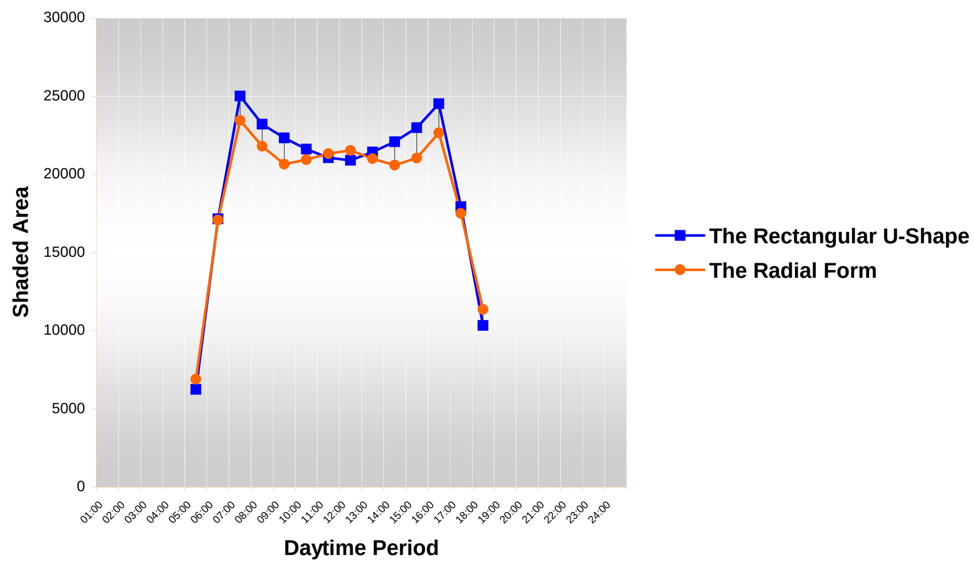
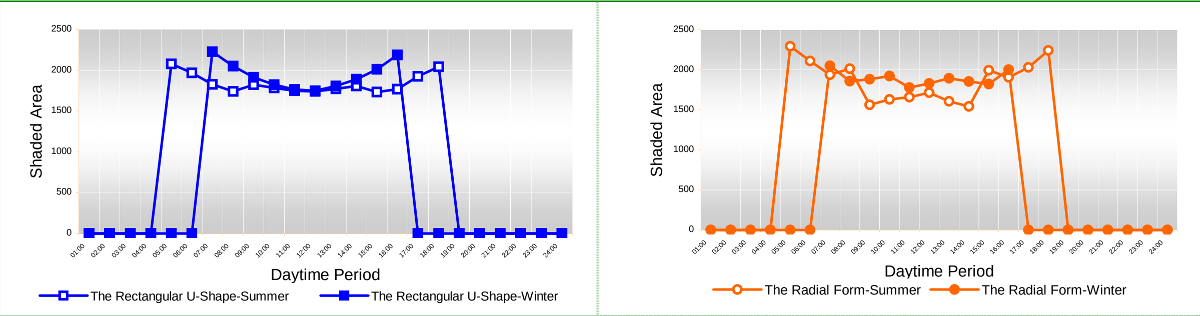


Figure 8.12: The Annual Distribution of the Shaded Area During Daytime

By studying the previous graph, it can be observed that the shaded area generated in the two forms is greater in the morning and afternoon in general. This can be attributed to the increased self-shading effect of the forms during these periods and due to the longer morning and afternoon shadows during the year. In the case of temperate climates, this can reflect the greater need for heating early in the morning and in the late afternoon in the winter period, while the need for cooling will be higher at midday in the summer period.

The small deviation of the graph from being completely symmetrical could be attributed to the fact that SunCast provides the hourly calculations of the shaded area at the middle time of each hour (11:30, 12:30, 13:30 etc.), while the graph tends to be symmetrical around an axis which is consistent with the access of symmetry for the sunpath, i.e. at solar noon (12:00). This is the reference plane for the solar azimuth, which is the vertical plane running north-south through the poles. In addition, this asymmetry can be attributed to the fact that the start and end points of the graph do not exactly match sunrise and sunset.

8.2.1.2.2 The Distribution of the Shaded Area in the Over and Underheated Periods

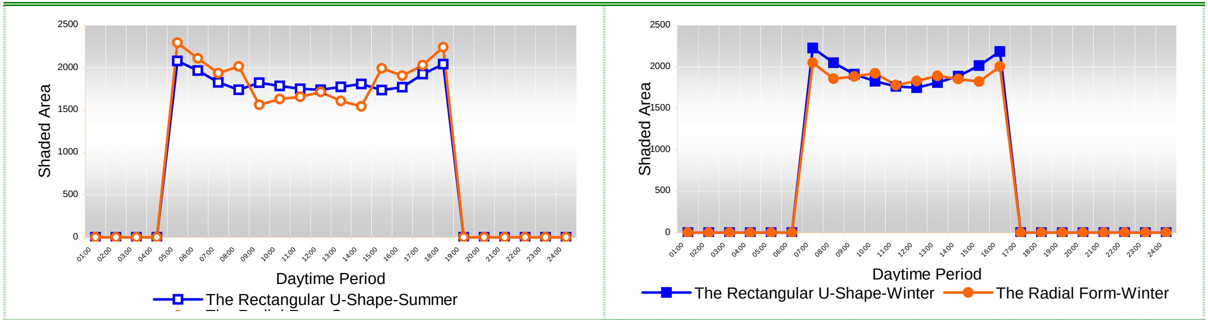


The Rectangular U-Shape	The Radial Form

Figure 8.13: The Distribution of the Shaded Area in the Over and Underheated Periods

In the case of the rectangular U-shape, in both seasons the amount of the shaded area during the sunlit hours reaches a higher level in the morning and afternoon periods and reaches its minimum at noon. However, the maximum shaded percentage is reached during the winter period (Figure 8.13). Increased shadow in these periods can be attributed to the low position of the sun in the sky. This low insolation rate in the early morning and late afternoon also evokes higher demand for heating in winter in temperate climates. The form is better exposed to sunrays in the noon period and this trend is more evident in winter. This minimum shaded area takes place when sunrays are perpendicular to the south facades of the rectangular form and when the sun is positioned high in the sky at midday.

The radial form is more shaded during the sunlit winter days; however, the maximum shaded percentage is reached in the early morning and late afternoon during the summer period. Also, the minimum shaded percentage takes place in summer in the noon period. Higher exposure at midday in summer evokes also a higher demand for cooling during this period in temperate climates.



The Distribution of the Shaded Area in the Overheated Period	The Distribution of the Shaded Area in the Underheated Period

Figure 8.14: The Distribution of the Shaded Area in the Over and Underheated Periods

When comparing the shaded area generated in the forms during daytime in both seasons, it can be observed that the radial form in winter is less shaded in the morning and afternoon, while at the noon period the radial form is more shaded. This trend is reversed during summer (Figure 8.14).

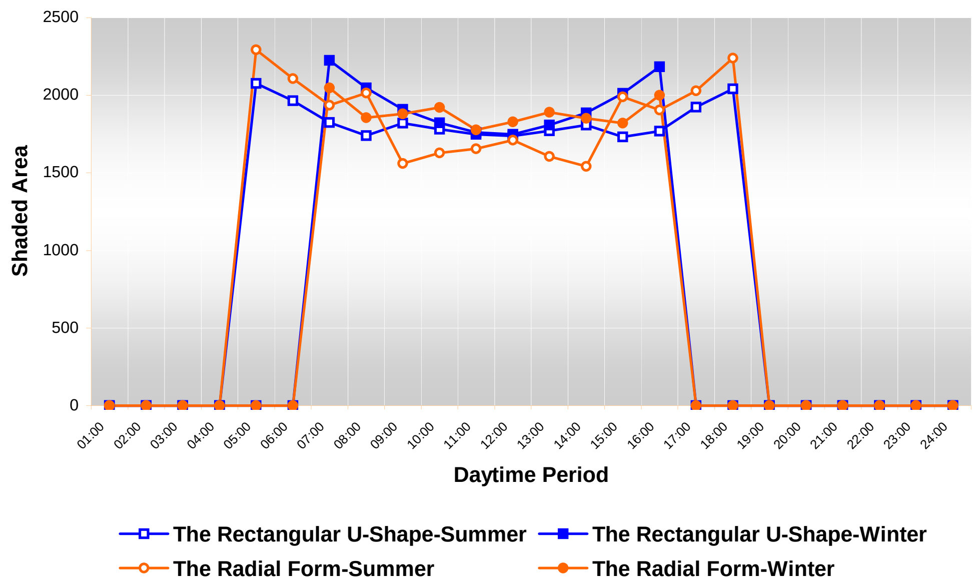


Figure 8.15: The Distribution of the Shaded Area in the Over and Underheated Periods

After studying the above graph (Figure 8.15), it can be noted that the highest shaded percentage occurs in the case of the radial form during the summer period (in the early morning and late afternoon) and the lowest shaded percentage occurs also in the case of the radial form during the summer period (approximately 3 hours before and after noon). Therefore, the most dynamic shadow pattern, where the biggest variation of shadow during daytime takes place, is the shadow pattern generated in the case of the radial form in summer.

8.2.1.2.3 The Distribution of the Shaded Area in the Outer and the Inner Surfaces Over the Whole Year

Outer surfaces in both forms are more shaded during daytime due to their northern orientation, while inner surfaces are more exposed due to their southern orientation in general (Figure 8.16).

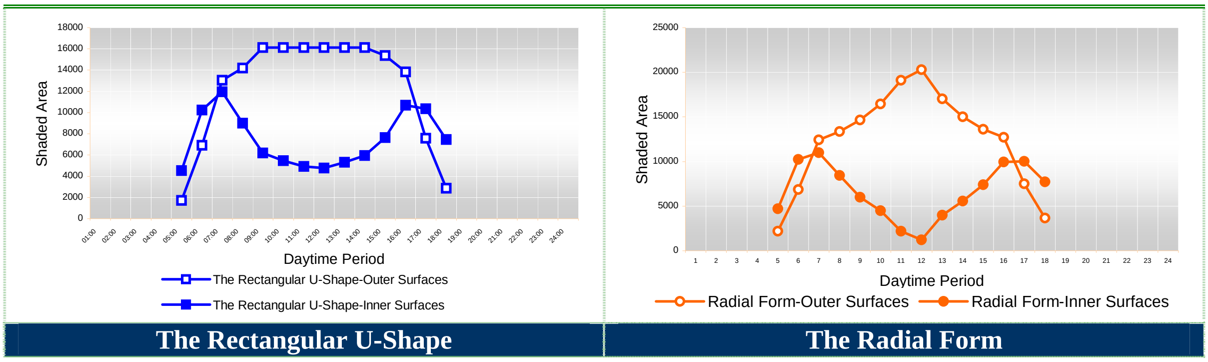


Figure 8.16: The Distribution of the Shaded Area in the Outer and the Inner Surfaces Over the Whole Year

For the two forms, the Balanced State, where the two groups of surfaces (outer and inner) have the same shaded percentage, takes place in the early morning and in the late afternoon. After reaching the state of balance, the outer surfaces continue to generate more shadow until the noon period, while the inner surfaces continue to be more exposed at the same time and the two groups of surfaces are approximately mirrored. While outer surfaces have the highest shaded percentage at the noon period, the inner surfaces have the lowest shaded percentage simultaneously. Therefore, the biggest variation between the two groups of surfaces, with regard to the generated shaded area, takes place at noon. Thus, in bilateral buildings, the morning and afternoon periods are characterised by a more equitable distribution of insolation on the opposite surfaces. Consequently, outer surfaces have to obtain the greatest benefit from sunrays during these periods and designers are recommended to make use of morning and afternoon sunrays when locating living spaces within the outer surfaces of the forms.

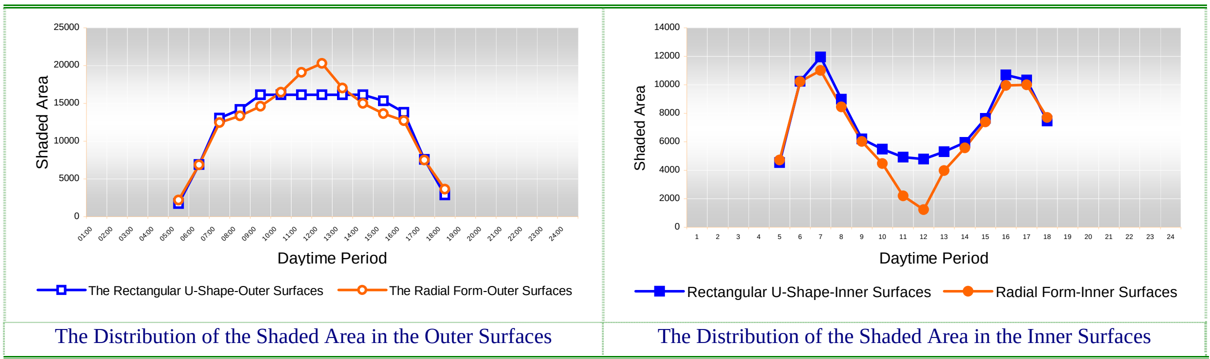


Figure 8.17: The Distribution of the Shaded Area in the Outer and the Inner Surfaces Over the Whole Year

By comparing the distribution of the shaded areas generated in the internal and external surfaces of both forms, it can be observed that inner surfaces in the rectangular U-shape are more shaded than the inner surfaces in the radial form, especially during the noon period

(Figure 8.17). Outer surfaces in the radial form are less shaded in the morning and in the afternoon and more shaded (to a higher extent) during the noon period than the outer surfaces in the rectangular U-shape. Consequently, the biggest variation between the two forms, with regard to the generated shadow on both the inner and outer surfaces, takes place during the noon period.

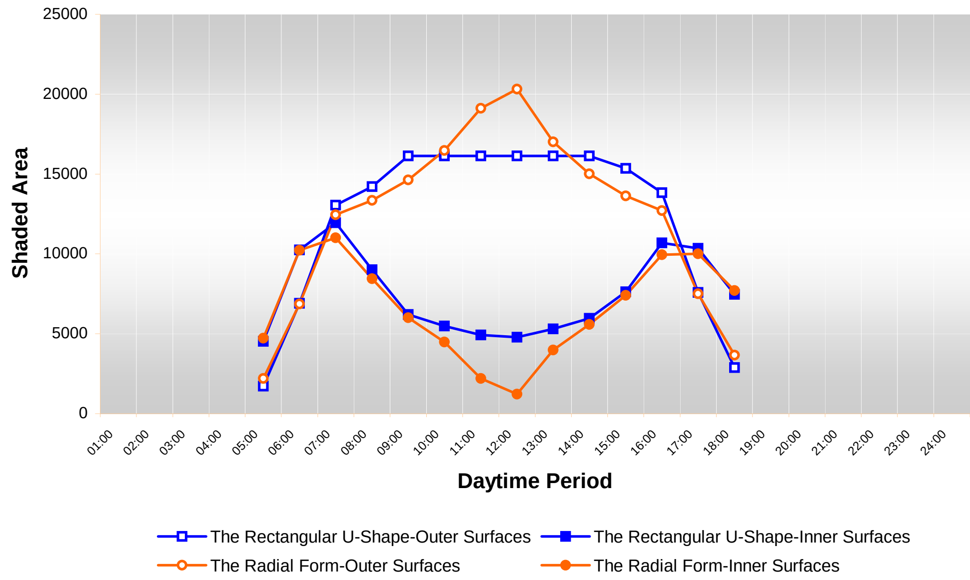


Figure 8.18: The Distribution of the Shaded Area in the Outer and the Inner Surfaces Over the Whole Year

Figure 8.18 shows that the biggest variation between the two forms, with regard to the generated shaded area, always occurs during the noon period. The graph also reveals that the highest shaded percentage takes place in the outer surfaces in the case of the radial form and the lowest shaded percentage takes place within the inner surfaces in the case of the radial form as well. Therefore, the variation between the two groups of surfaces (outer and inner) for the same form reaches its maximum during the noon period in the case of the radial form. Thus, the radial form has a less unbiased distribution of the shaded area in the two opposite surfaces and consequently has less suitability for bilateral buildings when compared with the rectangular U-shape.

1.2.1.2.4 The Distribution of the Shaded Area in the Outer and the Inner Surfaces in the Overheated and the Underheated Periods

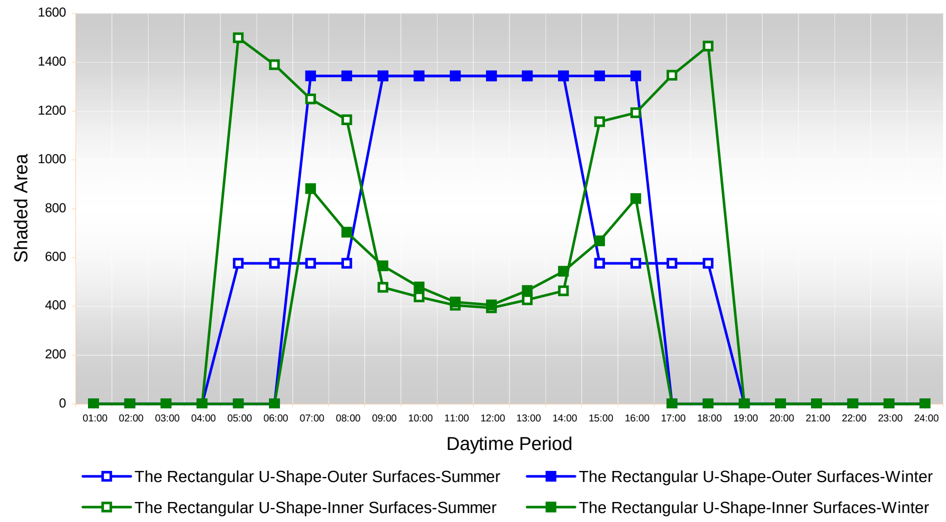


Figure 8.19: The Rectangular U-Shape: The Distribution of the Shaded Area Generated in the Outer and the Inner Surfaces

By studying the distribution of the shaded area generated by the outer and inner surfaces of the rectangular form during daytime in both seasons, it can be observed that the biggest variation between the two groups of surfaces occurs in winter (Figure 8.19). For the same group of surfaces, the main variation between the two seasons takes place in the early morning and in the late afternoon, while these surfaces have approximately the same amount of shaded area in the noon period. The biggest variation between the two groups of surfaces takes place at the noon period for both seasons. The graph also indicates that both the east and west sides of the outer surfaces receive sunrays for half of the day in winter, while the north part of the outer surfaces remains shaded. Thus, in the case of bilateral buildings, the greatest benefit of sunrays in winter is received by the west and east sides.

Figure 8.20 shows that in the radial form the biggest shaded area during daytime takes place in the outer surfaces during the winter period and the lowest shaded percentage takes place in the inner surfaces also in the winter period. The greatest variation between the outer and inner surfaces, with regard to the generated amount of shadow, occurs in winter, especially in the noon period. For the same group of surfaces, the biggest variation between the two seasons takes place in the early morning and in the late afternoon. In both seasons, the biggest variation in the shaded area between the outer and the inner surfaces takes place in the noon period.

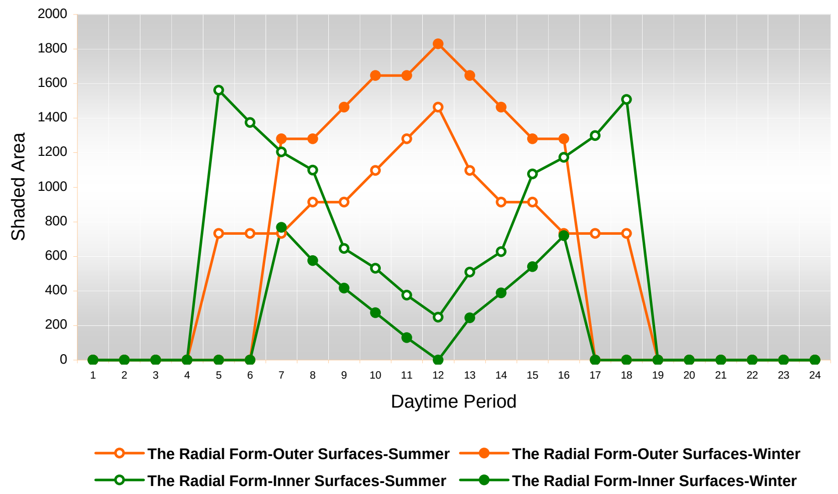


Figure 8.20: The Radial Form: The Distribution of the Shaded Area Generated in the Outer and the Inner Surfaces

The comparison between the outer surfaces in the two forms reveals that, in the summer period, the outer surfaces in the radial form are more shaded in the early morning and late afternoon, while the outer surfaces of the rectangular form are more shaded before and after noon (Figure 8.21). At noon, the outer surfaces of the radial form are more shaded. However, the amount of generated shadow over the daytime period is approximately the same in both cases.

In winter, the outer surfaces of the radial from are more shaded during the whole daytime period and this variation increases with the approach of noon. The biggest shaded area during the daytime takes place in the outer surfaces of the radial form in the winter period. Thus, in the case of bilateral buildings, the radial form will be less advantageous, as the outer surfaces will receive fewer sunrays in winter when compared to the outer surfaces in the rectangular U-shape.

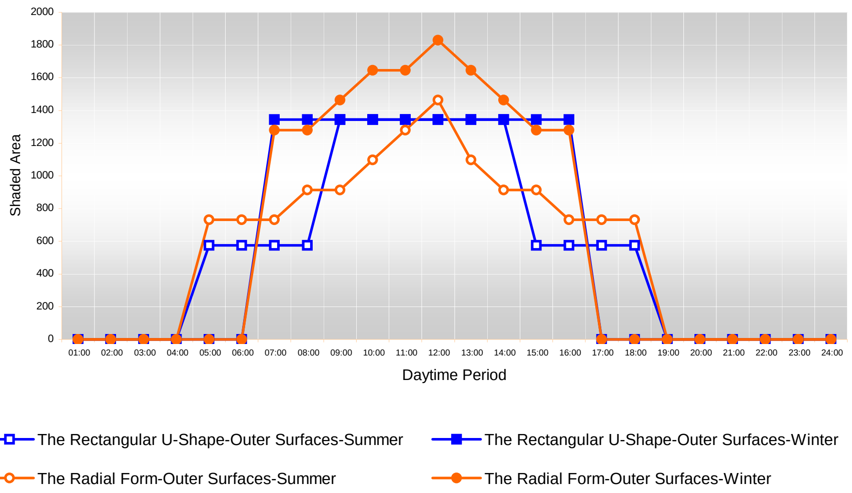


Figure 8.21: The Distribution of the Shaded Area Generated in the Outer Surfaces

In the summer period, the inner surfaces in both forms generate approximately the same amount of shadow and the distribution of the shaded area during the daytime period in both forms is approximately the same (Figure 8.22). This amount is bigger in both forms when it is compared to the shadow generated in the winter period. The biggest variation between the two forms, with regard to the amount of generated shadow, takes place in the winter period. This variation starts in the morning and then tends gradually to increase, reaching its maximum at noon. This greater exposure of the inner surfaces of the radial form in winter can be beneficial in the case of unilateral buildings where the south-oriented surfaces usually constitute the principal facade.

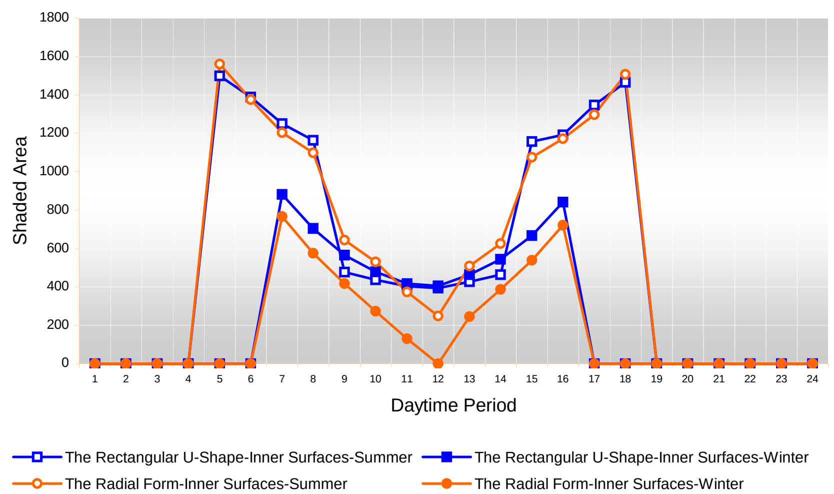


Figure 8.22: The Distribution of the Shaded Area Generated in the Inner Surfaces

The biggest shaded percentage during daytime takes place in the outer surfaces of the radial form in wintertime at noon, when the outer surfaces are completely shaded (Figure 8.23). The lowest shaded percentage during daytime takes place in the inner surfaces of the radial form in wintertime at noon as well, when the inner surfaces are completely exposed. Hence, the radial form has greater variation between the two opposite surfaces, which lessens its suitability for bilateral buildings compared to the rectangular U-shape.

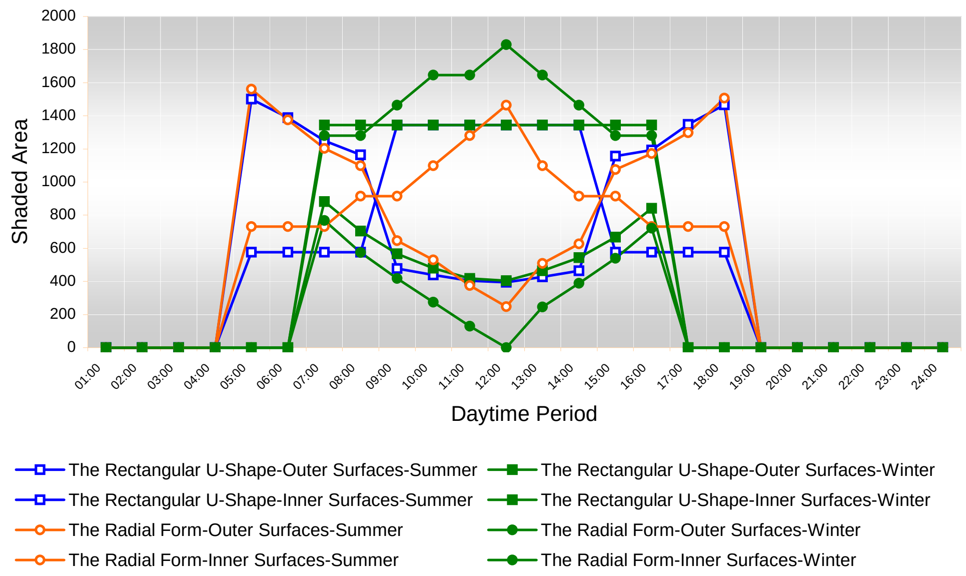


Figure 8.23: The Distribution of the Shaded Area Generated in the Outer and the Inner Surfaces

The trend revealed by these graphs is that the shaded area in the two seasons for both forms tends to increase with the approach to the noon period in the case of the outer surfaces, while the shaded area tends to decrease with proximity to the noon period in the case of the inner surfaces. This is due to the fact that the outer surfaces are more oriented towards the north, while the inner surfaces are more oriented toward the south. The maximum exposure of the inner surfaces takes place in the noon period when sunrays are perpendicular to the centre of the curve. At the same time, the outer surfaces have their maximum shaded area.

To conclude, it seems clear that the critical period, where the maximum variation between the two groups of surfaces (outer and inner) takes place, is the noon period. This variation is more emphasised in the case of the radial form and especially in the winter period when the outer surfaces are completely shaded and the inner surfaces are completely exposed. In this case, the most exposed parts of the form are the parts with more proximity to the centre of the concave facade and the most shaded ones are the parts with more proximity to the centre of the convex facade. So, in the case of unilateral buildings, where the south facade is the principal one, locating the main living area close to the centre of the concave facade is more advantageous, as this will receive as many sunrays as possible in winter. In the case of bilateral buildings, it is better to separate the main living spaces in the outer surfaces as much as possible from the centre of the convex facade.

8.2.2 North-facing Patterns

8.2.2.1 The Annual Shaded Area Generated by the Two Forms

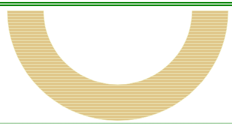
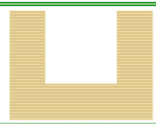
The Average Annual Shaded Percentage per Hour during Daytime			
The Radial Form	54.89 %	The Rectangular U-Shape	55.76 %
The Radial Form: Less Shaded Area		The Rectangular U-Shape: More Shaded Area	
			
54.89 %		55.76 %	
More Suitable for Heating Requirements		More Suitable for Cooling Requirements	

Figure 8.24: North-facing Patterns: The Average Annual Shaded Area Generated by the Two Forms

The calculations of the annual shaded area of the north-facing forms demonstrate that the rectangular U-shape produces more shadow than the radial one (Figure 8.24). This reflects the suitability of the rectangular U-shape for cooling requirements and the higher suitability of the radial form for heating requirements.

8.2.3 East-facing Patterns

8.2.3.1 The Average Annual Shaded Area Generated by the Two Forms

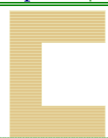
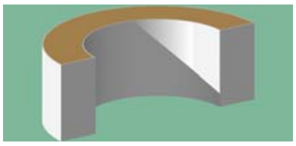
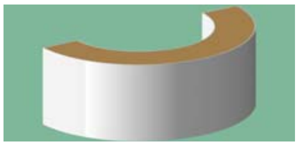
The Average Annual Shaded Percentage per Hour during Daytime			
The Radial Form	52.18 %	The Rectangular U-Shape	53.96 %
			
52.18 %		53.96 %	
More Suitable for Heating Requirements		More Suitable for Cooling Requirements	

Figure 8.25: East-facing Patterns: The Average Annual Shaded Area Generated by the Two Forms

Figure 8.25 reveals that the annual shaded area is bigger in the case of the east-facing rectangular U-shape and smaller in the case of the east-facing radial form. Thus, it can be derived that the rectangular U-shape is more suitable for cooling requirements, while the radial form is more suitable for heating requirements.

8.2.4 A Comparison between Radial Forms with Different Orientations
8.2.4.1 A Comparison between the Radial Forms Oriented South and North

8.2.4.1.1 The Annual Shaded Area Generated by the Two Radial Forms

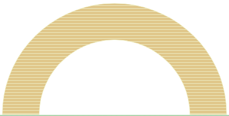
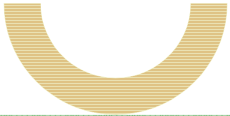
The Average Annual Shaded Percentage per Hour during Daytime			
The South-facing Radial	53.82%	The North-facing Radial	54.89%
			
53.82%		54.89%	
More Suitable for Heating Requirements		More Suitable for Cooling Requirements	

Figure 8.26: The Average Annual Shaded Area Generated by the Two Radial Forms

By comparing the two radial forms facing the north and the south, it can be observed that the annual shaded area is bigger in the case of the north-facing radial form and smaller in the case of the south-facing radial form (Figure 8.26). Therefore, it can be derived that the north-oriented radial form is more suitable for cooling requirements, while the other form is more adequate for heating requirements.

8.2.4.1.2 The Shaded Area Generated by the Two Radial Forms in the Two Seasons

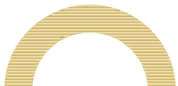
The Average Daily Shaded Percentage per Hour in the Two Seasons			
		Summer Period	**Winter Period**
The North-facing Radial Form		**52.54 %**	**54.74 %**
The South-facing Radial Form		**54.19%**	**54.62%**
			
52.54 %	54.19 %	54.74 %	54.62 %
The Shaded Area in Summer		The Shaded Area in Winter	
The South-facing Radial Form is More Suitable in Temperate Climates			

Figure 8.27: The Shaded Area of the Two Radial Forms in Over and Underheated Periods

When comparing the two radial forms oriented towards the south and the north, it can be stated that the south-facing radial form is more suitable in a temperate climate, as it has the largest amount of shaded area in summer and the least amount of shaded area in winter (Figure 8.27). The insolation efficiency of a building form can be measured by comparing the summer solar exposure with the winter solar exposure. For qualitative indicators to compare the performance of both forms, the efficiency factor E_W was computed in Table 8.7.

EW = Winter Solar Exposure/Summer Solar Exposure * 100	
The South-facing Radial Form	**EW = 45.38/ 45.81* 100 = 99.06 %**
The North-facing Radial Form	**EW = 45.26/ 47.46* 100 = 95.36 %**

Table 8.7: The Insolation Efficiency of the Two Radial Forms

In the case of unilateral buildings, and by studying the shaded area generated in the outer and inner surfaces of the south-facing radial form, it becomes more evident that the south-facing curve is more advantageous in a temperate climate. This is because the inner surfaces in this curve, which usually represent the main principal facade, are less shaded in winter when receiving sunrays is welcomed (Figure 8.28). In this case, sunrays come mainly from the southern direction, perpendicular to the concave facade, and their impact are maximal with the south facade remaining most of the daytime exposed to the sun. In addition, the curvilinear form enhances the maximum concentration of reflected radiation and the curved spaces absorb and focus solar heat, allowing occupants to utilize the outdoor living space during the cold winter. Also, the inner surfaces of the curve facing south are more shaded than the outer surfaces in summer when avoiding sunrays is desirable. In this case, the main south facade will be more shaded and will contribute to the cooling requirements of the open space, also encouraging the occupants to carry out some living activities in the outdoor environment.

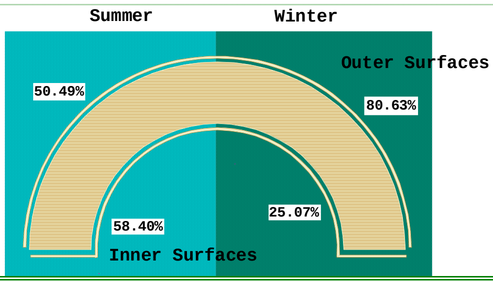


Figure 8.28: The South-facing Radial Form: The Shaded Area Generated in the Two Seasons

8.2.4.1.3 The Shaded Area Generated by the Outer and the Inner Surfaces Over the Whole Year

By reviewing results of the shaded area in the two radial forms, it can be seen that the biggest shaded area is generated in the inner surfaces in the north-oriented form, and the least shaded area is produced in the outer surfaces of the same form (Figure 8.29). Consequently, it can be stated that the south-facing curve is more suitable for bilateral buildings, as it has the least variation between the two opposite facades with regard to the created shaded area.

The Average Annual Shaded Percentage per Hour for the Outer and the Inner Surfaces			
	The Outer Surfaces	**The Inner Surfaces**	**The Variation**
The South-facing Radial Form	**66.09 %**	**39.89 %**	**26.2 %**
The North-facing Radial Form	**33.81 %**	**78.83 %**	**45.02 %**

54.89%	53.82%

The South-Facing Radial Form is More Suitable for Bilateral Types of Building

Figure 8.29: The Shaded Area Generated by the Outer and the Inner Surfaces Over the Whole Year

8.2.4.1.4 The Shaded Area Generated by the Outer and the Inner Surfaces in the Two Seasons

Comparing the shaded area of the outer and inner surfaces of the radial forms in both seasons reveals that the variation between the two opposite facades is higher in general for both forms in winter and the variation between the two opposite facades in both forms is approximately the same in the summer period (Figure 8.30). However, the variation between the two opposite facades in winter is less in the case of the south-oriented form. In addition, it can be noted that the biggest shaded area is produced by the inner surfaces of the north-oriented curve in the winter period and the least shaded area takes place in the outer surfaces of the same form also in the winter period. Thus, the north-oriented curve is less beneficial in bilateral buildings, as greater variation takes place in winter when having more exposure to the north surfaces is of greater importance.

The Average Shaded Percentage per Hour for the Outer and the Inner Surfaces						
	The Outer Surfaces		**The Inner Surfaces**		**The Variation**	
	Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
The South-facing Radial Form	**50.49 %**	**80.63 %**	**58.40 %**	**25.07 %**	**7.91 %**	**55.56 %**
The North-facing Radial Form	**49.06 %**	**18.91 %**	**56.50 %**	**95.45 %**	**7.44 %**	**76.54 %**

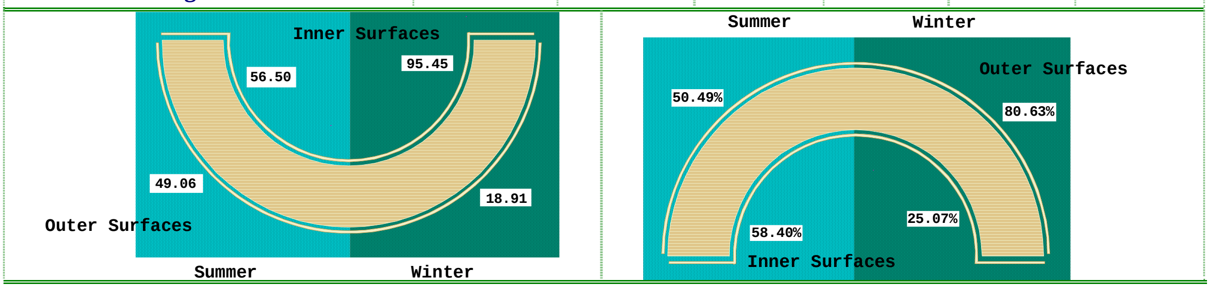


Figure 8.30: The Shaded Area Generated by the Outer and the Inner Surfaces in the Two Seasons

EW = Winter Solar Exposure/Summer Solar Exposure * 100				
The South-facing Radial Form	**The Outer Surfaces-Exposure**		**The Inner Surfaces-Exposure**	
	Summer	**Winter**	**Summer**	**Winter Period**
	49.51 %	**19.37 %**	**41.6 %**	**74.93 %**
Ew	**39.12 %**		**180.12 %**	
The North-facing Radial Form	**The Outer Surfaces-Exposure**		**The Inner Surfaces-Exposure**	
	Summer	**Winter**	**Summer**	**Winter Period**
	50.94 %	**81.09 %**	**43.5 %**	**4.55 %**
Ew	**159.19 %**		**10.46 %**	
	Outer Surfaces	**Inner Surfaces**	**The Variation**	**The Average**
The South-facing Radial Form	**39.12 %**	**180.12 %**	**141 %**	**105.157 %**
The North-facing Radial Form	**159.19 %**	**10.46 %**	**148.73 %**	**89.56 %**

Table 8.8: The Solar Insulation Efficiency of the Outer and Inner Surfaces in the Two Forms

The calculation of Ew of the inner and outer surfaces in both forms confirms the higher suitability of the south-facing radial form in temperate climates and for bilateral buildings, because it has a higher average of insolation efficiency in general and a lower variation between the outer and inner surfaces with regard to insolation efficiency. The best insolation efficiency is achieved in the inner surfaces in the case of the south-facing radial form and the least insolation efficiency is generated in the inner surfaces in the case of the north-facing radial from (Table 8.8).

In both forms, the surfaces which are oriented more towards the south (the inner surfaces of the south-facing form and the outer surfaces of the north-facing form) have better insolation efficiency than surfaces which are oriented more towards the north (the outer surfaces of the south-facing form and the inner surfaces of the north-facing form). In unilateral buildings, where the south facade is the principal facade, the south-facing form can be more suitable, as the insolation efficiency of the south facade (the inner surfaces) is higher than the insolation efficiency of the south facade (the outer surfaces) of the north-facing form.

8.2.4.2 The Annual Shaded Area Generated by Radial Forms with Different Orientations

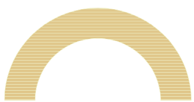
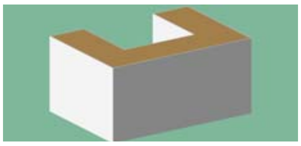
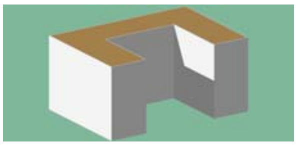
		
54.89 %	53.82 %	52.18 %
More Suitable for Cooling Requirements		More Suitable for Heating Requirements

Figure 8.31: The Average Annual Shaded Area Generated by Radial Forms with Different Orientations

By studying the previous three radial forms oriented south, north and east, it becomes evident that the radial form with its open space oriented towards the east has the least amount of annual generated shaded area (Figure 8.31). This is because the radial form in this orientation has fewer parts oriented to the north and the vast majority of its sides are more oriented towards the east and west. The radial form in this position has also the least amount of self-shading, as this effect in this case occurs during the noon period when the sun is high in the sky. The rapid changing in the sun's position at noon also shortens this period and consequently minimises the effect of self-shading. Hence, the east-facing radial form is more suitable for heating requirements, while the north-facing form is more suitable for cooling requirements as it generates the highest amount of shadow.

8.2.5 A Comparison between Rectangular U-shapes Oriented South and North

8.2.5.1 The Annual Shaded Area Generated by the Two Rectangular U-shapes

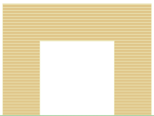
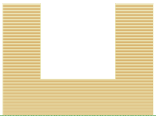
	
55.62%	55.76%
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure 8.32: The Average Annual Shaded Area Generated by the Two Rectangular U-shapes

By comparing the two rectangular U-shapes, oriented south and north, it can be observed that the annual shaded area of the north-facing rectangular U-shape is slightly greater than the annual shaded area of the south-facing rectangular U-shape (Figure 8.32). Therefore, it can be derived that the north-oriented rectangular U-shape is more suitable for cooling requirements, while the south-oriented rectangular U-shape is more suitable for heating requirements.

8.2.5.2 The Annual Shaded Area Generated by Rectangular U-shapes with Different Orientations

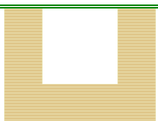
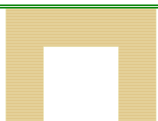
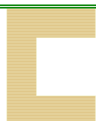
		
55.76%	55.62%	53.96%
More Suitable for Cooling Requirements		More Suitable for Heating Requirements

Figure 8.33: The Shaded Area Generated by Rectangular U-shapes with Different Orientations

When studying the annual shaded area of the three rectangular U-shapes (oriented south, north and east), it becomes clear that the east-facing rectangular U-shape has the least amount of shaded area and is therefore preferable for heating requirements (Figure 8.33). On the other hand, the north-facing rectangular U-shape is preferable for cooling requirements as it generates the most amount of shaded area over the year.

8.2.6 A Comparison Between Radial forms and Rectangular U-Shapes with Different Orientations

8.2.6.1 A Comparison between the Annual Shaded Area Generated by the Radial Forms and the Rectangular U-shapes

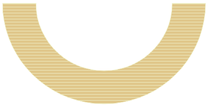
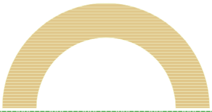
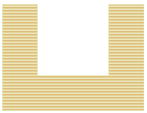
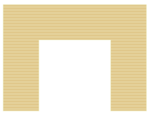
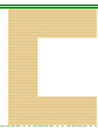
	1.07 %		1.64 %	
54.89 %		53.82 %		52.18 %
0.87 %		1.8 %		1.78 %
	0.14 %		1.66 %	
55.76 %		55.62 %		53.96 %
More Suitable for Cooling Requirements			More Suitable for Heating Requirements	

Figure 8.34: The Shaded Area Generated by the Radial Forms and the Rectangular U-shapes

By studying the resulting calculations of the annual shaded areas of U-shapes and radial forms in the three different orientations, it becomes very obvious that in all identical orientations, the rectangular U-shape is always more shaded than the radial one (Figure 8.34). In the two patterns, forms oriented towards the north generate more shadow than other forms, while the forms oriented towards the east generate the least amount of shadow.

It can also be noted that the variation between the two radial forms oriented south and north (1.07%) is greater than the variation between the identical forms in the rectangular pattern (0.14%). So, the orientation of the open space, north or south, in the case of the rectangular U-shape does not make a major difference in the amount of shaded area generated by the form. The least amount of shaded area is generated by the radial form oriented east (52.18%), while the biggest shaded area is generated by the north-facing rectangular U-shape (55.76%). Thus, the east-facing radial form is the most preferable form for heating requirements, while the north-facing rectangular U-shape is the most preferable form for cooling requirements. In Palestine, the east-facing radial form could be more suitable in the mountain area, while the north-facing rectangular U-shapes could be more advantageous in the coastal plain.

8.2.6.2 A Comparison between the Shaded Area Generated by the Radial Forms and the Rectangular U-shapes in the Two Seasons

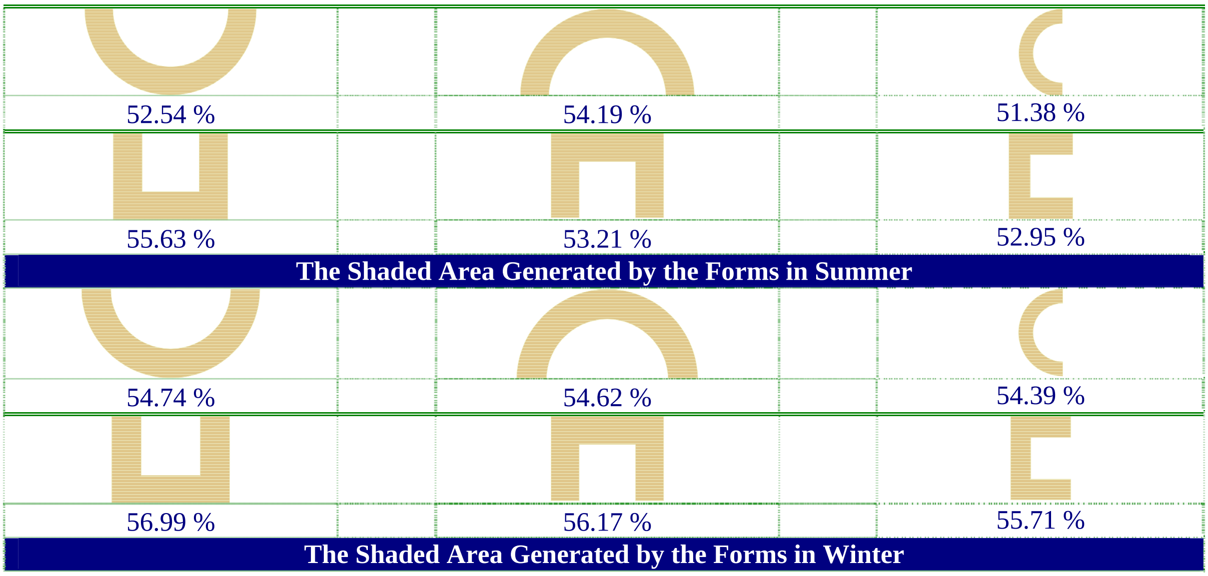


Figure 8.35: The Shaded Area Generated by the Forms in the Two Seasons

The comparison between the radial forms and the rectangular U-shapes (oriented south, north and east) reveals that in both seasons, the least amount of shaded area is generated by the east-facing radial form, while the largest amount of shaded area is generated by the north-facing rectangular U-shape (Figure 8.35). Thus, the east-facing radial form is beneficial for heating requirements during winter, while the north-facing rectangular U-shape is more suitable for meeting cooling needs in summer (Figure 8.36).

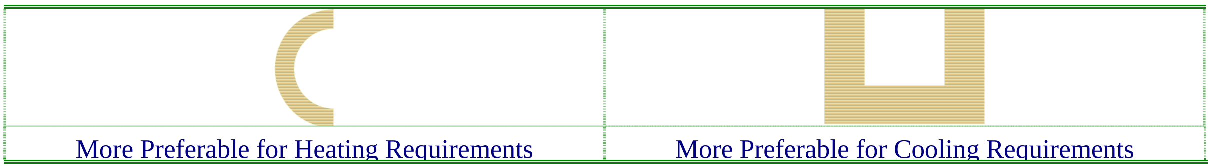


Figure 8.36: The East-Facing Radial Form and the North-Facing Rectangular U-shape

For qualitative indicators to compare the relative performance of both forms in temperate climates, where receiving more sunrays in winter is welcomed and avoiding summer heat is preferable, the efficiency factor E_W can be utilized. The insulation efficiency of a building form can be measured by comparing the summer solar exposure with the winter solar exposure.

E_W = Winter Solar Exposure/Summer Solar Exposure * 100	
The South-facing Radial Form	**Ew = 45.38/45.81* 100 = 99.06 %**
The North-facing Radial Form	**Ew = 45.26/47.46* 100 = 95.36 %**
The East-facing Radial Form	**Ew = 45.61/48.62* 100 = 93.81 %**
The South-facing Rectangular U-shape	**Ew = 43.83/46.79* 100 = 93.67 %**
The North-facing Rectangular U-shape	**Ew = 43.01/44.37 * 100 = 96.93 %**
The East-facing Rectangular U-shape	**E_W = 44.29/47.05 * 100 = 94.13 %**

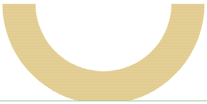
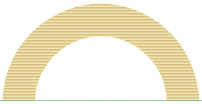
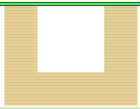
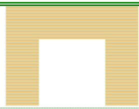
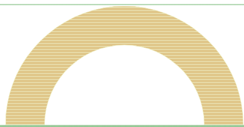
				
95.36 %		99.06 %		93.81 %
				
96.93 %		93.67 %		94.13 %
The south-facing radial form has the best insolation efficiency, while the south-facing U-shape has the lowest insolation efficiency				

Figure 8.37: The Efficiency Factors (EW) for the Radial Forms and the Rectangular U-shapes

As shown in Figure 8.37, the results of the Ew measurements confirm that the south-oriented radial form is more suitable in Palestine and other temperate climates, as the form has higher insolation efficiency (Figure 8.38).



99.06 %

The South-Facing Radial Form has the Best Insulation Efficiency

Figure 8.38: The South-facing Radial Form is More Suitable in Temperate Climates

8.3 Apache Heat Loss and Heat Gain: A Comparison between the Radial Form and the U-shape

The surfaces of buildings exposed to direct solar radiation, not only affect the surrounding environment, but also affect the thermal comfort inside the buildings themselves. The shadow pattern varies from one form to another and calculating the shaded area means that the average direct solar radiation received by forms is indirectly examined (surfaces which are not shaded are exposed). The investigation of inside air temperatures in this simulation aims to establish the influence of urban geometry and building orientation on the indoor environment of the previously mentioned urban patterns. In addition, the thermal evaluation provides further clarification for the relations between the shadow pattern generated by the urban form and its impact on the thermal performance of the form.

APACHE (Applications Program for Air-Conditioning and Heating Engineers), a program within the IES (Integrated Environmental Solutions) products, was used to conduct this simulation. APACHE is a program for analysing thermal performance and heat gains and losses (Appendix B2).

8.3.1 South-facing Forms
8.3.1.1 Heat Gain

Heat Gain calculates cooling loads and free-floating temperatures. The method calculates heat gains and losses by conduction, infiltration and mechanical ventilation. The program makes allowance for casual and solar gains. The effects of external solar shading, as calculated by SunCast, are incorporated. The main weather file data used in the simulation are listed below (Table 8.9).

Location:	Jerusalem	Longitude:	35.22° E
Latitude:	31.78° N	Ext Winter Design Temp:	0.0°C
Ht. above sea level:	757.0 metres	Wind Exposure	Normal
Ground reflectance	0.20		
Maximum Temperature Levels:			
Dry-Bulb	34.40°C	Wet-Bulb	24.90°C

Table 8.9: The Main Weather File Data Used in the Simulation

8.3.1.2 Inside Air Temperature

The Inside Air Temperature is defined as the average temperature of the indoor environment air in °C.

	Inside Air Temperature		The Shaded Area	
The South-facing Forms	**The U-shape**	**The Radial Form**	**The U-shape**	**The Radial Form**
The Average Annual Inside Air Temperature	21.66 °C	21.68 °C	55.62 %	53.82 %

Table 8.10: The Average Annual Inside Air Temperature of the Two Forms

An evaluation of the inside air temperature in both forms (Table 8.10) reveals that the average annual inside air temperature is slightly greater in the radial form. This indicates that the radial form collects more heat gains than the U-shape. This can be attributed to the greater exposure of the radial form to sunrays (Figure 8.39).

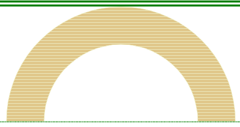
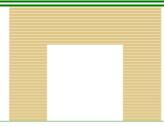
	
53.82%	55.62%
The Radial Form: Less shaded area	The Rectangular U-shape: More shaded area
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure 8.39: The Average Annual Shaded Area Generated by the Two Forms

8.3.1.3 Mean Surface Temperature

The Mean Surface Temperature is the average surface temperature of building's internal walls in °C.

	Mean Surface Temperature		The Shaded Area	
South-facing Forms	**The U-shape**	**The Radial Form**	**The U-shape**	**The Radial Form**
The Average Annual Mean Surface Temperature	21.35 °C	21.37 °C	55.62 %	53.82 %

Table 8.11: The Average Annual Mean Surface Temperature of the Two Forms

By studying the measures of the mean surface temperature in both forms (Table 8.11), it can be noted that the average annual mean surface temperature of the radial form is slightly larger. It becomes evident that the greater exposure of the radial form to sunrays enables the form to gain more heat than the U-shape.

8.3.1.4 Comfort Temperature

The Comfort Temperature is the average building comfort temperature in °C. It is calculated as a weighted average of the air and mean surface temperatures.

	Comfort Temperature		The Shaded Area	
The South-facing Forms	**The U-shape**	**The Radial Form**	**The U-shape**	**The Radial Form**
The Average Annual Comfort Temperature	21.51 °C	21.53 °C	55.62 %	53.82 %

Table 8.12: The Average Annual Comfort Temperature of the Two Forms

The table (8.12) reveals that the average annual comfort temperature is bigger in the case of the radial form. The increased heat gain of the radial form refers to the greater exposure of the form to sunrays.

8.3.1.5 Conduction

Conduction Heat Gain is the sum of gains from the construction (walls, partitions, ceilings, floors etc.) into the building. The data include storage from the fabric.

	Conduction (Watts)			The Shaded Area		
	The U-shape	**The Radial Form**	**Variation**	**The U-shape**	**The Radial Form**	**Variation**
The South-facing Forms	1426848	1470122		55.62 %	53.82 %	1.80 %
	97.06 %	100 %	2.94 %			

Table 8.13: Conduction Heat Gain in the Two Forms

The annual sum of gains from the conduction through walls into the indoor environment is bigger in the case of the radial form (Table 8.13). This can be attributed to the greater exposure of the radial surfaces to sunrays.

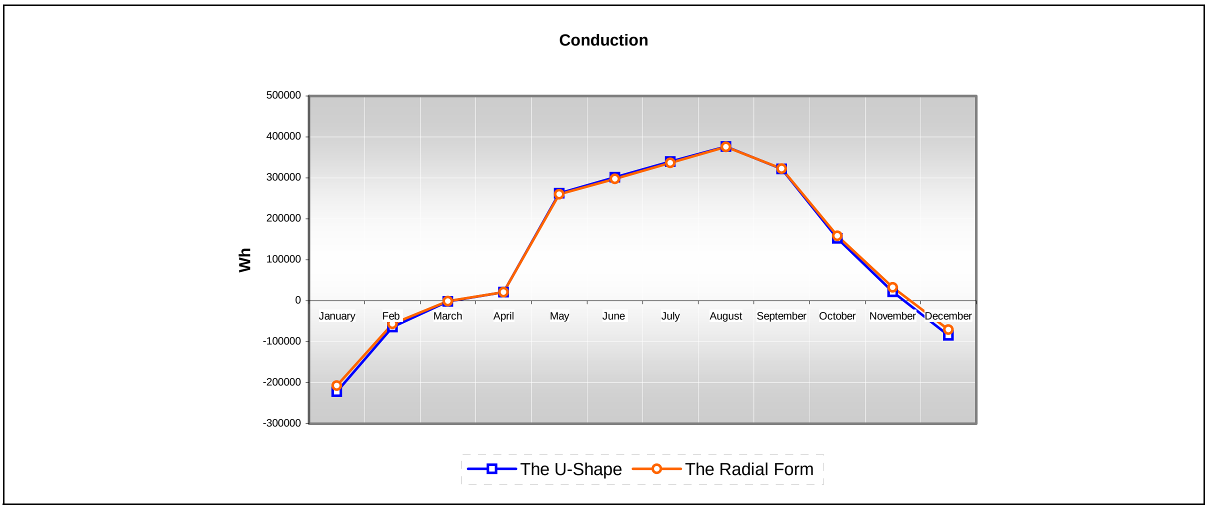


Figure 8.40: The Monthly Gains Distribution of the Two Forms

The graph (Figure 8.40), which illustrates the monthly gains distribution for the whole form, reveals the significant contribution of the summer period towards the conduction heat gained through walls. As regard the conduction heat gains, it can be noted that the radial form has fewer gains in summer than the U-shape (when the radial form is less exposed). The U-shape in summer has less shaded area than the radial form and therefore has greater conduction heat gains (Table 8.14).

	The Shaded Area			Conduction Heat Gains		
	The U-shape	**The Radial Form**	**Variation**	**The U-shape**	**The Radial Form**	**Variation**
Summer	53.21%	54.19%	0.98%	301720 (100 %)	297607 (98.64 %)	4113 (1.36 %)
Winter	56.17%	54.62%	1.55%	-84658 (-100 %)	-70370 (-83.12 %)	-14288 (16.88 %)

Table 8.14: Conduction Heat Gains (Watts) and the Shaded Area in the Two Seasons in the Two Forms

In the winter period, the radial form has less shaded area than the U-shape and therefore it has less conduction heat losses (Figure 8.41). However, this variation in winter, with regard to the shaded area, is of a greater extent than the variation in summer time. This makes the radial form less shaded than the U-shape in general and consequently enables it to collect more conduction heat gains over the year. The greatest variation between the two forms, with regard to both the generated shaded area and the conduction heat gains, occurs in wintertime. The greatest amount of shadow in the U-shape in wintertime is reflected in the greater amount of heat losses. Thus, by reviewing these results, it becomes evident that the increase of the exposed area of the form results in maximising heat gains and vice versa. It also becomes clear that winter is the season which provides the most significant variation between the two forms with regard to both the shaded area and conduction heat gains.

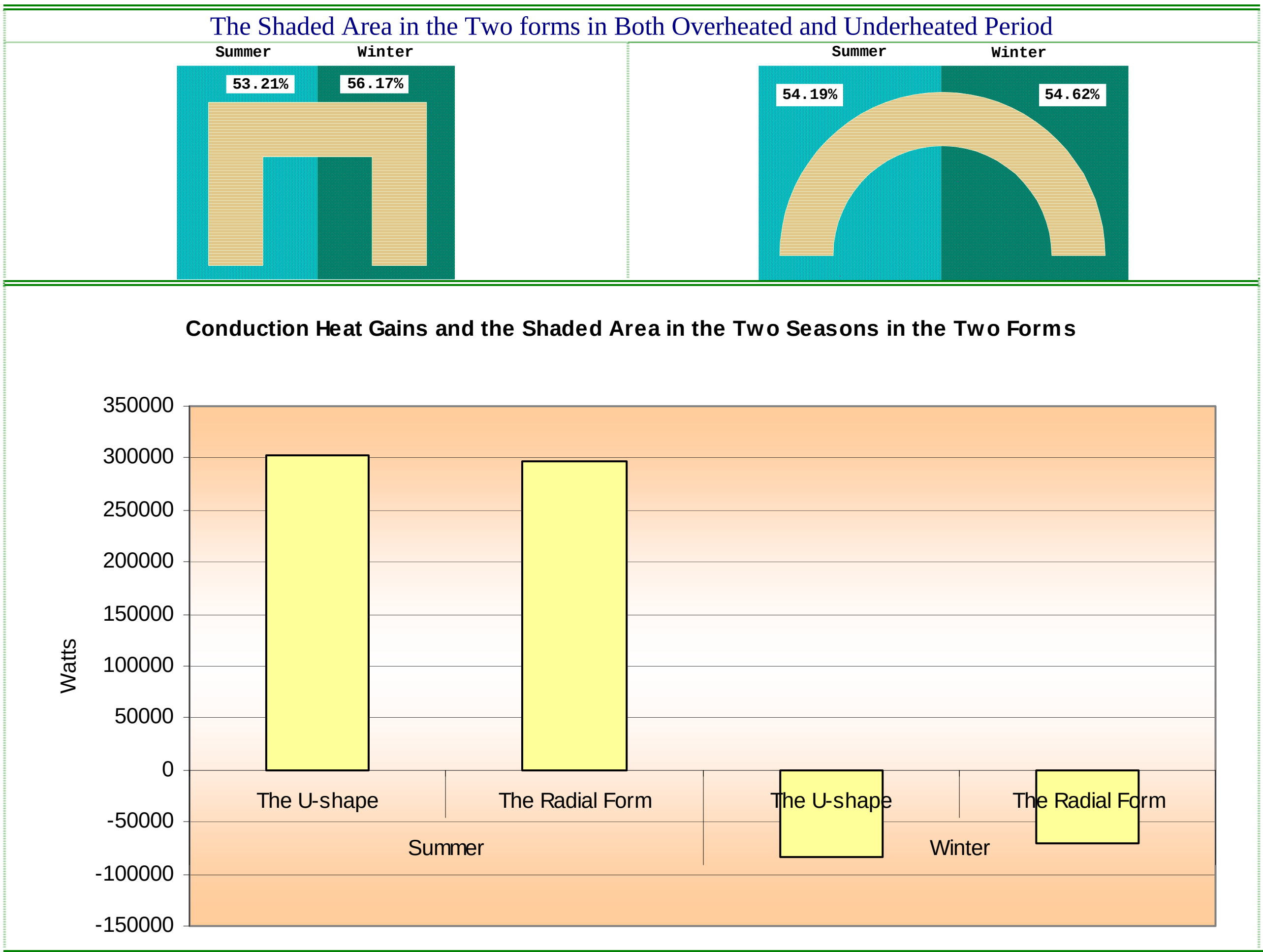


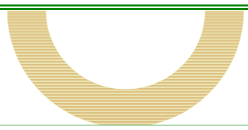
Figure 8.41: The Average Daily Shaded Area and the Conduction Heat Gains in Both Seasons for the Two Forms

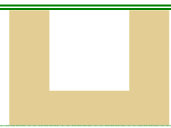
8.3.2 The North-facing Forms
8.3.2.1 Inside Air Temperature

	Inside Air Temperature		The Shaded Area	
The North-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	21.66	21.68	55.76 %	54.89 %

Table 8.15: Inside Air Temperature and the Shaded Area of the Two Forms

The evaluation of the inside air temperature in the north-facing forms reveals that the average annual inside air temperature is slightly greater in the radial form (Table 8.15). This indicates that the radial form collects more heat gains than the U-shape. This can be attributed to the greater exposure of the radial form to sunrays (Figure 8.42).





54.89 %	55.76 %
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure 8.42: North-facing Patterns: The Average Annual Shaded Area Generated by the Two Forms

8.3.2.2 Mean Surface Temperature

	Mean Surface Temperature		The Shaded Area	
The North-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	21.35	21.37	55.76 %	54.89 %

Table 8.16: Mean Surface Temperature and the Shaded Area of the Two Forms

By reviewing the measures of the mean surface temperature in both forms, it can be noted that the average annual mean surface temperature of the radial form is slightly higher (Table 8.16). It becomes evident that the greater exposure of the radial form to sunrays results in more heat gains and consequently a higher temperature than the U-shape.

8.3.2.3 Comfort Temperature

	Comfort Temperature		The Shaded Area	
The North-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	21.51	21.52	55.76 %	54.89 %

Table 8.17: Comfort Temperature and the Shaded Area of the Two Forms

The table (8.17) reveals that the average annual comfort temperature is higher in the case of the radial form. In the software, the Comfort Temperature is calculated as a weighted average of the air and mean surface temperatures.

8.3.2.4 Conduction

	Conduction		The Shaded Area	
The North-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	1428874 (Watts)	1471538 (Watts)	55.76 %	54.89 %
	97.10 %	100 %		

Table 8.18: Conduction Gains and the Shaded Area of the Two Forms

The sum of gains from the construction through walls into the indoor environment is bigger in the case of the radial form (Table 8.18). This reflects the greater exposure of the radial surfaces to sunrays.

8.3.3 The East-facing Forms
8.3.3.1 Inside Air Temperature

	Inside Air Temperature		The Shaded Area	
The East-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	21.67	21.71	53.96 %	52.18 %

Table 8.19: Inside Air Temperature and the Shaded Area of the Two Forms

The evaluation of inside air temperature in the east-facing forms (Table 8.19) reveals that the average annual inside air temperature is slightly greater in the radial form. This indicates that the radial form collects more heat gains than the U-shape. This finding is consistent with the shadow analysis which indicates the greater exposure of the radial form to sunrays (Figure 8.43).

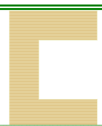
	
52.18 %	53.96 %
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure 8.43: East-facing Patterns: The Average Annual Shaded Area Generated by the Two Forms

8.3.3.2 Mean Surface Temperature

	Mean Surface Temperature		The Shaded Area	
The East-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	21.36	21.40	53.96 %	52.18 %

Table 8.20: Mean Surface Temperature and the Shaded Area of the Two Forms

By reviewing the measures of the mean surface temperature in both forms, it can be noted that the average annual mean surface temperature of the radial form is slightly higher (Table 8.20).

8.3.3.3 Comfort Temperature

	Comfort Temperature		The Shaded Area	
The East-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	21.52	21.56	53.96 %	52.18 %

Table 8.21: Comfort Temperature and the Shaded Area of the Two Forms

The table (8.21) reveals that the average annual comfort temperature is higher in the case of the radial form.

8.3.3.4 Conduction

	Conduction		The Shaded Area	
The East-facing Forms	The U-shape	The Radial Form	The U-shape	The Radial Form
	1408016	1613473	53.96 %	52.18 %
	87.27 %	100 %		

Table 8.22: Conduction Gains and the Shaded Area of the Two Forms

The sum of the gains from the conduction through walls into the indoor environment is bigger in the case of the radial form (Table 8.22). The increased heat gain of the form refers to the greater exposure of the radial surfaces to sunrays.

8.3.4 A Comparison between the Radial Forms and the U-shapes

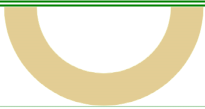
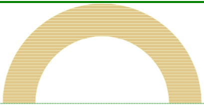
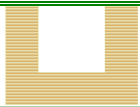
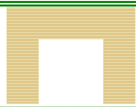
	1.07 %		1.64 %	
54.89 %		53.82 %		52.18 %
0.87 %		1.8 %		1.78 %
	0.14 %		1.66 %	
55.76 %		55.62 %		53.96 %
More Suitable for Cooling Requirements			More Suitable for Heating Requirements	

Figure 8.44: The Shaded Area Generated by the Radial Forms and the Rectangular U-shapes

By studying the resulting calculations of the annual shaded area of the U-shapes and the radial forms in the three different orientations (Figure 8.44), it can be observed that in all identical orientations, the rectangular U-shape is always more shaded than the radial one. Correspondingly, the U-shape in all orientations has lower inside air temperatures (Table 8.23). In the two patterns, forms oriented towards the north generate more shadow than other forms, while forms oriented towards the east generate the least amount of shadow. In conclusion, the north-facing forms have the lowest inside air temperatures, while the east-facing forms have the highest inside air temperatures (Table 8.23).

	Inside Air Temperature		The Shaded Area	
	The U-Shape	**The Radial Form**	**The U-Shape**	**The Radial Form**
East-facing Forms	21.67042	21.71260	53.96 %	52.18 %
South-facing Forms	21.66198	21.67799	55.62 %	53.82 %
North-facing Forms	21.66191	21.67708	55.76 %	54.89 %
	Mean Surface Temperature		**The Shaded Area**	
	The U-Shape	**The Radial Form**	**The U-Shape**	**The Radial Form**
East-facing Forms	21.36097	21.39931	53.96 %	52.18 %
South-facing Forms	21.35330	21.36785	55.62 %	53.82 %
North-facing Forms	21.35326	21.36698	55.76 %	54.89 %
	Comfort Temperature		**The Shaded Area**	
	The U-Shape	**The Radial Form**	**The U-Shape**	**The Radial Form**
East-facing Forms	21.51799	21.55833	53.96 %	52.18 %
South-facing Forms	21.51003	21.52528	55.62 %	53.82 %
North-facing Forms	21.51000	21.52438	55.76 %	54.89 %

Table 8.23: The Average Annual Temperatures and the Shaded Area in the Two Forms

In both cases, the variation between the east-facing forms and other forms (the south and north-facing), with regard to the generated shaded area, is greater than the variation between the south-facing forms and the north-facing forms. This trend is also maintained in the temperature analysis of the two forms (Table 8.24).

U-Shape Forms	East-facing	South-facing	Variation	South-facing	North-facing	Variation
The Shaded Area	53.96 %	55.62 %	1.66 %	55.62 %	55.76 %	0.14 %
Inside Air Temperature	21.67042	21.66198	0.00844	21.66198	21.66191	0.00007
Mean Surface Temperature	21.36097	21.35330	0.00767	21.35330	21.35326	0.00004
Comfort Temperature	21.51799	21.51003	0.00796	21.51003	21.51000	0.00003

Table 8.24: The Relation between the Generated Shaded Area and the Temperature

To conclude, the thermal evaluation provides further clarification for the relations between the shadow pattern generated by the urban forms and their thermal performance. The thermal calculations show a clear correlation between the generated shaded area and the resulted inside air temperature. By reviewing the previous results, it becomes evident that the increased heat gains and consequently the higher inside air temperature of the radial forms can be attributed to the greater exposure of the radial forms to sunrays. However, the accuracy of the judgment in this case has to be considered with the attention to the relatively small variation between the obtained inside air temperatures in the different urban configurations. Although solar insolation of the external envelope of the forms is doubtlessly one of the main contributors towards this variation, the influence of the urban geometry and building orientation on the indoor environment of the previously mentioned urban patterns cannot be ignored. Nevertheless, the weight of the influence of the shadow pattern on the inside air temperature is enhanced by the fact that the trend of the shadow behaviour of the forms is consistent with their thermal performance. The small variation between the two forms can also be attributed to the fact that, in order to isolate the effect of the geometry of the form, all other variables have been neutralized. The two forms have been set to have similar built volumes and external surface areas and to occupy the same floor area. In addition, construction material, environmental file and other climatic variables have been maintained the same. The effect of airflow pattern has been eliminated in the simulation in order to simplify the simulations. The airflow pattern within the curvilinear layout will differ from the rectangular one. The difference in the simulation results obtained between the two forms may increase if this variable is accounted for, because of its effect on the generated heat gains through an external envelope which, in turn, affects the indoor thermal environment.

8.4 The Application of the Radial and the Rectangular Forms in Palestine

8.4.1 The Rectangular and Radial Forms Oriented East and North

In Palestine, the preferable orientation of the form has also to be guided by the period of the major concern; the choice between forms also depends on geographical location. The climate along the coastal plain (which has a hot, humid summer and a temperate winter) requires passive solar solutions of a limited extent, the major concern being to avoid summer heat. The mountain area (which has a cold winter and temperate to hot-dry summer) requires better passive solar heating systems for winter, as the major concern is to receive winter sunrays.

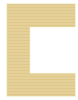
	The Radial Forms		**The Rectangular Forms**	
				
Summer Period	51.38 %	52.54 %	52.95 %	55.63 %
Winter Period	54.39 %	54.74 %	55.71 %	56.99 %
	The Radial Forms are More Suitable in the Mountain Area		The Rectangular U-shapes are More Suitable in the Coastal Plain	

Figure 8.45: The Average Annual Shaded Area Generated by the Forms

When comparing the radial forms and the rectangular U-shapes oriented east and north, it can be discovered that the radial forms are more suitable in the mountain area, as they generate the smallest shaded area in the winter period, while the rectangular U-shapes can be more advantageous in the coastal plain, as they generate greater amounts of shadow in the summer period (Figure 8.45).

8.4.2 The South-facing Rectangular and Radial Forms

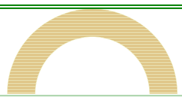
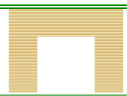
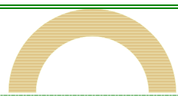
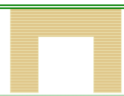
			
54.19 %	53.21 %	54.62 %	56.17 %
The Shaded Area Generated by the Forms in Summer		The Shaded Area Generated by the Forms in Winter	
The Radial Form is More Suitable in Temperate Climate			

Figure 8.46: The Shaded Area of the Two Forms in the Over and Underheated Periods

When comparing the south-facing radial and rectangular forms, it becomes evident that the radial form is more suitable in a temperate climate, as it has the biggest amount of shaded area in summer and the least amount of shaded area in winter (Figure 8.46). For qualitative indicators to compare the performance of both forms, the efficiency factor E_W can be applied (Table 8.25).

EW = Winter Solar Exposure/Summer Solar Exposure * 100	
The Radial From	EW = 45.38/ 45.81* 100 = 99.06%
The Rectangular Form	EW = 43.83/ 46.79* 100 = 93.67%

Table 8.25: The Insulation Efficiency of the Two Forms

However, the radial form could be more preferable in the mountain area, as the variation between the two forms, with regard to the generated shaded area, is greater in winter. Also, the fact that the radial form is less shaded than the rectangular U-shape predominantly in winter makes the form more beneficial for the mountain areas, where the major concern is the utilization of sunrays in winter. In addition, the radial form has the least amount of shaded area over the year (Figure 8.47) and therefore is more suitable for heating requirements in general; this supports the competence of the radial form in the mountain area.

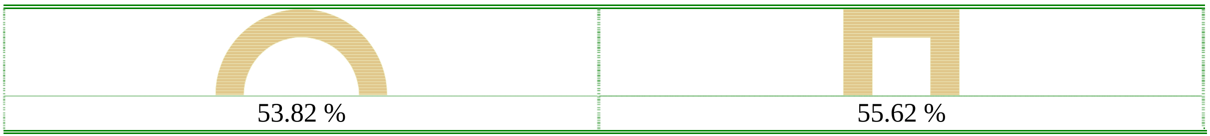


Figure 8.47: The Average Annual Shaded Area Generated by the Two Forms

The radial form can be even more beneficial in the mountain area for unilateral buildings. In such cases, it is common to have the south facade of the building as the main facade because it is less shaded over the whole year (Figure 8.48). This aspect gives an advantage to the radial form, as its south facade (the inner surfaces) is less shaded than the south facade of the rectangular U-shape over the year.

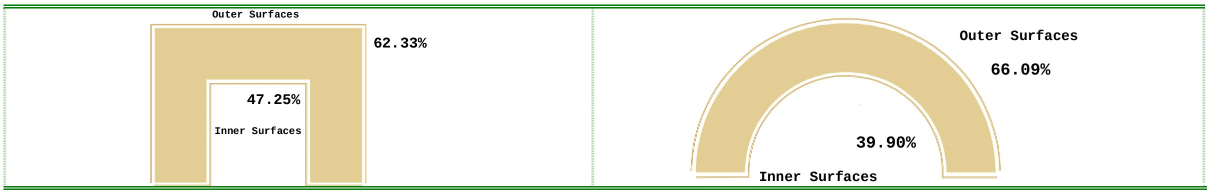


Figure 8.48: The Shaded Area Generated by the Outer and the Inner Surfaces Over the Year

Moreover, it was proved that the greatest variation between the inner surfaces of the two forms, with regard to the generated shaded area, occurs in wintertime (Figure 8.49). Consequently this makes the radial form more effective in gaining winter sunrays, and consequently heat, when it is crucial in the mountain area.

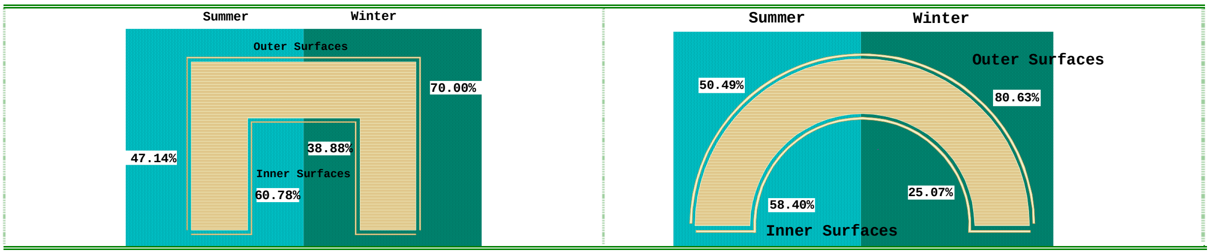


Figure 8.49: The Shaded Area Generated by the Outer and the Inner Surfaces in the Two Seasons

Shadow distribution in the inner surfaces during daytime over the whole year also reveals that the main variation between the two forms occurs during the noon period (Figure 8.50). So, this variation takes place mainly when inner surfaces (which almost are south-facing) receive maximum radiation, thus contributing to gaining more heat in the south facade. The variation during this period is more effective as it increases the preferability of using the radial form in the mountain area.

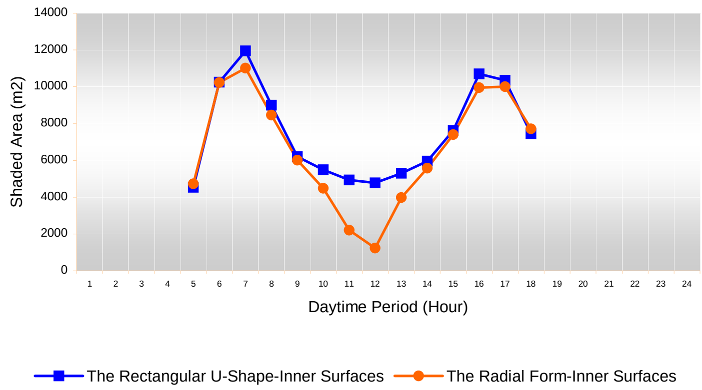


Figure 8.50: The Annual Distribution of the Shaded Area in the Inner Surfaces during the Daytime Period

Furthermore, the shadow distribution in the inner surfaces during daytime in both seasons reveals that the main variation between the inner surfaces of both forms occurs in wintertime and this variation reaches its maximum during the noon period (Figure 8.51). Thus, the variation between both forms takes place in winter and especially at noon which makes the utilization of the radial form in the mountain area even more preferable.

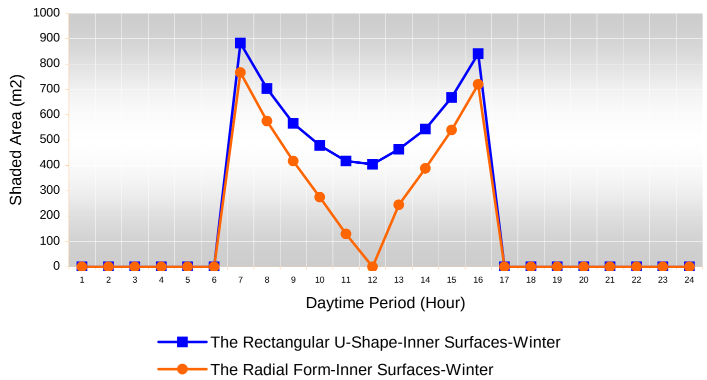


Figure 8.51: The Distribution of the Shaded Area in the Inner Surfaces in the Under-heated Period

8.5 Conclusion

The measurements of the annual shaded area generated in the two south-facing forms show that the annual shaded area is greater in the case of the rectangular U-shape and therefore it is more suitable for cooling requirements, while the radial form can be more suitable for heating requirements. As the variation between the outer and the inner surfaces is less in the case of the rectangular U-shape, this form is more suitable for bilateral buildings. The radial form is more beneficial in unilateral buildings, as its south-facing inner surfaces are less shaded than the inner surfaces of the rectangular U-shape over the year.

The south-facing radial form has the least amount of shadow in winter when sun exposure is desirable and the greatest amount of shadow in summer when sheltering the building from sunrays is required. Thus, in Palestine and other temperate climates, the radial form may be preferable, as the form has better insolation efficiency. However, the fact that the radial form is less shaded than the rectangular U-shape, predominantly in winter, makes the form more beneficial in the mountain areas. This makes the radial form more effective in gaining winter sunrays and consequently heat when it is crucial in the mountain area.

By comparing the generated shaded area during daytime in the two seasons, it can be observed that in the rectangular U-shape, the increased shadow in the morning and afternoon in wintertime evokes higher demand for heating in temperate climates. On the other hand, in the radial form, the higher exposure in the noon period in summer evokes higher demand for cooling.

The distribution of the annual shaded area during daytime in the outer and inner surfaces of the two forms reveal that the variation between the two groups of surfaces (outer and inner) for the same form reaches its maximum during the noon period. Thus, in bilateral buildings, morning and afternoon periods are characterised by a more equitable distribution of insolation in the two opposite sides. The biggest shaded area during daytime takes place in the outer surfaces of the radial form in wintertime at noon, while the lowest shaded area takes place in the inner surfaces of the radial form at the same time. Hence, the radial form has greater variation between the two opposite surfaces. Thus, the radial form has less suitability for bilateral buildings, as the north-facing outer surfaces of the radial form will receive fewer sunrays in winter, compared to the outer surfaces of the rectangular U-shape. However, the greater exposure of the inner surfaces of the radial form in winter can be beneficial in the case of unilateral buildings where the south-oriented surfaces usually constitute the principal facade.

The calculations of the annual shaded area of the north and east-facing forms demonstrate that the rectangular U-shapes produce more shadow than the radial ones. This reflects the suitability of the rectangular U-shape for cooling requirements and the higher suitability of the radial form for heating requirements.

By comparing the two radial forms facing north and south, it can be observed that the annual shaded area is bigger in the case of the north-facing radial form; therefore, it is more suitable for cooling requirements. The south-facing form has better insolation efficiency in a temperate climate, as it has the biggest amount of shaded area in summer and the least amount in winter. By reviewing the annual shaded area generated in the outer and inner surfaces in the two forms, it becomes evident that the south-facing curve is more suitable for bilateral buildings, as it has the least variation between the two opposite facades. Also, in unilateral buildings, the south-facing form may be more suitable, as the insolation efficiency of the south-oriented surfaces of this form is higher than the insolation efficiency of the south-oriented surfaces of the north-facing form.

By studying the three radial forms oriented south, north and east, it becomes evident that the east-facing form generates the least amount of annual shaded area, due to the lower level of self-shading, as this effect in this case occurs during the noon period when the sun is high in the sky. Hence, the east-facing form is more suitable for heating requirements, while the north-facing form is more suitable for cooling requirements as it generates the highest amount of shadow.

By studying the calculations of the annual shaded area of the radial and the rectangular forms in the three different orientations, it becomes very obvious that in all identical orientations, the rectangular U-shape is always more shaded than the radial one. The results of the Ew measurements confirm that the south-facing radial form is more suitable in Palestine and other temperate climates, as it has higher insolation efficiency than other forms. In the two patterns, the north-facing forms produce more shadow than other forms, while the east-facing forms generate the least amount of shadow. However, the least amount of shaded area is generated by the east-facing radial form, while the biggest amount of shaded area is generated by the north-facing rectangular U-shape. Thus, the east-facing radial form is preferable for heating requirements, while the north-facing rectangular U-shape is preferable for cooling requirements. In Palestine, the east-facing radial forms could be more suitable in the mountain area, while the north-facing rectangular U-shapes could be more advantageous in the coastal plain.

CHAPTER 9

OVERALL CONCLUSIONS AND FURTHER RESEARCH

9. Overall Conclusions and Further Research
9.1 Summary of Contributions

The first part of the parametric studies investigated the relationship between different urban forms and the shadow patterns they generate. The study aimed to make a comparison between the performances of different urban forms, and to establish a comprehensive approach and methodology by which any urban form can be fully investigated, in terms of the generated shadow patterns. The experiment examined more sophisticated forms which have been given less attention in the previous research studies, especially forms that can create self-shading effects. Analyses included the evaluation of the amount of the shaded area generated in the over-heated and under-heated periods, as well as over the year. Also, the investigations illustrated the distribution of the shaded area during the daytime period. This comprehensive approach gives a full explanation of the status of the generated shadow, which facilitates the best interpretation of results, and also allows deriving maximum benefits from it. Among the considerations, which were also investigated, is the inter-relationship between the solar insolation and thermal performance of urban patterns. This part of the research mainly focused on discovering the main characteristics of the radial form. Finally, the chapter discussed the possible application of these forms 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.

One of the clear implications of this 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.

With regard to the comparison between the Jerusalem and London latitudes, it was proved that the effectiveness of bilateral buildings (for urban forms elongated east-west) is greater in Jerusalem, where the variation in the shaded area between the two opposite facades is smaller. In London or more northerly latitudes, the tendency to have unilateral buildings will be preferable, as the exposed area is almost all concentrated on one facade (the southern one). Thermal calculations revealed that heat gains from building fabric, due to both external temperatures and incident solar radiation, is greater in the case of the rectangular form and therefore it is more suitable for heating requirements, while the radial form is more suitable for cooling demands. Hence, it can be observed that the gained heat increases where the shaded area is smaller (the rectangular form), and gained heat decreases where the shaded area is larger (the radial form). It can also be observed that the main variation between the two forms, with regard to both gained heat and shaded area, takes place in summer. Thus, greater variations in the shaded areas between the two forms result in greater variations in the obtained heat gains.

The second part of the parametric studies compared two urban patterns (radial and rectangular), in terms of the generated shadow pattern. The experiment aimed to clarify the influence of the self-shading effect of the radial form and investigated the variation between the two patterns with respect to the distribution of the shaded area during the daytime period within the canyon facades in both seasons. Also, the experiment evaluated the two patterns regarding of the amount of generated shadow in the overheated and underheated periods and over the whole year. In addition, the experiment intended 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 compared patterns 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. Therefore, the relation between solar insolation, orientation and building intensity was also discussed.

When comparing the shadow pattern generated during daytime in the facades of the two urban patterns with a canyon lying east-west, more significant variation is found in the summer period than in winter, as the sun's position in winter is more directed towards the south, while the self-shading effect generated in this pattern is mainly produced by sunrays coming from the east and west when sunrays match the long axis of the urban canyon. 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 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.

The calculations of the average annual shaded area in the two patterns, with the canyon lying south-north, 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. The shadow caused by one block to another in this pattern is more significant, as the shadowing occurs early in the morning or late in the afternoon when sun is closer to the horizon. The shadow from the south block to the north one in patterns with the canyon lying east-west is limited, as the shadowing takes place during the noon period when the sun is high in the sky. By comparing the patterns in both positions, it becomes evident that the variation between the radial and the rectangular patterns within the same orientation is greater in the case of the canyons oriented east-west. Thus, it becomes apparent that the main variations in the generated shadow between the radial and rectangular patterns are created by the self-shading of the individual radial block, while the effect from one block to another is approximately the same in the two patterns.

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. A more significant increase of site size with a long south-north axis occurs due to longer morning and afternoon shadows during the year; this dictates a larger distance between the buildings. Thus, the most intensified use of the site can be achieved with canyons on the east-west axis. 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.

The third part of the parametric studies discussed the Solar Insolation Aspects in Bilateral Types of Building, where the living areas are located in opposite directions. The study aimed to focus on bilateral buildings, which is a very common urban pattern in Palestine. This type of buildings can allow for greater building intensity, which is a crucial aspect for urban design in Palestine due to the lack of land and the need to accommodate millions of refuges. In the bilateral design of buildings, the way in which the shaded area is distributed within the form becomes a fundamental issue. While previous studies have mainly focused on investigating the optimum orientation of the buildings regardless of the distribution of living spaces within the form, in bilateral buildings, the insolation of opposite facades in a way that assures the access of sunrays to all residential units located in both sides of the form is crucial. As was proved by previous experiments, the north facade of the rectangular forms (elongated east-west) receives no sunrays at all in wintertime for Jerusalem. This situation provides advantages to units located to the south side and undermines the northern ones. The radial form might be the solution to this problem because it receives winter sunrays on both facades (north and south). So, the radial form could distribute solar insolation in winter among all residential units in a more even manner. Having knowledge of such advantages of the radial forms, from the solar point of view, could encourage the use of these forms. This increase of utilising radial forms will also boost the aesthetic value and diversity of the urban structure. As the main feature that determines the shape of the radial form is the extension of the concavity, it was necessary to compare several types of radial form with various extents of concavity in order to find out which one could be more suitable for bilateral types of building. The most suitable form is the one with the least differences of the shaded percentage between the two opposite facades during both the summer and winter periods, and also throughout the whole year. The experiment aimed also to establish a methodology by which the urban form can be evaluated with regard to the insolation efficiency of its different sides. Thus, the determination of the optimum orientation for any building form can be always considered together with its suitability for unilateral or bilateral buildings in mind.

By reviewing the generated shadow patterns in the opposite facades of the radial forms in the summer period, it can be observed that the supreme variation between the two facades occurs early in the morning, in the late afternoon, and at noon. However, this variation decreases with the increase of the form's concavity. Therefore, the distribution of the shadow pattern in the two opposite facades during daytime becomes more regular with increases of concavity. So, both facades in radial forms with more concavity can enjoy more homogenous solar accessibility during daytime.

In wintertime, the variation between the two opposite facades within the same form is more evident. However, the variation between the two facades decreases with an increase of the form's concavity, as a larger percentage of the south facade becomes shaded in the morning and afternoon and a larger percentage of the north facade becomes exposed simultaneously. It is also observed that the gradual increase of the shaded area in the south facade is intensified at a higher rate than the exposed area in the north facade.

One of the trends that has become evident by studying the results of this experiment is that the two opposite facades in radial forms with more concave characteristics have the least variation of sun exposure and can enjoy sunrays most of the daytime in both seasons, as they are approximately partially exposed throughout the whole day. This illustrates the suitability of radial forms with more concavity for bilateral buildings. The comparison between the forms, with regard to the total generated shaded area in the whole form over the year, reveals that there is no major variation between the forms; the main variation is in the distribution of the shaded area within the facades of these forms.

As regards insolation efficiency, winter is the season which creates major differences in insolation efficiency between the two opposite facades, as the shaded area for the two facades is approximately the same in the summer period. Insolation efficiency decreases with the increase of the form's concavity in the case of the south facade and increases in the case of the north facade. Consequently, the variation in the insolation efficiency between the two opposite facades decreases with the increase of the form's concavity. This finding confirms the suitability of the radial form with more concave characteristics for bilateral buildings. In unilateral buildings, where the south facade is the principal facade, the radial form with less concavity will be more suitable, as the insolation efficiency of the south facade increases with a decrease of the form's concavity.

The last part of the parametric studies aimed to prove that the methodology which was developed in this research can also be used to evaluate complex forms. The forms considered in this experiment are radial forms and the rectangular U-Shape. These forms, which can create a space surrounded and defined by walls, can offer self-protection against unfavourable weather and create their own microclimate. Such forms are very common within the urban structure and this principle is adequate in residential areas, since such spaces can be used as playgrounds for children and can enhance social activities and human contact. These forms could be considered as intermediate types between closed and open layouts. In Palestine and other temperate climates, a layout which is semi-closed could be more beneficial, as completely closed or completely open layouts are preferable in arid zones and cold climates respectively. Studies in this case cover the three basic classified types of urban forms: pavilions, urban canyons and complex forms (or forms that can create open spaces). Therefore, the experiment proves the capability and universality of this comprehensive approach which includes all the points that should be examined in order that the maximum benefit can be derived. In addition, the method illustrates how these analyses could be related to aspects of design and energy.

The measurements of the annual shaded area generated in the two south-facing forms (the radial form and the rectangular u-shape) show that the annual shaded area is greater in the case of the rectangular U-shape and therefore it is more suitable for cooling requirements, while the radial form can be more suitable for heating requirements. As the variation between the outer and the inner surfaces is less in the case of the rectangular U-shape, this form is more suitable for bilateral buildings. The radial form is more beneficial in unilateral buildings, as its south-facing inner surfaces are less shaded than the inner surfaces of the rectangular U-shape over the year.

The south-facing radial form has the least amount of shadow in winter when sun exposure is desirable and the greatest amount of shadow in summer when sheltering the building from sunrays is required. Thus, in Palestine and other temperate climates, the radial form may be preferable, as the form has better insolation efficiency. However, in Palestine, the fact that the radial form is less shaded than the rectangular U-shape, predominantly in winter, makes the form more beneficial in the mountain areas. This makes the radial form more effective in gaining winter sunrays and consequently heat when it is crucial in the mountain area.

The calculations of the annual shaded area of the north and east-facing forms demonstrate that the rectangular U-shapes produce more shadow than the radial ones. This reflects the suitability of the rectangular U-shape for cooling requirements and the higher suitability of the radial form for heating requirements.

By studying the calculations of the annual shaded area of the radial forms and the rectangular U-shapes in the three different orientations, it becomes very obvious that in all identical orientations, the rectangular U-shape is always more shaded than the radial one. In the two patterns, the north-facing forms produce more shadow than other forms, while the east-facing forms generate the least amount of shadow. However, the least amount of shaded area is generated by the east-facing radial form, while the biggest amount of shaded area is generated by the north-facing rectangular U-shape. Thus, the east-facing radial form is preferable for heating requirements, while the north-facing rectangular U-shape is preferable for cooling requirements. In Palestine, the east-facing radial forms could be more suitable in the mountain area, while the north-facing rectangular U-shapes could be more advantageous in the coastal plain.

As can be seen from the above summary, it becomes evident that the geometry of the urban form as an urban design tool is crucial. The following tabulated results, extracted from the parametric studies, aim to demonstrate the rich potential in using passive design as a means of influencing urban design (Table 9.1). These tabulated results can provide designers with simple and easy environmental design guidelines to assist relevant proposals. They also provide a significant step forward in understanding the built environment and increase the awareness of the relation between the geometric characteristics of the urban form and its insolation efficiency. The tables demonstrate how passive solar principles of saving energy can influence the design of urban form. Identifying the main characteristics of common urban patterns will enable designers to bear this consideration in mind when they start the design process and will help them in selecting from different options. These tables intend to highlight the significance of an environmental approach to urban design and can help in developing a bioclimatic urban form design guidance for some common urban patterns in Palestine.

The main features included in these tables are:

- Urban forms suitability for Temperate Climate
- The preferable utilisation in Palestinian areas
- The suitability for Cooling/Heating Requirements
- The suitability for Bilateral/ Unilateral Types of Buildings
- The Insolation Efficiency (Ew) of the forms
- The Insolation Efficiency (Ew) of the South-facing Surfaces
- The Total Annual Shaded Area
- The generated shaded area in Over and Underheated periods
- The distribution of the Shaded Area in the facades of the forms
- The Variation between the Two Opposite Facades

For urban canyons, other related issues such as, the overshadowing from one block to another, building intensity, etc. have been also illustrated.

Table 9.1: Samples of A Bioclimatic Urban Form Design Guidance for some Common Urban Patterns in Palestine

Samples of A Bioclimatic Urban Form Design Guidance for some Common Urban Patterns in Palestine (Table 9.1)

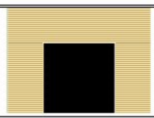
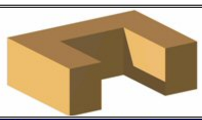
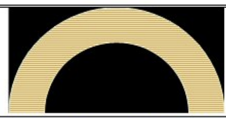



The Radial and Rectangular Forms: Forms Elongated East-west

	Temperate Climate	Insolation Efficiency (Ew)	Mountain Area (West Bank)	Coastal Plain (Gaza Strip)	The Insolation Efficiency (Ew) of the South-facing Surfaces	Unilateral Types of Buildings	Bilateral Types of Buildings	The Total Annual Shaded Area	Cooling/Heating Requirements
The Rectangular Form	Less Suitable	100 %	More Suitable	Less Suitable	233.32 %	Less Suitable in Unilateral Types	Less Suitable in Bilateral Types	50 %	More Suitable for Heating
The Radial Form	More Suitable	115.12 %	Less Suitable	More Suitable	261.36 %	More Suitable in Unilateral Types	More Suitable in Bilateral Types	55.20 %	More Suitable for Cooling

The Generated Shaded Area

	Summer				Winter				The Annual Shaded area			
The Rectangular Form	S. F.	N. F.	The Variation between the Two Opposite Facades	Total	S. F.	N. F.	The Variation between the Two Opposite Facades	Total	S. F.	N. F.	The Variation between the Two Opposite Facades	Total
	57.14 %	42.86 %	14.28 %	50 %	0 %	100 %	100 %	50 %	19.79 %	80.56 %	60.77 %	50 %
	Summer				Winter				The Annual Shaded area			
The Radial Form	S. F.	N. F.	The Variation between the Two Opposite Facades	Total	S. F.	N. F.	The Variation between the Two Opposite Facades	Total	S. F.	N. F.	The Variation between the Two Opposite Facades	Total
	64.34 %	51.43 %	12.91 %	54.39 %	6.8 %	96 %	89.2 %	52.17 %	38.81 %	74.97 %	36.16 %	56.89 %

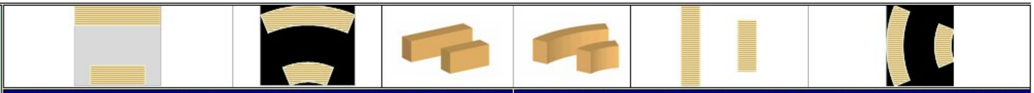





The Radial Form and the Rectangular U-Shape: Forms with Open Space Oriented South

	Temperate Climate	Insolation Efficiency (Ew)	Mountain Area (West Bank)	Coastal Plain (Gaza Strip)	The Insolation Efficiency (Ew) of the South-facing Surfaces	Unilateral Types of Buildings	Bilateral Types of Buildings	The Annual Shaded Area	Cooling/ Heating Requirements
The Rectangular U-Shape	Less Suitable	93.67 %	Less Suitable	More Suitable	155.84 %	Less Suitable in Unilateral Types	More Suitable in Bilateral Types	55.62 %	More Suitable for Cooling
The Radial Form	More Suitable	99.06 %	More Suitable	Less Suitable	180.12 %	More Suitable in Unilateral Types	Less Suitable in Bilateral Types	53.82 %	More Suitable for Heating

The Generated Shaded Area

	Summer				Winter				The Annual Shaded area			
The Rectangular U-Shape	O. S.	I. S.	The Variation between the Two Opposite Facades	Total	O. S.	I. S.	The Variation between the Two Opposite Facades	Total	O. S.	I. S.	The Variation between the Two Opposite Facades	Total
	47.14%	60.78%	13.64%	53.21%	70%	38.88%	31.12%	56.17%	62.33%	47.25%	15.08 %	55.62%
	Summer				Winter				The Annual Shaded area			
The Radial Forms	O. S.	I. S.	The Variation between the Two Opposite Facades	Total	O. S.	I. S.	The Variation between the Two Opposite Facades	Total	O. S.	I. S.	The Variation between the Two Opposite Facades	Total
	50.49%	58.40%	7.91%	54.19%	80.63%	25.07%	55.56%	54.62%	66.09%	39.9%	26.19%	53.82%



	The Radial and Rectangular Urban Patterns With Canyon Located on the East-West Axis					The Radial and Rectangular Urban Patterns With Canyon Located on the North-South Axis			
	The Total Annual Shaded Area	Cooling/Heating Requirements	Mountain Area (West Bank)	Coastal Plain (Gaza Strip)	Bilateral Types of Buildings	The Total Annual Shaded Area	Cooling/Heating Requirements	Mountain Area (West Bank)	Coastal Plain (Gaza Strip)
The Rectangular Configuration	50.30 %	More Suitable for Heating	More Suitable	Less Suitable	Less Suitable in Bilateral Types	53.82 %	There are no major differences between the two patterns with regard to heating and cooling requirements	There are no major differences between the two patterns with regard to the location (West Bank/Gaza Strip)	
The Radial Form Configuration	54.76 %	More Suitable for Cooling	Less Suitable	More Suitable	More Suitable in Bilateral Types	53.82 %			

	The Self-shading Effect of the Radial Form			The Overshadowing from One Block to Another			Building Intensity	
The Radial and Rectangular Urban Patterns With Canyon Located on the East-West Axis	More Self-Shading Effect	**The Rectangular Pattern**	**The Radial Pattern**	Less Overshadowing	**The Rectangular Pattern**	**The Radial Pattern**	More intensified use of the site	Arranging the blocks on the site can allow for greater building intensity, while maintaining the same quality of sunlight
		The South Block-The South Facade			The Shadow From the South Block to the North One			
		19.79 %	28.85 %		0.54 %	0.6778 %		
		The Variation						
		9.06 %						
The Radial and Rectangular Urban Patterns With Canyon Located on the North-South Axis	Less Self-Shading Effect	The East Block-The East Facade		More Overshadowing	The Shadow From the East Block to the West One		Less intensified use of the site	The spacing between the two blocks has to be greater if it is required that the same standard of solar accessibility is maintained
		51.04 %	51.56 %		7.41 %	6.97 %		
		The Variation			The Shadow From the West Block to the East One			
		0.52 %			10.63 %	10.87 %		

Radial Forms with Different Concavities

	60/360			90/360			120/360			150/360			180/360		
The Annual Shaded Area	54.72 %			55.18 %			55.01 %			55.00 %			55.31 %		
	There is no major variation in the amount of the generated shaded area, but the main difference is in the distribution of the shaded area in the facades of the forms														
	N. F.	S. F.	Variation	N. F.	S. F.	Variation	N. F.	S. F.	Variation	N. F.	S. F.	Variation	N. F.	S. F.	Variation
	78.30 %	33.80 %	44.5 %	74.97 %	39.57 %	35.4 %	72.12 %	44.50 %	27.62 %	69.06 %	48.50 %	20.56 %	66.39 %	51.93 %	14.46 %
Bilateral Types of Buildings	Less suitable for bilateral buildings												More suitable for bilateral buildings		
Unilateral Types of Buildings	More suitable for unilateral buildings												Less suitable for unilateral buildings		

	Bilateral Buildings	Unilateral Buildings	The Generated Shaded Area: Summer S. F.	Summer N. F.	Summer Variation	Winter S. F.	Winter N. F.	Winter Variation	The Insolation Efficiency: S. F.	N. F.	Variation
The Radial Form: 60/360	Less suitable for bilateral buildings	More suitable for unilateral buildings	68.05 %	48.21 %	19.84 %	0 %	100 %	100 %	312.99 %	0 %	312.99 %
The Radial Form: 90/360			66.23 %	51.43 %	14.8 %	6.86 %	96 %	89.14 %	275.81 %	8.24 %	267.57 %
The Radial Form: 120/360			65.24 %	52.5 %	12.74 %	17.16 %	90.5 %	73.34 %	238.61 %	20 %	218.61 %
The Radial Form: 150/360			64.88 %	50.71 %	14.17 %	27.06 %	85.5 %	58.44 %	207.69 %	29.42 %	178.27 %
The Radial Form: 180/360	More suitable for bilateral buildings	Less suitable for unilateral buildings	64.61 %	50.71 %	13.9 %	35.76 %	81 %	45.24 %	181.52 %	38.55 %	142.97 %

9.2 Possible Utilisation of the Shadow Analyses

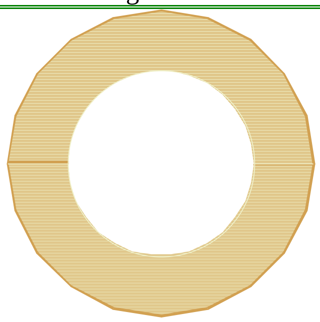
The previous analyses can also be used to evaluate some aspects of solar insolation related to the Palestinian climate and to investigate the interaction between solar insolation and the various types of urban form.

9.2.1 The Annual Shaded Percentage per Hour for Vertical Surfaces in Jerusalem

The annual shaded area generated by different segments constituting the outer surfaces of both radial forms oriented north and south could be used as indicators of the annual shaded area, which can be generated by different vertical surfaces with different surface azimuth angles in Jerusalem. As each radial surface consists of ten segments, Table 9.2 below shows the average annual shaded area for 20 different vertical surfaces with 18^0 as the interval of their surface azimuth angles.

The Surface Azimuth Angle	The Average Shaded Percentage	The Surface Azimuth Angle	The Average Shaded Percentage
9.00 °	78.89 %	189.00 °	21.11 %
27.00 °	75.43 %	207.00 °	24.57 %
45.00 °	65.40 %	225.00 °	34.60 %
63.00 °	57.78 %	243.00 °	42.22 %
81.00 °	52.25 %	261.00 °	47.75 %
99.00 °	48.10 %	279.00 °	51.90 %
117.00 °	40.83 %	297.00 °	59.17 %
135.00 °	34.60 %	315.00 °	65.40 %
153.00 °	24.57 %	333.00 °	75.43 %
171.00 °	20.07 %	351.00 °	79.93 %

The Average Annual Shaded Percentage per Hour for Vertical Surfaces in Jerusalem



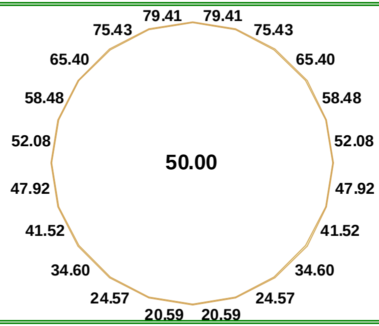


Table 9.1: The Average Annual Shaded Percentage per Hour for Different Vertical Surfaces in Jerusalem

Additionally, the average annual shaded area of the vertical surfaces with azimuth surface angles coinciding with the four principal directions could be derived from the results obtained from the shadow analysis of the rectangular form (Table 9.3). As the rectangular form does not generate any self-shading effect, the calculation of its surfaces could be the same for vertical surfaces in Palestine with the same surface azimuth angle. These results are beneficial for architects and designers in the area. Although it is well known among architects in Palestine that south facades are better exposed than north facades, there are currently no available quantitative indicators for the ratios between the exposed areas in the two facades over the year. This outcome makes it clear that the ratio between the exposed areas in the north and the south facades is 1: 4 respectively and the south facade gets approximately 80% of daylight during the year, while the north one obtains only 20% of daylight during the year.

The Average Daily Shaded Percentage per Hour for the Principal Vertical Surfaces in Jerusalem for Each Month					
	West Facade	**North Facade**	**East Facade**	**South Facade**	**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 %

The Average Annual Shaded Percentage per Hour for the Principal Vertical Surfaces in Jerusalem	
The Surface Azimuth Angle	**The Annual Shaded Percentage per Hour**
The North Facade (0)	80.00 %
The East Facade (90)	50.00 %
The South Facade (180)	20.00 %
The West Facade (270)	50.00 %

Table 9.2: The Average Shaded Percentage per Hour for the Principal Vertical Surfaces in Palestine

9.2.2 A Comparison between a Cylindrical and a Cubic Form

By using the measurements of the average annual shaded area in the radial and rectangular forms, a comparison between cylindrical and cubic forms can be established. The previous calculations of the shaded area generated by the external surfaces of the two radial forms can also represent the average annual shaded area of the external surfaces of a cylindrical form. The shaded area of the surfaces which constitute the cubic form, could be derived from the calculations related to the rectangular form, as the four vertical surfaces of both forms have the same surface azimuth angles. The shaded area of a polygonal form can be also computed by using the obtained results for the radial and rectangular forms.

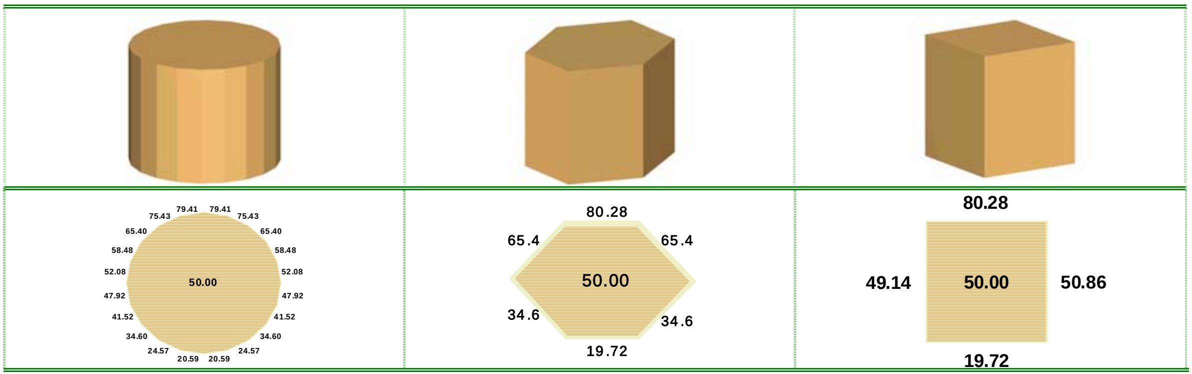


Figure 9.1: The Average Annual Shaded Percentage per Hour for the Cylindrical and Cubic Forms

The comparison reveals that the three forms have the same average annual shaded percentage per hour (50 %) over the year (Figure 9.1). This can be attributed to the fact that the three forms are symmetrical and do not generate any self-shading effect. All forms are symmetrical according to two axes (bilateral symmetry) (Figure 9.2). The first axis of symmetry is consistent with the access of symmetry for the sunpath (an axis lying south north). The second axis of symmetry is an axis at right angles with the previous one (located on the east-west axis). In this case, all forms are half shaded, half exposed in any of the sun's azimuth angles and the forms are half shaded, half exposed during the daytime period over the whole year.

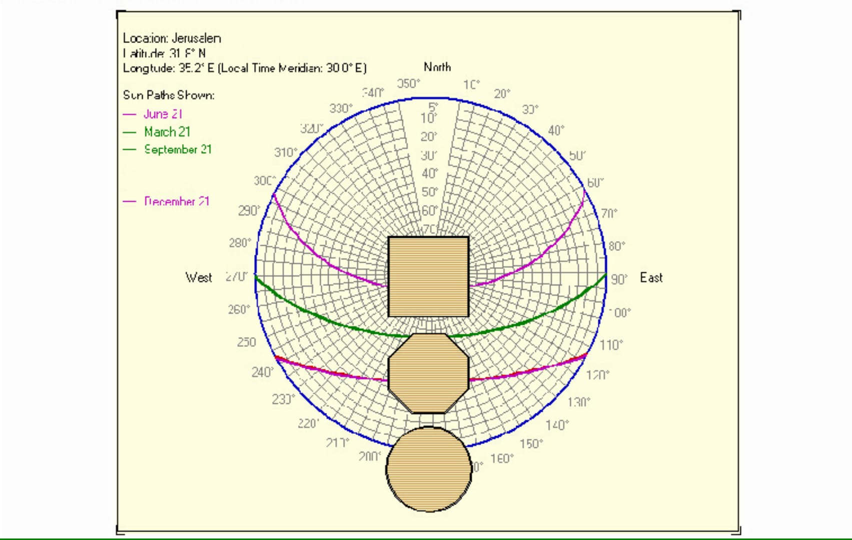


Figure 9.2: Forms with Bilateral Symmetry

9.2.3 A Comparison between Triangular Forms

The previous calculations of the average annual shaded area generated by vertical surfaces with different azimuth surface angles could also be used to evaluate different types of urban forms with regard to the generated shaded area. For example, the calculations can be used to evaluate two groups of triangular forms. The first group consists of five triangles with south-facing linear surfaces and different azimuth surface angles for the side facades with intervals of 18^0. The second group consists of the same arrangement but with north-facing linear surfaces of triangles (Figure 9.3).

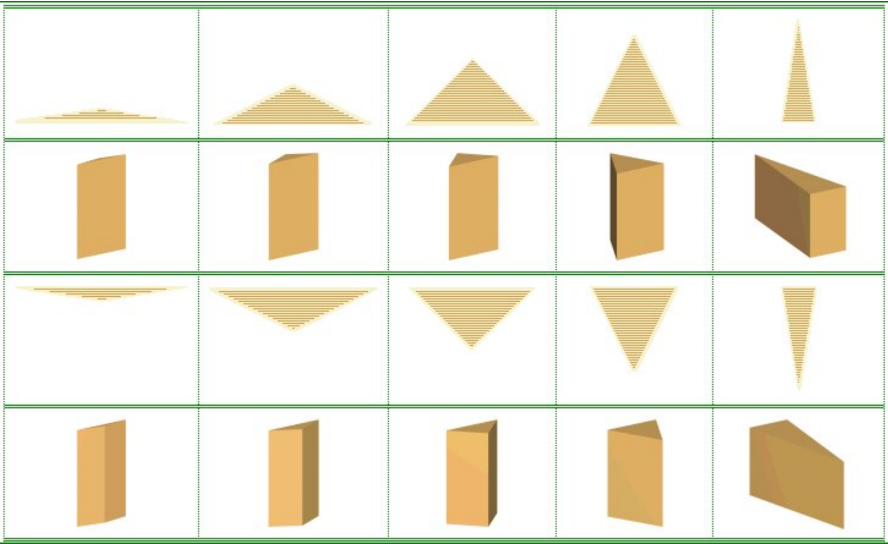


Figure 9.3: South-Facing And North-Facing Triangles

The comparison reveals that, in general, the triangular forms with linear surfaces facing south have less of a shaded percentage than the identical counterparts in the other group with north-facing linear surfaces (Figure 9.4). The biggest shaded percentage is generated by the triangular form which has 63^0 as α angle (approximately a triangle with equal lengths of surfaces) and which has a north-facing linear surface. Such a form is therefore more suitable for cooling requirements. The triangular form which also has 63^0 as α angle and with a south-facing linear surface generates the least shaded percentage and thus is more suitable for heating requirements (Figure 9.5).

	The South-facing Linear Surfaces	**The North-facing Linear Surfaces**
α Angle = 81^0	47.85 %	52.48 %
α Angle = 63^0	46.54 %	53.80 %
α Angle = 45^0	46.64 %	53.71 %
α Angle = 27^0	49.35 %	50.99 %
α Angle = 9^0	49.91 %	50.42 %

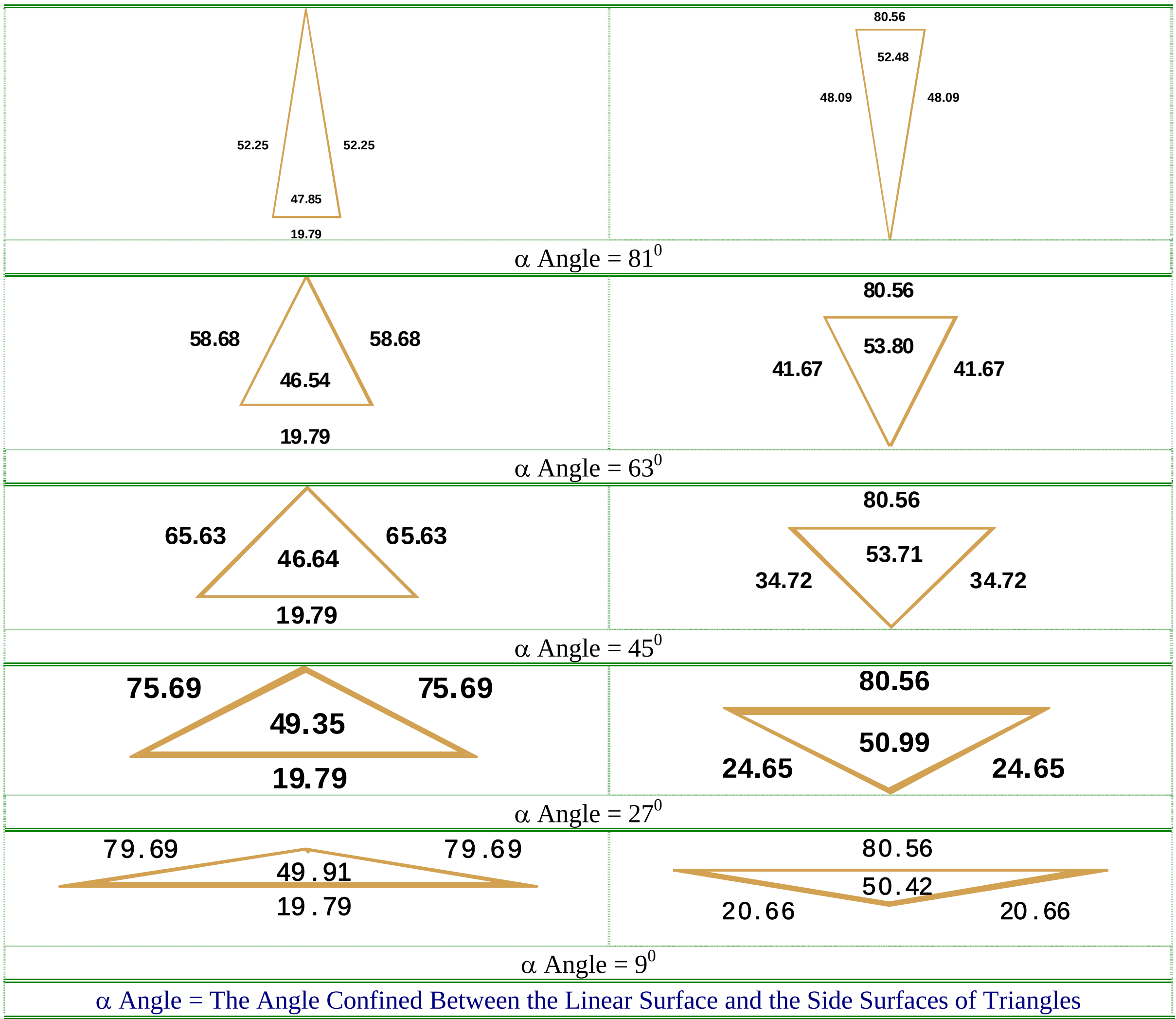


Figure 9.4: The Average Annual Shaded Area Generated by the Triangular Forms

Also, it is observed that the shaded percentage before and after the triangle with 63^0 as the α angle and with a south-facing linear surface increases. In forms which have smaller α angles than this triangle, the sloped sides of the form become more oriented towards the north; therefore they contribute more shadow. The form before this triangle in this arrangement (with a α angle greater than this triangle) has slightly different proportions between the sloped sides and the linear side. The linear side of the form, which is more exposed, has less contribution in the resulting shaded area in this case, due to its relatively smaller size; consequently the form is more shaded.

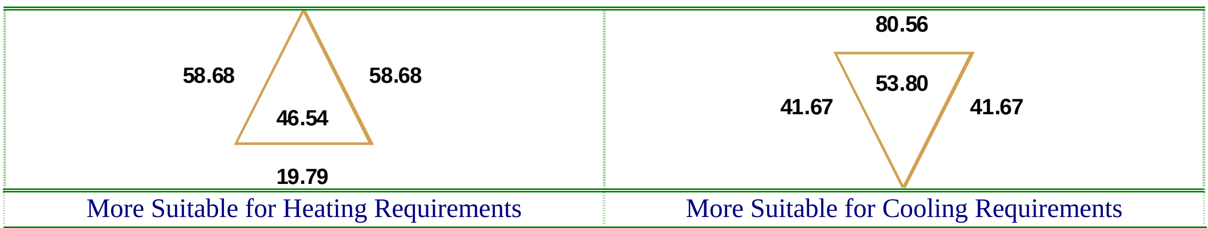


Figure 9.5: Triangular Form Applications

It is noted that the shaded percentage, before and after the triangular form with 63^0 as its α angle and with a north-facing linear surface, decreases. In forms which have smaller α angles than this triangle, the sloped sides of the form became more oriented towards the south; therefore their contribution in the total generated shaded area is smaller. The form before this triangle (with 81^0 α as its angle) has slightly different proportions between the sloped sides and the linear one; the linear side, which is more shaded, has less contribution in the resulting shaded area and thus the form is more exposed.

9.3 Recommendations for Further Research

The environmental aspects of the current design do not attract the considerations they deserve. The lack of applicable and suitable information and climatic data is one of the main problems that discourages designers from giving this aspect the required attention. The target of urban design in the future must be to conserve natural resources and to use renewable forms of energy, especially solar energy, as extensively as possible, so that many undesirable developments can be avoided. Economic pressures, which have a significant impact on the way architects work, have always informed building design. Conducting an environmental assessment for projects, especially for small-scale projects, does not seem feasible for many designers, due to its financial cost and the required time. This can delay the design process and cost extra money which, in some cases, exceeds the benefits derived from these studies. Overcoming such difficulties can be achieved by improving the current situation. In order to attain these goals, it will be necessary to establish an environmental index for the common urban and building models, as well as to develop computer software in accordance with the new objectives.

i. The Development of Software Tools

As building systems become more complex, the designer is increasingly reliant on technical and environmental assessment to inform the design process. With the advance of software tools technology, it is possible to achieve more savings in building costs. The simulation, calculation and measurement of conditions governing the thermal performance of buildings must be systematically represented and made available in a clear and comprehensible form. To be able to perform these assessments, computer software is required that will perfectly simulate the building and easily illustrate how the building will operate, enabling designers to have much greater insight into how the building will actually perform. To produce successful passive buildings, the designer responsible must have an accurate, simple and easy analytical tool to enhance the possibility of successful design. This software has to enable designers to understand the building operation prior to the actual building.

However, current software suffers from some limitations, mainly concerning the way it ignores sophisticated and complicated shapes which are common in the urban structure since the vast majority of these programs have been designed to examine simple shapes. Software and computer simulation technology has not provided sufficient capabilities to satisfy the demands for efficient and environmentally friendly buildings. In addition, the experimentations in this field have not been explicit enough and have not included all aspects of the challenge in most cases. Thus, this makes it difficult to benefit from such software in real practice.

Although current software produces shadow analyses swiftly and quickly, the output is given for each surface individually and the information is given in a unrefined status. This information usually needs a great deal of effort from the researcher to process the outcomes and to present them in such a way that will enable designers to prepare calculations that could be directly reflected in the design process. Although some building simulation technology is being used on an increasing number of projects, the current software in this field does not achieve the required level of development which will make such tools popular.

Updated tools have to be integrated with CAD software so that the building of the physical model for constructional purposes will be used for the environmental assessment as well so that no work has to be duplicated. In this case, instead of only visualising the 3D space, the designer can investigate how the building will perform in terms of daylight and solar insolation, occupant comfort, low energy design and sustainability. Therefore, in the longer term, this simulation software will have a more significant effect on the design process than CAD. The design process will be no longer concentrated on CAD, and simulation technology will result in a shift of emphasis of the design process. Thus, more effort will be performed to enable designers to produce more effective design decisions.

The information produced by such software will help architects and urban designers to evaluate the performance of buildings at any stage during the design process. Also, the software has to improve integration between different aspects of design, consequently speeding up design calculations. The software has to enable design change to be carried out more quickly, easily and with greater flexibility, so that design process can be shortened. These new tools have to give designers freedom in proposing whatever form they desire without making any compromise to have their proposals evaluated by the software.

Environmental design principles have to be considered from the beginning of the building design process when the project is still being analysed and decisions regarding geometry, materials and the exact site arrangements are still to be made. These aspects of the design are the most important determinants of overall building performance. This is a process that involves the generation of ideas that will need to be tested later, so that it can be rejected immediately or be considered for further refinement.

Analytical feedback can guide the decision-making process right from the first adjustment towards more effective design solutions, helping to avoid unnecessary work on unsuitable options. So, traditional methods of testing design ideas by quick perspective sketches and simple geometric analyses have to be enhanced by computer simulation. The ability to incorporate the environmental point of view to other design aspects will enable designers quickly to reject inappropriate ideas and save significant time and effort.

As the design develops and the model is refined, designers can progressively make more detailed choices as different issues become relevant. However, the range of options provided means that designers can test different design options and assess their outcomes in many different areas, deriving a diverse range of feedback. In many cases, the absolute accuracy of the calculations is not crucial at the earliest stages, as long as the relative accuracy is preserved and the comparative calculations maintain correct proportional measurements. However, the software has to be able to provide more accurate results by using more focused validation tools, as the design process advances into a more refined stage and the project approaches its completion. Thus, the software has to offer a wide range of different analysis and simulation options. It should also be noted that the most comprehensive and accurate simulation methods can only be made at the end of the design process as they require the exact specification of design elements.

This research establishes a comprehensive approach and methodology which can be used for the evaluation of urban forms and illustrates the main points that should be examined so that maximum benefits can be derived. Also, the research illustrates how these analyses could be related to aspects of design and energy in real practice. Therefore, this research can also help software companies to develop their programs in a way that assures maximum useful processing of information. In addition, the research clarifies the necessary type of calculations and the required graphics and illustrations that can assist designers to decide between different types of urban form. Hence, the methodology which was conducted by the researcher, can give some hints for programmers about the necessary improvements required for developing this software.

This, in terms of solar insolation, mainly include:

- The ability of the software to give the shaded coefficient for the whole urban form, as well as for the individual surfaces.
- The evaluation of the shadow pattern generated during the daytime period and the capability to provide these measurements annually, in summer, winter, and for each month. For more accurate results, the calculation has to be provided each half an hour if possible (the current software usually gives records every hour).
- The capability to determine the group of surfaces which the designer desires to be analysed as one group. This grouping method depends on the shape of the urban form and the required analyses. For example, this method was used to investigate the rectangular U-shape, so it was divided into inner and outer surfaces, as each side could serve different residential units and each group of surfaces could face different types of urban microclimate. In addition, the radial facade has no simple direction and, in order to be examined, it was divided into many parts, as the simulation has to be done for a surface with a specific surface azimuth angle. In this case, the radial facade was simulated as a number of segments which were summed at the end.
- It is essential to integrate these applications within CAD software, or to make these files compatible with other well-known CAD programs.
- To encourage designers, the software has to provide some examples representing how this software can be used in real practice.

- The software has to be able to provide the insolation efficiency of the urban pattern, as this unit is one of the most important aspects determining the thermal performance of buildings in temperate climates.
- The software has to provide information in a more processed and refined manner, such as providing graphs and charts illustrating the numerical calculations, obtained.

In all cases, an evaluation of the solar insolation has to be an integral part of the comprehensive evaluation tools which will take into account other factors influencing the design, including other environmental and socio-economic aspects. Consequently, designers can optimise their designs and improve the quality of the built environment for the benefit of society.

ii. More Investigation Towards Establishing a Bioclimatic Urban Form Design Guidance

Urban designers are under increasing pressure to minimise the impact of energy on the environment. The aspect of climate has forced communities to reconsider their energy strategies and ultimately reduce their energy costs. Architects and designers are now looking forward to finding out more about environmental solutions in order to meet current legislation, save costs, and minimise the environmental impact of energy consumption. Architects and planners must design their projects with a knowledge of local conditions, existing resources, and the main criteria that govern the integration of solar energy into the design process.

Unfortunately, since passive solar techniques have become popular, much has been written on the topic, most of which is primarily descriptive. However, relatively little has been done to overcome the problem of applying theory to practice, in particular to meet designer’s need in terms of providing simple and easy environmental guidelines. Therefore, more investigation has to be carried out to examine the thermal behaviour of the common urban forms in different latitudes. An exploration of the main characteristics of some common building forms or standardised urban patterns will make it easier for designers to bear this consideration in mind when they start the design process and will help them in selecting from different options. An environmental index which explains the main thermal features for these common patterns, can be established and suitable guidelines can be proposed for different climatic conditions. This index will help designers rapidly and easily to assist their proposals if they use typical urban forms which are frequently used in the area and are included in this guidance. The approach established by the researcher can be applicable for different types of urban forms and latitudes and thus can facilitate the establishment of such environmental indices, accelerating further researches in this field. The previously mentioned table (9.1) shows a tabulated approach to arrange extracted results from the previous experiments in a bioclimatic urban form design guidance.

Building standards, regulations and laws have also to be adapted to meet the new requirements of these climatic design considerations. More technical regulation means that the designer must not only understand how the building will look, but also how it will perform. In future, the role of urban design as a responsible profession will be more important in this respect. Designers must be trained to develop the necessary design skills to take into consideration the influence of the urban microclimate in order to improve thermal comfort, control energy consumption in buildings, and reduce undesirable environmental impacts. Designers have to have the ability to create suitable and realistic design responses to urban climate variation and to be able to apply recommendations in their projects to consolidate the principles of climate-conscious design in practice. Designers must have a more decisive influence on the layout of urban structures and buildings, and thus on the use of energy, than they have in the past.

The use of environmentally friendly urban forms must be planned from a holistic point of view. New design concepts must be developed in such a way that will increase awareness of solar energy as a source of light and heat. For greater acceptance by the general public of buildings adapted to solar technology, convincing visual ideas and examples have to be proffered. In addition, providing further training and education to architects and engineers must be related to the future needs of bioclimatic design; academic institutions are required to develop relevant options. Moreover, regarding professional knowledge in all functional, technical and design relationships, climatic considerations have to be a precondition for the creation of modern architecture. In view of the responsibility, designers are required to strengthen the considerations of environmental design in relation to that of commercial undertakings.

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APPENDIXES

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Appendix A: Samples of the Shadow and Thermal Analyses*

Appendix A1: The Shadow Analyses and Thermal Calculations of the Radial and Rectangular Forms

	Jun											
	The Rectangular Form						The North-facing Radial Form					
	15th		21st		Average		15th		21st		Average	
Daytime	South	North	South	North	South	North	South	North	South	North	South	North
01:00												
02:00												
03:00												
04:00												
05:00	100	0	100	0	100	0	80	43.71	80	43.17	80	43.44
06:00	100	0	100	0	100	0	70	56.66	70	56.23	70	56.445
07:00	100	0	100	0	100	0	60	64.21	60	63.88	60	64.045
08:00	100	0	100	0	100	0	50	65.58	60	64.77	55	65.175
09:00	0	100	0	100	0	100	50	65.98	50	65.7	50	65.84
10:00	0	100	0	100	0	100	30	74.52	30	74.04	30	74.28
11:00	0	100	0	100	0	100	0	100	10	96.55	5	98.275
12:00	0	100	0	100	0	100	0	100	0	100	0	100
13:00	0	100	0	100	0	100	30	78.34	30	78.31	30	78.325
14:00	0	100	0	100	0	100	40	68.15	40	68	40	68.075
15:00	100	0	100	0	100	0	50	65.13	50	64.9	50	65.015
16:00	100	0	100	0	100	0	60	65.41	60	65.22	60	65.315
17:00	100	0	100	0	100	0	70	59.35	70	59.26	70	59.305
18:00	100	0	100	0	100	0	80	48.54	80	48.56	80	48.55
19:00												
20:00												
21:00												
22:00												
23:00												
24:00												
Total	800	600	800	600	800	600	670	955.58	690	948.59	680	952.085
The Average Daily Shaded Area per Hour (%) = Total Daily Shaded Area/14												
					57.14%	42.86%					48.57%	68.01%

Table A1.1: The North-facing Radial Form and the Rectangular Form: Shadow Patterns in Summer

	December											
	The Rectangular Form						The Radial Form					
	15th		21st		Average		15th		21st		Average	
Daytime	South	North	South	North	South	North	South	North	South	North	South	North
01:00												
02:00												
03:00												
04:00												
05:00												
06:00												
07:00	0	100	0	100	0	100	20	99.71	20	99.75	20	99.73
08:00	0	100	0	100	0	100	10	99.8	10	99.8	10	99.8

* Due to the oversized quantities of the simulations, which have been carried out to conduct this thesis, it has been seen as unfeasible and unattainable to provide all tabulated information and data related to the different types of these simulations and their numerical calculations. Instead of that, samples of these results, which show the variety of these analyses, have been mentioned in this appendix.

09:00	0	100	0	100	0	100	0	100	0	100	0	100
10:00	0	100	0	100	0	100	0	100	0	100	0	100
11:00	0	100	0	100	0	100	0	100	0	100	0	100
12:00	0	100	0	100	0	100	0	100	0	100	0	100
13:00	0	100	0	100	0	100	0	100	0	100	0	100
14:00	0	100	0	100	0	100	0	100	0	100	0	100
15:00	0	100	0	100	0	100	0	100	0	100	0	100
16:00	0	100	0	100	0	100	10	99.72	10	99.72	10	99.72
17:00												
18:00												
19:00												
20:00												
21:00												
22:00												
23:00												
24:00												
Total	0	1000	0	1000	0	1000	40	999.23	40	999.27	40	999.25
The Average Daily Shaded Area per Hour (%) = Total Daily Shaded Area/10												
					0 %	100 %					4 %	99.9 %

Table A1.2: The North-facing Radial Form and the Rectangular Form: Shadow Patterns in Winter

The Radial Form												
	December						Jun					
	15th		21st		Average		15th		21st		Average	
Daytime	South	North	South	North	South	North	South	North	South	North	South	North
01:00												
02:00												
03:00												
04:00												
05:00							99.46	20	99.49	20	99.475	20
06:00							96.16	30	96.28	30	96.22	30
07:00	30.89	80	31.47	80	31.18	80	88.95	40	89.2	40	89.075	40
08:00	10.56	90	11.05	90	10.81	90	74.74	50	75.88	40	75.31	45
09:00	0	100	0	100	0	100	59.16	50	59.65	50	59.405	50
10:00	0	100	0	100	0	100	40.36	70	40.98	70	40.67	70
11:00	0	100	0	100	0	100	0	100	10.13	90	5.065	95
12:00	0	100	0	100	0	100	0	100	0	100	0	100
13:00	0	100	0	100	0	100	33.9	70	33.73	70	33.815	70
14:00	0	100	0	100	0	100	53.44	60	53.33	60	53.385	60
15:00	0	100	0	100	0	100	69.64	50	69.46	50	69.55	50
16:00	27.11	90	25.82	90	26.47	90	85.61	40	85.44	40	85.525	40
17:00							94.5	30	94.39	30	94.445	30
18:00							98.8	20	98.74	20	98.77	20
19:00												
20:00												
21:00												
22:00												
23:00												
24:00												
Total	68.56	960	68.34	960	68.45	960	894.72	730	906.7	710	900.71	720
The Average Shaded Area per Hour (%) = Total Daily Shaded Area/												
	10						14					
					6.8 %	96 %					64.34 %	51.43%

Table A1.3: The South-facing Radial Form: Shadow Patterns in the Two Seasons

The Rectangular Form													
15th													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	500	500	600	600	700	700	700	600	600	600	500	500	7100
North Facade	1000	1100	1200	1000	800	600	700	900	1200	1200	1000	1000	11700
East Facade	500	600	600	700	700	700	700	700	600	600	500	500	7400
South Facade	0	0	0	300	600	800	700	400	0	0	0	0	2800
Total	500	550	600	650	700	700	700	650	600	600	500	500	7250
21st													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	500	500	600	600	700	700	700	600	600	600	500	500	7100
North Facade	1000	1100	1200	1000	700	600	700	900	1200	1100	1000	1000	11500
East Facade	500	600	600	700	700	700	700	700	600	500	500	500	7300
South Facade	0	0	0	300	700	800	700	400	0	0	0	0	2900
Total	500	550	600	650	700	700	700	650	600	550	500	500	7200
Average													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	500	500	600	600	700	700	700	600	600	600	500	500	7100
North Facade	1000	1100	1200	1000	750	600	700	900	1200	1150	1000	1000	11600
East Facade	500	600	600	700	700	700	700	700	600	550	500	500	7350
South Facade	0	0	0	300	650	800	700	400	0	0	0	0	2850
Total	500	550	600	650	700	700	700	650	600	575	500	500	7225

The Annual Shaded Area Generated by the Rectangular Form

The South-facing Radial Form													
15th													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	200	300	400	500	600	700	700	500	400	400	200	200	5100
Outer Surface-N	960	980	980	910	800	730	770	850	930	1020	940	960	10830
East Facade	200	300	400	500	600	600	600	600	400	400	200	200	5000
Inner Surface-S	83.14	207.05	397.59	646.84	847.54	894.72	872.76	688.37	467.51	309.51	100.96	68.56	5584.55
Total	526.40	595.65	676.11	741.42	772.53	764.37	776.63	736.28	674.01	667.78	522.40	521.86	7975.48
21st													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	200	300	400	500	600	700	600	500	400	300	200	200	4900
Outer Surface-N	960	980	960	880	790	710	770	880	940	990	940	960	10760
East Facade	200	300	400	600	600	600	600	600	400	300	200	200	5000
Inner Surface-S	83.14	207.05	397.59	648.1	847.53	904.55	872.62	687.48	464.42	309.51	100.96	68.56	5591.51
Total	526.40	595.65	666.56	738.06	767.75	757.88	766.02	750.32	677.82	632.33	522.40	521.86	7923.10
Average													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	200	300	400	500	600	700	650	500	400	350	200	200	5000
Outer Surface-N	960	980	970	895	795	720	770	865	935	1005	940	960	10795
East Facade	200	300	400	550	600	600	600	600	400	350	200	200	5000
Inner Surface-S	83.14	207.05	397.59	647.47	847.535	899.635	872.69	687.925	465.965	309.51	100.96	68.56	5588.03
Total	526.40	595.65	671.33	739.74	770.14	761.13	771.32	743.30	675.91	650.05	522.40	521.86	7949.29

The Annual Shaded Area Generated by the South-facing Radial Form

The North-facing Radial Form													
15th													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	800	800	800	800	800	800	800	700	800	800	800	800	9500
Outer Surface-S	40	120	220	390	600	670	630	450	270	180	60	40	3670
East Facade	800	800	800	800	800	700	700	800	800	800	800	800	9400
Inner Surface-N	998.94	1093.72	1175.96	1173.14	1060.76	955.58	999.06	1108.35	1155.72	1190.16	997.91	999.23	12908.5
Total	499.14	566.84	640.18	720.45	785.71	775.81	770.25	718.35	657.74	625.50	508.37	499.23	7767.63
21st													

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Façade	800	800	800	700	800	800	800	700	800	800	800	800	9400
Outer Surface-S	40	120	240	420	610	690	630	420	260	110	60	40	3640
East Façade	800	800	800	800	800	700	800	800	800	800	800	800	9500
Inner Surface-N	998.67	1091.66	1167.27	1144.03	1031.07	948.59	1023.23	1141.9	1165.56	1093	998.32	999.27	12802.5
Total	499.06	566.20	647.02	715.14	781.24	783.18	788.34	714.48	656.03	561.84	508.50	499.25	7720.33
Average													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
West Facade	800	800	800	750	800	800	800	700	800	800	800	800	9450
Outer Surface-S	40	120	230	405	605	680	630	435	265	145	60	40	3655
East Facade	800	800	800	800	800	700	750	800	800	800	800	800	9450
Inner Surface-N	998.80	1092.69	1171.61	1158.58	1045.91	952.08	1011.14	1125.12	1160.64	1141.58	998.11	999.25	12855.5
Total	499.10	566.52	643.60	717.79	783.47	779.49	779.30	716.41	656.89	593.67	508.43	499.24	7743.98

The Annual Shaded Area Generated by the North-facing Radial Form

The Average Annual Shaded Area per an Hour = The Annual Shaded Area/12*12

	The Annual Shaded Area			The Average Annual Shaded Area per an Hour		
	Rectangular	North-facing Form	South-facing Form	Rectangular	North-facing Form	South-facing Form
West Facade	7100	9450	5000	49.31 %	65.63 %	34.72 %
The Inner Surface-North	11600	12855.55	10795	80.56 %	89.27 %	74.97 %
The East Facade	7350	9450	5000	51.04 %	65.63 %	34.72 %
The Outer Surface-South	2850	3655	5588.03	19.79 %	25.38 %	38.81 %
Total Average	7225	7743.984	7949.296	50 %	53.78 %	55.20 %

Table A1.5: The Average Annual Shaded Area per Hour for the Rectangular and Radial Forms

Hour	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
0	-3009	-3268	-2365	-2407	-1681	-760	-115	-544	-1262	-1919	-1760	-2528	-21618
1	-3048	-3297	-2400	-2529	-1814	-901	-225	-667	-1357	-1977	-1801	-2554	-22570
2	-3057	-3338	-2438	-2615	-1926	-1040	-324	-780	-1410	-1974	-1804	-2591	-23297
3	-2901	-3479	-2426	-2694	-2098	-1245	-513	-833	-1437	-2174	-1850	-2705	-24355
4	-2901	-3479	-2426	-2694	-2098	-1245	-513	-833	-1437	-2174	-1850	-2705	-24355
5	-2900	-3520	-2451	-2728	-2149	-1381	-626	-923	-1482	-2221	-1895	-2719	-24995
6	-2927	-3545	-2487	-2775	-2194	-1468	-749	-1010	-1535	-2261	-1932	-2721	-25604
7	-2940	-3553	-2553	-2817	-2241	-1533	-806	-1066	-1578	-2313	-1972	-2759	-26131
8	-2947	-3578	-2591	-2867	-2281	-1504	-820	-1120	-1616	-2363	-1985	-2762	-26434
9	-2963	-3591	-2615	-2871	-2142	-1198	-627	-1057	-1650	-2374	-1988	-2719	-25795
10	-2968	-3602	-2576	-2631	-1777	-727	-242	-814	-1548	-2348	-1956	-2705	-23894
11	-2935	-3567	-2372	-2168	-1285	-122	268	-370	-1215	-2203	-1917	-2681	-20567
12	-2875	-3467	-2032	-1646	-824	278	693	232	-786	-1754	-1814	-2618	-16613
13	-2739	-3176	-1521	-911	-314	625	1121	542	-252	-1240	-1580	-2458	-11903
14	-2456	-2808	-1197	-293	7	877	1448	762	5	-701	-1339	-2141	-7836
15	-2325	-2525	-1025	-158	75	1012	1505	951	81	-361	-1235	-1947	-5952
16	-2155	-2372	-889	-346	-215	907	1382	847	92	-364	-1116	-1842	-6071
17	-2137	-2353	-774	-417	-232	1102	1573	854	96	-334	-1024	-1825	-5471
18	-2264	-2474	-1005	-724	-175	846	1417	789	88	-534	-1157	-1995	-7188
19	-2453	-2651	-1227	-903	-234	755	1220	587	-187	-894	-1296	-2167	-9450
20	-2625	-2827	-1613	-1202	-514	441	845	369	-492	-1237	-1459	-2307	-12621
21	-2697	-3005	-1884	-1545	-773	137	526	135	-672	-1513	-1552	-2379	-15222
22	-2772	-3136	-2083	-1875	-1042	-80	263	-82	-898	-1699	-1607	-2451	-17462
23	-2870	-3212	-2219	-2109	-1266	-346	47	-263	-1086	-1821	-1643	-2499	-19287
Total	-65864	-75823	-47169	-43925	-29193	-6570	6748	-4294	-21538	-38753	-39532	-58778	-424691

The Rectangular Form: Annual Loads - Fabric Gains - sQc + sQs

Hour	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
0	-3008	-3267	-2364	-2406	-1681	-760	-115	-544	-1262	-1919	-1759	-2527	-21612
1	-3047	-3296	-2399	-2528	-1813	-901	-225	-666	-1356	-1976	-1801	-2553	-22561

2	-3056	-3337	-2437	-2614	-1925	-1039	-323	-780	-1409	-1973	-1804	-2590	-23287
3	-2900	-3478	-2425	-2693	-2098	-1244	-513	-833	-1437	-2173	-1850	-2704	-24348
4	-2900	-3478	-2425	-2693	-2098	-1244	-513	-833	-1437	-2173	-1850	-2704	-24348
5	-2899	-3518	-2451	-2727	-2149	-1380	-626	-923	-1482	-2220	-1894	-2718	-24987
6	-2925	-3544	-2486	-2774	-2193	-1468	-749	-1009	-1535	-2260	-1931	-2720	-25594
7	-2939	-3552	-2552	-2816	-2241	-1532	-806	-1065	-1577	-2312	-1971	-2758	-26121
8	-2946	-3577	-2590	-2866	-2285	-1511	-824	-1120	-1616	-2362	-1984	-2761	-26442
9	-2962	-3590	-2614	-2880	-2158	-1236	-653	-1069	-1650	-2373	-1988	-2718	-25891
10	-2967	-3600	-2584	-2664	-1837	-823	-327	-856	-1564	-2350	-1955	-2704	-24231
11	-2934	-3576	-2410	-2225	-1323	-187	198	-433	-1274	-2228	-1920	-2680	-20992
12	-2887	-3494	-2119	-1800	-941	152	571	74	-913	-1849	-1836	-2628	-17670
13	-2775	-3245	-1694	-1189	-543	409	875	308	-453	-1383	-1629	-2486	-13805
14	-2521	-2906	-1372	-643	-273	565	1097	493	-204	-852	-1396	-2197	-10209
15	-2393	-2619	-1186	-421	-173	740	1211	712	-108	-511	-1313	-2022	-8083
16	-2234	-2478	-1032	-548	-407	688	1147	648	-81	-487	-1193	-1913	-7890
17	-2214	-2458	-939	-648	-444	823	1270	629	-84	-479	-1099	-1892	-7535
18	-2326	-2558	-1168	-960	-408	553	1094	536	-92	-675	-1204	-2041	-9249
19	-2484	-2706	-1366	-1100	-425	532	968	372	-321	-984	-1324	-2186	-11024
20	-2626	-2855	-1683	-1322	-610	341	724	222	-553	-1280	-1458	-2306	-13406
21	-2696	-3004	-1906	-1587	-819	84	480	76	-699	-1513	-1552	-2378	-15514
22	-2771	-3135	-2082	-1892	-1068	-132	208	-108	-901	-1699	-1606	-2451	-17637
23	-2869	-3210	-2218	-2108	-1274	-365	27	-266	-1085	-1821	-1642	-2498	-19329
Total	-66279	-76481	-48502	-46104	-31186	-8935	4196	-6435	-23093	-39852	-39959	-59135	-441765
The Radial Form: Annual Loads - Fabric Gains - sQc + sQs													

Table A1.8: Fabric Gains (sQc + sQs) of the Radial and Rectangular Forms

Appendix A2: The Shadow Analyses of the Radial and Rectangular Urban Patterns

Day 15th													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
South Block-WF	500	500	600	600	700	700	700	600	600	600	500	500	7100
South Block-NF	1000	1100	1200	1000	800	600	700	900	1200	1200	1000	1000	11700
South Block-EF	500	600	600	700	700	700	700	700	600	600	500	500	7400
South Block-SF	0	0	0	300	600	800	700	400	0	0	0	0	2800
South Block	500	550	600	650	700	700	700	650	600	600	500	500	7250
North Block-WF	500	500	600	600	700	700	700	600	600	600	500	500	7100
North Block-NF	1000	1100	1200	1000	800	600	700	900	1200	1200	1000	1000	11700
North Block-EF	500	600	600	700	700	700	700	700	600	600	500	500	7400
North Block-SF	23.5	0	0	300	600	800	700	400	0	0	8.1	45.9	2877.5
North Block	509.54	550	600	650	700	700	700	650	600	600	503.28	518.63	7281.46
Total Rec. Pattern	505.59	550	600	650	700	700	700	650	600	600	501.92	510.93	7268.45
Day 21st													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
South Block-WF	500	500	600	600	700	700	700	600	600	600	500	500	7100
South Block-NF	1000	1100	1200	1000	700	600	700	900	1200	1100	1000	1000	11500
South Block-EF	500	600	600	700	700	700	700	700	600	500	500	500	7300
South Block-SF	0	0	0	300	700	800	700	400	0	0	0	0	2900
South Block	500	550	600	650	700	700	700	650	600	550	500	500	7200
North Block-WF	500	500	600	600	700	700	700	600	600	600	500	500	7100
North Block-NF	1000	1100	1200	1000	700	600	700	900	1200	1100	1000	1000	11500
North Block-EF	500	600	600	700	700	700	700	700	600	500	500	500	7300
North Block-SF	16.1	0	0	300	700	800	700	400	0	0	14.7	47.3	2978.1
North Block	506.53	550	600	650	700	700	700	650	600	550	505.96	519.20	7231.71
Total Rec. Pattern	503.83	550	600	650	700	700	700	650	600	550	503.50	511.26	7218.60

Average													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
South Block-WF	500	500	600	600	700	700	700	600	600	600	500	500	7100
South Block-NF	1000	1100	1200	1000	750	600	700	900	1200	1150	1000	1000	11600
South Block-EF	500	600	600	700	700	700	700	700	600	550	500	500	7350
South Block-SF	0	0	0	300	650	800	700	400	0	0	0	0	2850
South Block	500	550	600	650	700	700	700	650	600	575	500	500	7225
North Block-WF	500	500	600	600	700	700	700	600	600	600	500	500	7100
North Block-NF	1000	1100	1200	1000	750	600	700	900	1200	1150	1000	1000	11600
North Block-EF	500	600	600	700	700	700	700	700	600	550	500	500	7350
North Block-SF	19.8	0	0	300	650	800	700	400	0	0	11.4	46.6	2927.8
North Block	508.03	550	600	650	700	700	700	650	600	575	504.62	518.92	7256.58
Total Rec. Pattern	504.71	550	600	650	700	700	700	650	600	575	502.71	511.09	7243.53

The Annual Shaded Area of the Rectangular Pattern - Urban Canyon Oriented East West

15th													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
South Block-NF	1000	1080	1100	980	790	680	710	910	1040	1150	1000	1000	11440
South Block-EF	300	400	500	600	700	700	600	600	500	500	400	400	6200
South Block-SF	0	27.38	205.14	509.83	773.53	862.03	829.71	583.12	285.73	103.28	0	0	4179.75
South Block-WF	400	400	500	600	700	700	700	600	500	500	400	400	6400
South Block	513.83	569.50	659.49	729.26	758.37	739.20	727.14	722.03	658.49	650.17	528.73	528.73	7784.99
North Block-NF	1000	1080	1100	980	790	680	710	910	1040	1150	1000	1000	11440
North Block-EF	300	400	500	600	700	700	600	600	500	500	400	400	6200
North Block-SF	30.04	27.55	199.19	460.75	709.61	807.82	770.85	519.75	267.04	102.89	15.05	51.93	3962.47
North Block-WF	400	400	500	600	700	700	700	600	500	500	400	400	6400
North Block	519.48	563.04	654.38	717.16	743.85	731.83	722.50	708.18	653.22	640.31	522.57	536.51	7713.09
Total Rad. Pattern	517.39	566.62	665.16	743.72	782.73	771.90	760.16	738.57	667.55	648.43	524.85	533.63	7920.75

21st													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
South Block-NF	1000	1080	1050	940	750	670	760	940	1080	1080	1000	1000	11350
South Block-EF	300	500	500	600	700	700	600	600	500	400	400	300	6100
South Block-SF	0	41.47	250.96	547.17	792.86	865.28	805.88	551.84	240.84	33.41	0	0	4129.71
South Block-WF	400	400	500	600	700	700	700	600	500	500	400	400	6400
South Block	513.83	588.52	652.41	723.80	747.64	736.06	740.65	725.16	661.74	586.16	528.73	513.83	7718.59
North Block -NF	1000	1080	1050	940	750	670	760	940	1080	1080	1000	1000	11350
North Block-EF	300	500	500	600	700	700	600	600	500	400	400	300	6100
North Block-SF	22.3	41.08	240.51	489.22	733.29	811.51	744.98	492.74	228.68	33.29	22.89	53	3913.49
North Block-WF	400	400	500	600	700	700	700	600	500	500	400	400	6400
North Block	516.56	576.91	647.66	710.05	734.93	728.75	735.06	711.38	656.59	573.96	525.53	528.17	7645.60
Total Rad. Pattern	515.55	583.00	660.29	738.84	773.98	768.94	772.04	740.38	668.93	579.93	526.71	522.86	7851.50

Average													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
South Block-NF	1000	1080	1075	960	770	675	735	925	1060	1115	1000	1000	11395
South Block-EF	300	450	500	600	700	700	600	600	500	450	400	350	6150
South Block-SF	0	34.425	228.05	528.5	783.195	863.65	817.79	567.48	263.285	68.345	0	0	4154.73
South Block-WF	400	400	500	600	700	700	700	600	500	500	400	400	6400
South Block	513.83	579.01	655.95	726.53	753.00	737.63	733.90	723.60	660.11	618.16	528.73	521.28	7751.79
North Block -NF	1000	1080	1075	960	770	675	735	925	1060	1115	1000	1000	11395
North Block-EF	300	450	500	600	700	700	600	600	500	450	400	350	6150
North Block-SF	26.17	34.31	219.85	474.98	721.45	809.66	757.91	506.24	247.86	68.09	18.97	52.46	3937.98
North Block-WF	400	400	500	600	700	700	700	600	500	500	400	400	6400
North Block	518.02	569.98	651.02	713.60	739.39	730.29	728.78	709.78	654.91	607.14	524.05	532.34	7679.35
Total Rad. Pattern	516.47	574.81	662.72	741.28	778.35	770.42	766.10	739.47	668.24	614.18	525.78	528.25	7886.13

The Annual Shaded Area of the Radial Pattern - Urban Canyon Oriented East West

	The Average Annual Shaded Area per one Hour			
	The Rectangular Form		The Radial Form	
The South Block-NF	11600/144	80.56	11395/144	79.13
The South Block-EF	7350/144	51.04	6150/144	42.71

The South Block-SF	2850/144	19.79	4154.73/144	28.85
The South Block-WF	7100/144	49.31	6400/144	44.44
The South Block	7225/144	50.17	7751.79/144	53.83
The North Block -NF	11600/144	80.56	11395/144	79.13
The North Block-EF	7350/144	51.04	6150/144	42.71
The North Block-SF	2927.8/144	20.33	3937.98/144	27.35
The North Block-WF	7100/144	49.31	6400/144	44.44
The North Block	7256.58/144	50.39	7679.35/144	53.33
Total Pattern	7243.53/144	50.30	7886.13/144	54.76

Table A2.5: The Annual Shaded Area Generated in the Radial and Rectangular Patterns

Appendix A3: The Shadow Analyses of the Radial Forms with Different Concavities

Time	The Inner Surface - South Facade						The Outer surface - North Facade					
	15th		21st		Average		15th		21st		Average	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
01:00												
02:00												
03:00												
04:00												
05:00	99.95		99.96		99.955		10		10		10	
06:00	99.05		99.11		99.08		20		20		20	
07:00	95.85	0	95.99	0	95.92	0	30	100	30	100	30	100
08:00	87.8	0	88.17	0	87.985	0	40	100	40	100	40	100
09:00	67.66	0	68.51	0	68.085	0	60	100	50	100	55	100
10:00	39.45	0	40.56	0	40.005	0	70	100	70	100	70	100
11:00	0	0	0	0	0	0	100	100	100	100	100	100
12:00	0	0	0	0	0	0	100	100	100	100	100	100
13:00	26.71	0	26.49	0	26.6	0	80	100	80	100	80	100
14:00	59.7	0	59.5	0	59.6	0	60	100	60	100	60	100
15:00	83.23	0	83.09	0	83.16	0	50	100	50	100	50	100
16:00	94.13	0	94.06	0	94.095	0	30	100	30	100	30	100
17:00	98.43		98.4		98.415		20		20		20	
18:00	99.84		99.83		99.835		10		10		10	
19:00												
20:00												
21:00												
22:00												
23:00												
24:00												
Total	951.8	0	953.67	0	952.735	0	680	1000	670	1000	675	1000
					68.05 %	0 %					48.21 %	100 %
The average daily shaded area per one hour in summer = The total shaded area generated during daytime/ number of hours (14)												
The Inner Surface - South Facade							952.735/14 = 68.05 %					
The Outer Surface - North Facade							675/14 = 48.21 %					
The average daily shaded area per one hour in winter = The total shaded area generated during daytime / number of hours (10)												
The Inner Surface - South Facade							0/10 = 0 %					
The Outer Surface - North Facade							1000/10 = 100 %					

Table A3.1: South-facing Radial Form-60/360: The Shadow Pattern in the Two Seasons

	15th												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
The West Facade	300	400	500	500	700	700	700	600	500	400	300	300	5900
The North Facade	1000	1060	1060	950	820	680	750	900	1000	1110	1000	1000	11330

The East Facade	300	400	400	600	600	600	600	600	500	500	300	300	5700
The South Facade	0	70.28	281.11	594.13	851.3	951.8	912.15	666.81	369.27	179.57	0	0	4876.4
Total	519.991	595.52	665.19	730.42	773.01	739.29	758.84	743.87	678.34	660.57	519.99	519.99	7905.0
21st													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
The West Facade	400	400	500	500	700	700	700	500	500	400	300	300	5900
The North Facade	990	1050	1030	920	780	670	770	920	1040	1050	1000	1000	11220
The East Facade	300	400	500	600	600	600	600	600	500	400	300	300	5700
The South Facade	11.53	94.63	324.6	634.11	887.07	953.67	886.28	635.79	329.07	100.14	0	0	4856.8
Total	534.843	597.47	679.69	727.88	765.17	735.54	760.74	728.30	685.06	598.87	519.9	519.99	7853.5
Average													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
The West Facade	350	400	500	500	700	700	700	550	500	400	300	300	5900
The North Facade	995	1055	1045	935	800	675	760	910	1020	1080	1000	1000	11275
The East Facade	300	400	450	600	600	600	600	600	500	450	300	300	5700
The South Facade	5.765	82.455	302.85	614.12	869.18	952.73	899.21	651.3	349.17	139.85	0	0	4866.6
Total	527.417	596.50	672.44	729.15	769.09	737.42	759.79	736.09	681.70	629.72	519.99	519.99	7879.3

The Average Annual Shaded Area per One Hour = The Annual Shaded Area/12*12		
	The Annual Shaded Area	The Annual Shaded Area /One Hour
The West Facade	5900/144	40.97 %
The North Facade	11275/144	78.30 %
The East Facade	5700/144	39.58 %
The South Facade	4866.655/144	33.80 %
Total Average	7879.344/144	54.72 %

Table A3.6: South-facing Radial Form-60/360: The Annual Shaded Area

Appendix A4: The Thermal Calculations of the Radial Forms and the Rectangular U-Shapes

Mean Surface Temperature													
The U-Shape - South-facing Forms													
(Hrs)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
01:00	17.96	18.43	19.19	22.25	22.98	23.07	23.17	23.28	23.16	22.8	22.42	18.39	257.1
02:00	17.95	18.39	19.16	22.23	22.97	23.05	23.15	23.26	23.15	22.78	22.41	18.32	256.82
03:00	17.94	18.3	19.05	22.22	22.95	23.04	23.14	23.25	23.14	22.77	22.4	18.31	256.51
04:00	17.93	18.28	18.9	22.17	22.94	23.03	23.13	23.24	23.13	22.76	22.25	18.3	256.06
05:00	17.92	18.27	18.72	21.97	22.93	23.02	23.12	23.23	23.12	22.75	22.2	18.29	255.54
06:00	17.92	18.26	18.66	21.88	22.92	23.01	23.11	23.23	23.11	22.74	22.15	18.28	255.27
07:00	17.91	18.25	18.61	21.82	22.91	23	23.11	23.22	23.1	22.73	22.1	18.27	255.03
08:00	17.91	18.25	18.57	21.77	22.9	22.99	23.1	23.22	23.1	22.73	22.06	18.27	254.87
09:00	17.91	18.25	18.53	21.72	22.9	22.99	23.1	23.22	23.1	22.72	22.03	18.27	254.74
10:00	17.91	18.25	18.53	21.7	22.9	22.99	23.1	23.22	23.1	22.73	22	18.27	254.7
11:00	17.91	18.25	18.53	21.68	22.91	23	23.11	23.22	23.1	22.73	21.99	18.27	254.7
12:00	17.92	18.26	18.54	21.69	22.92	23.01	23.12	23.23	23.11	22.74	22	18.28	254.82
13:00	17.92	18.27	18.55	21.73	22.94	23.03	23.14	23.24	23.12	22.75	22.02	18.29	255
14:00	17.93	18.28	18.59	21.81	22.97	23.06	23.16	23.27	23.15	22.78	22.06	18.3	255.36
15:00	17.96	18.31	18.67	21.9	23	23.09	23.19	23.3	23.18	22.8	22.13	18.33	255.86
16:00	17.98	18.33	18.75	21.99	23.03	23.11	23.21	23.32	23.2	22.83	22.21	18.35	256.31
17:00	18	18.35	18.87	22.2	23.05	23.14	23.23	23.34	23.22	22.85	22.28	18.37	256.9
18:00	18.01	18.37	19.08	22.34	23.07	23.15	23.25	23.36	23.24	22.87	22.48	18.38	257.6
19:00	18.02	18.43	19.22	22.35	23.08	23.16	23.26	23.36	23.25	22.87	22.48	18.39	257.87
20:00	18.02	18.51	19.29	22.35	23.08	23.16	23.26	23.36	23.24	22.87	22.48	18.43	258.05
21:00	18.01	18.53	19.3	22.34	23.07	23.15	23.25	23.36	23.24	22.86	22.47	18.46	258.04
22:00	18	18.49	19.26	22.32	23.06	23.14	23.23	23.34	23.22	22.85	22.46	18.43	257.8
23:00	17.98	18.43	19.2	22.3	23.03	23.12	23.21	23.32	23.2	22.83	22.44	18.41	257.47
24:00	17.97	18.44	19.21	22.28	23.01	23.09	23.19	23.3	23.18	22.81	22.43	18.42	257.33
Total	430.89	440.18	452.98	529.01	551.52	553.6	556.04	558.69	555.86	546.95	533.95	440.08	6149.75

The Radial Form - South-facing Forms													
01:00	17.96	18.48	19.22	22.25	22.98	23.07	23.17	23.28	23.16	22.8	22.44	18.48	257.29
02:00	17.95	18.44	19.18	22.24	22.97	23.05	23.15	23.26	23.15	22.78	22.43	18.4	257
03:00	17.94	18.34	19.1	22.22	22.95	23.04	23.14	23.25	23.14	22.77	22.42	18.33	256.64
04:00	17.93	18.29	18.94	22.18	22.94	23.03	23.13	23.24	23.13	22.76	22.34	18.32	256.23
05:00	17.92	18.28	18.76	21.97	22.93	23.02	23.12	23.23	23.12	22.75	22.29	18.31	255.7
06:00	17.92	18.27	18.7	21.88	22.92	23.01	23.11	23.23	23.11	22.74	22.24	18.3	255.43
07:00	17.91	18.27	18.65	21.82	22.91	23	23.11	23.22	23.1	22.73	22.19	18.29	255.2
08:00	17.91	18.26	18.61	21.77	22.9	22.99	23.1	23.22	23.1	22.73	22.15	18.29	255.03
09:00	17.91	18.26	18.57	21.73	22.9	22.99	23.1	23.22	23.1	22.72	22.11	18.29	254.9
10:00	17.91	18.26	18.55	21.7	22.9	22.99	23.1	23.22	23.1	22.73	22.09	18.29	254.84
11:00	17.91	18.27	18.55	21.69	22.91	23	23.11	23.22	23.1	22.73	22.08	18.29	254.86
12:00	17.92	18.27	18.56	21.69	22.92	23.01	23.12	23.23	23.11	22.74	22.08	18.3	254.95
13:00	17.92	18.28	18.57	21.74	22.94	23.03	23.14	23.24	23.12	22.75	22.1	18.31	255.14
14:00	17.93	18.29	18.63	21.81	22.97	23.06	23.16	23.27	23.15	22.78	22.15	18.32	255.52
15:00	17.96	18.32	18.71	21.9	23	23.09	23.19	23.3	23.18	22.8	22.22	18.34	256.01
16:00	17.98	18.34	18.79	21.99	23.03	23.11	23.21	23.32	23.2	22.83	22.29	18.37	256.46
17:00	18	18.36	18.91	22.21	23.05	23.13	23.23	23.34	23.22	22.85	22.37	18.39	257.06
18:00	18.01	18.38	19.12	22.34	23.07	23.15	23.25	23.36	23.24	22.87	22.5	18.4	257.69
19:00	18.02	18.48	19.25	22.35	23.08	23.16	23.26	23.36	23.25	22.87	22.51	18.43	258.02
20:00	18.02	18.55	19.32	22.35	23.08	23.16	23.25	23.36	23.24	22.87	22.5	18.52	258.22
21:00	18.01	18.58	19.33	22.34	23.07	23.15	23.25	23.36	23.24	22.86	22.5	18.56	258.25
22:00	18	18.57	19.32	22.32	23.06	23.14	23.23	23.34	23.22	22.85	22.48	18.57	258.1
23:00	17.98	18.55	19.29	22.3	23.03	23.12	23.21	23.32	23.2	22.83	22.46	18.55	257.84
24:00	17.97	18.51	19.25	22.28	23.01	23.09	23.19	23.3	23.18	22.81	22.45	18.52	257.56
Total	430.89	440.9	453.88	529.07	551.52	553.59	556.03	558.69	555.86	546.95	535.39	441.17	6153.94

	Mean Surface Temperature		The Shaded Area	
The South-facing Forms	The U-Shape	The Radial Form	The U-Shape	The Radial Form
	6149.75/288	6153.94/288		
The Average Annual Mean Surface Temperature	21.35 °C	21.37 °C	55.62 %	53.82 %

Table A4.16: The Monthly Distribution of the Mean Surface Temperature in the South-facing Forms

Conduction													
The U-Shape - South-facing Forms													
(Hrs)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
01:00	-5347	0	0	2579	14808	15959	17345	19230	17464	10805	2997	0	95840
02:00	-5964	0	0	2240	14495	15796	17122	19011	17084	10045	2098	-7	91920
03:00	-7443	0	0	1111	13920	15516	16861	18179	15790	8393	164	-1894	80597
04:00	-9926	-2010	0	0	12608	14360	15780	16896	13756	5765	0	-3772	63457
05:00	-10352	-3494	0	0	10457	12481	13977	14792	11876	5059	0	-4291	50505
06:00	-10802	-3944	0	0	8646	10249	11885	13517	11338	4450	0	-4840	40499
07:00	-11246	-4388	0	0	8009	9692	11411	13039	10808	3851	0	-5381	35795
08:00	-11653	-4795	0	0	7424	9182	10977	12600	10323	3301	0	-5876	31483
09:00	-11995	-5137	0	0	6933	8752	10612	12230	9914	2838	0	-6293	27854
10:00	-12250	-5392	-306	0	6567	8433	10341	11956	9610	2494	0	-6603	24850
11:00	-12399	-5541	-507	0	6353	8246	10181	11795	9432	2292	0	-6785	23067
12:00	-12433	-5575	-553	0	6352	8268	10180	11758	9391	2247	0	-6826	22809
13:00	-12349	-5491	-405	0	6718	8622	10497	12033	9601	2403	0	-6724	24905
14:00	-12102	-5177	0	0	7295	9160	11001	12541	10120	2910	0	-6423	29325
15:00	-11591	-4619	0	0	8006	9814	11605	13157	10765	3578	0	-5851	34864
16:00	-10992	-3993	0	0	9551	11549	12834	13817	11461	4316	0	-5186	43357
17:00	-10384	-3367	0	0	12106	13936	15328	16315	13346	5705	0	-4503	58482
18:00	-8985	-1295	0	419	13694	15436	16850	17993	15628	8370	23	-2842	75291
19:00	-6666	0	0	2061	14578	16189	17640	19300	17180	10014	1951	-561	91686

20:00	-5484	0	0	2742	15089	16381	17929	19781	17770	10808	2908	0	97924
21:00	-5062	0	0	2863	15099	16349	17870	19742	17774	10924	3162	0	98721
22:00	-5240	0	0	2456	14633	15870	17364	19224	17267	10504	2862	0	94940
23:00	-5643	0	0	2190	14429	15539	16876	18780	17092	10564	2903	0	92730
24:00	-5342	0	0	2592	14821	15941	17294	19190	17432	10842	3177	0	95947
Total	-221650	-64218	-1771	21253	262591	301720	339760	376876	322222	152478	22245	-84658	1426848
The Radial Form - South-facing Forms													
01:00	-4712	0	0	2375	14582	15744	17102	18961	17256	10888	3863	0	96059
02:00	-5444	0	0	2094	14387	15633	16998	18817	16893	10179	2919	0	92476
03:00	-6928	0	0	1280	13860	15273	16674	18242	15918	8599	1004	-1046	82876
04:00	-9390	-1503	0	0	12600	14272	15750	17003	13836	5975	0	-2914	65629
05:00	-9816	-2978	0	0	10355	12318	13847	14736	11889	5273	0	-3432	52192
06:00	-10265	-3428	0	0	8560	10107	11769	13469	11352	4665	0	-3980	42249
07:00	-10709	-3871	0	0	7923	9551	11297	12991	10823	4066	0	-4520	37551
08:00	-11115	-4278	0	0	7339	9041	10863	12552	10338	3517	0	-5015	33242
09:00	-11457	-4620	0	0	6848	8612	10498	12183	9929	3055	0	-5432	29616
10:00	-11712	-4874	0	0	6482	8293	10227	11909	9626	2711	0	-5742	26920
11:00	-11861	-5023	-163	0	6268	8105	10068	11748	9447	2509	0	-5924	25174
12:00	-11895	-5058	-209	0	6267	8127	10066	11711	9406	2462	0	-5965	24912
13:00	-11812	-4974	-62	0	6630	8479	10381	11983	9615	2618	0	-5864	26994
14:00	-11566	-4662	0	0	7205	9015	10883	12490	10132	3123	0	-5564	31056
15:00	-11057	-4106	0	0	7914	9666	11485	13104	10774	3788	0	-4994	36574
16:00	-10459	-3482	0	0	9445	11387	12704	13762	11468	4524	0	-4331	45018
17:00	-9853	-2858	0	0	12055	13803	15223	16307	13405	5904	0	-3650	60336
18:00	-8463	-797	0	700	13666	15261	16772	18178	15767	8562	855	-1997	78504
19:00	-6159	0	0	1939	14487	15970	17486	19143	16996	10107	2766	0	92735
20:00	-4941	0	0	2540	14875	16200	17733	19530	17551	10911	3792	0	98191
21:00	-4351	0	0	2687	14826	16070	17589	19480	17682	11256	4293	0	99532
22:00	-4149	0	0	2562	14505	15627	17146	19184	17590	11339	4476	0	98280
23:00	-4197	0	0	2457	14379	15397	16851	18972	17468	11263	4415	0	97005
24:00	-4415	0	0	2467	14558	15656	17018	18987	17369	11109	4252	0	97001
Total	-206726	-56512	-434	21101	260016	297607	336430	375442	322530	158403	32635	-70370	1470122

	Conduction (Watts)			The Shaded Area		
	The U-Shape	The Radial Form	Variation	The U-Shape	The Radial Form	Variation
The South-facing	1426848	1470122		55.62 %	53.82 %	1.80 %
	97.06 %	100 %	2.94 %			

Table A4.18: The Monthly Distribution of the Conduction Heat Gains in the South-facing Forms

Appendixes B: Software Description

Appendix B1: SunCast: Solar Shading and Analysis Software

1. Introduction to SunCast

Managing the effects of the sun has always been a feature of good building design. IES (Virtual Environment) takes solar analysis into the 21st Century with its powerful SunCast software. SunCast is a powerful solar analysis program that performs solar geometry studies on a building and its site. SunCast performs shading and solar insolation analysis studies and can generate images and animations quickly and easily. SunCast enables you to understand and control the geometric relationship between the sun and the building. It performs graphical and numerical solar studies, visualise shading and solar penetration, optimise building position and orientation, assess right to light, and minimise cooling plant or heating requirements.

SunCast can be used at any stage of the design process and creates solar shading and insolation information from a model created by the IES ModelBuilder or from 2D or 3D CAD data. It can be used at the earliest stages of the design process to maximise site orientation, for right to light studies and when seeking planning approval.

SunCast can be used to investigate:

- External obstruction and self-shading of a building;
- Solar mapping through windows and openings;
- The effects of changing orientation of building.

SunCast generates shadows and internal solar insolation from any sun position defined by date, time, orientation, site latitude and longitude. This shadow information can be stored for subsequent analysis by:

- Viewing shadows from any eye position;
- Animating the solar analyses by generating a sequence of images and creating an avi movie to send to your client.
- Making opaque surfaces "transparent" to permit the user to better view the solar insolation on internal surfaces e.g. “removing” roofs or surfaces to identify internal solar insolation paths;
- Displaying solar surface shading/insolation statistics

SunCast can be used in a variety of studies including passive solar design and is essential at the planning stage to visualise the effect of the building on surrounding buildings. SunCast has also been used to study problems such as grass growth in sports stadia and ‘right of light’ issues. In addition, because it is possible to remove surfaces to investigate solar penetration, SunCast can be used to investigate internal design issues from office layouts to positioning of art in museums.

2. SunCast Features
2.1 Model Data
2.1.1 Interoperability

• Uses the Integrated Data Model from IES <Virtual Environment>.
• Derives site location and orientation from the Integrated Data Model.
• Generates solar shading files for use by APACHE system to improve the quality of the thermal analysis.

2.1.2 Shading Analyses

• Preview – single time-step shading view, defined by date, time, azimuth and altitude.
• Daily shading analysis – user-defined view and time-step options to set up series of images for a particular view, date and time period.
• Fly-round – single time-step fly round sequence for a particular rotational view series for a particular date and time.
• View scripting – complex user defined sequence of time and view options.

2.1.3 Other Analyses

• Sunrise/sunset times – table of monthly data.
• Sunrise/sunset chart – annual graph.

• Sunpath diagram – shows solar position in terms of azimuth and altitude.
• Numerical solar shading analysis that generates a file for use in the APACHE system.
• Display Site location.
• Display Site orientation.
• Make rooms and/or surfaces 'invisible' to enable you to see where the sun has fallen on internal surfaces at any particular time.

2.2 Outputs and deliverables
2.2.1 Display Features

• Store images (add and delete).
• Zoom in and out of any image. Zoom can be fixed or user -defined.
• Set zoom on series of images.
• Create an AVI animation from a series of images.

2.2.2 Analysis Options

• Define colours of different surface 'types' e.g. walls, floors, and ground.
• Switch ground shadow On/Off.
• Set position (height) of ground shadow.
• Show/hide obstructions.
• Set status of zones/surfaces.

3. How SunCast works
3.1 SunCast Geometry

SunCast takes its geometry from the IES <Virtual Environment> Integrated Data Model (IDM). It understands that solar rays pass through windows and holes as defined. You can also create the geometry for surrounding site buildings or shading devices, using IES ModelBuilder products.

3.2 Sun Position

SunCast calculates the position of the Sun in the sky, tracks solar insolation throughout the building interior and calculates all shadows. To perform these analyses, Suncast draws on:

- The bearing angle of your model and the Latitude and Longitude of the site (already defined)
- The date and time
- Your viewing position in terms of altitude and azimuth.

3.3 Generating Images

SunCast can generate images of the effects of the sun on the building, seen from your 'viewing' position. You can zoom in on any point in the image to clarify what is happening. Options for generating series of images include daily and fly-around. These can be animated to create a windows compatible 'movie', helping you to communicate how the sun impacts on a building and enhance presentations. For each image you can choose to make rooms and/or surfaces invisible. This enables you to see which internal surfaces receive solar radiation through windows and holes.

3.4 Numerical Analysis

You can also perform a numerical analysis of your building. SunCast will create a file containing the time-series solar shading information for each external and internal surface. The information can be used by IES APACHE to refine the solar gain calculations performed as part of thermal analysis.

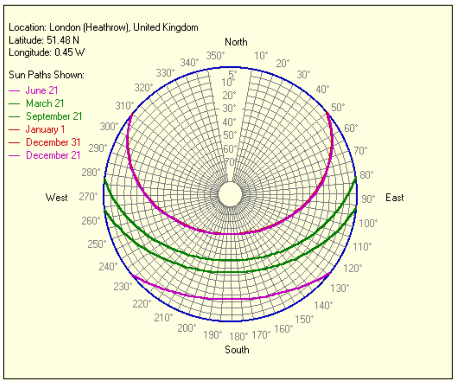
4. Calculations Menu

This menu item allow access to the main calculation functionality in Suncast.

4.1 Sunrise/Sunset times: This window displays the Sun-up / Sun-down times and the azimuth of the sun at the horizon for any day of the year. The data is specific to the location defined in the project.

4.2 SunPath diagram: The SunPath digram in SunCast is a reduced functionality version of the Facet suite's SunPath program.

The diagram for the sun path looks like this:



The diagram represents the sky with the apparent paths of the sun shown for one or more days. Compass directions are shown round the outside of the diagram (these give the azimuth of the sun), and each of the internal circles represents altitude. This gives a plot of the sun's course. The latitude of the observer is shown in the top sector of the plot. This is reversed for observers in the Southern Hemisphere.

4.3 Solar Shading for Apache

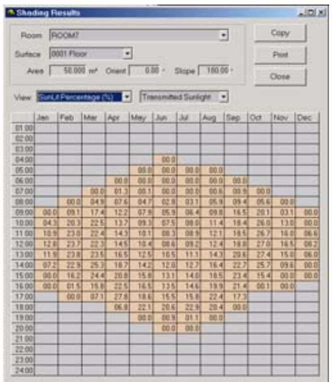
APACHE (Applications Program for Air-Conditioning and Heating Engineers) is a comprehensive program for analysing the thermal performance and energy use of buildings. It examines the thermal properties of constructional elements, calculate heat gains and losses, calculate heating energy requirements using the degree-day method, check for conformance with Building Regulations, and perform dynamic simulations of system and building operation. The dialogue is used to define the calculation parameters for performing the shading solar calculations for the APACHE program.

4.4 Shading Results

This window allow the user to interrogate the results of a previously run calculation for shading analysis (carried out in the current session). The shading analysis is automatically stored in a \suncast\projectname.shd file, so that APACHE can use them later.

The Shading Results dialogue: The shading results are analyzed with the dialogue described in the following table:

- Room: Select the room which you want to analyse.
- Surface: Select the required surface.
- Area: Displays the area of the selected surface.
- Orient: Displays the orientation of the surface.
- Slope: Displays the inclination (slope) of the surface.
- View: Contains two associated drop-down boxes:



Analysis Type	Description
Shaded Area	The area (in square metres) that is shaded.
Shaded Percentage	The area (as a % of total area) that is shaded.
Sunlit Area	The area (in square metres) that is illuminated by the sun.
Sunlit Percentage	The area (as a % of total area) that is illuminated by the sun.

Light type	Description
Direct Sunlight	Light that is directly incident from the sun.
Transmitted Sunlight	Light that has traveled through an intermediate medium (i.e. glazing)

Appendix B2: Apache
1. Introduction

The Apache view is a view within the Virtual Environment's Thermal category. Apache is the name given to the thermal analysis programs in the Virtual Environment. The Apache view provides facilities for:

- Preparation of input data for the thermal analysis programs Part L, APcalc, APsim
- Calculations and simulations using APcalc, APsim, APhvac and MacroFlo and Part L

The preparation of thermal input data consists of three main tasks:

- Specification of building location and weather data
- Specification of building element data (properties of the building fabric)
- Specification of room data (conditions in each room)

The interfaces to the thermal analysis programs provide facilities for:

- Setting up the calculations and simulations
- Specifying the results to be recorded

2. Thermal Analysis: CIBSE Heat Loss & Heat Gain (APcalc)

The program CIBSE Heat Loss & Heat Gain (APcalc) performs heat loss and heat gain calculations according to the procedures laid down in CIBSE Guide A (1995, 1999, 2001). It also covers checks under Part L of the Building Regulations (England and Wales) and CIBSE B18 annual energy estimates.

2.1 Calculation Methods: Heat Gain
2.1.1 Heat Gain Methodology

The Heat Gains program is based on the 'Simple Model' described in Section 5.6.3 and Appendix 5A.2 of the CIBSE Guide [CIBSE Guide A Environmental Design - The Chartered Institution of Building Services Engineers, London, 1999]. The method has been extended within the guidelines set out in the Guide to provide a more general and accurate treatment of solar gains through glazing. The main features of the 'Simple Model' are as follows:

- The method calculates heat gains and losses by conduction, infiltration and mechanical ventilation.
- Conduction calculations are based on the CIBSE Admittance method.
- The calculations are performed for the 24 hours of each design day, on the hour.
- The program makes allowance for casual and solar gains.
- Heat gains from adjacent rooms may be accounted for at the user's option, using the Modified U-value method described in Section 5.5.3 of the Guide.
- Long-wave radiation exchange is modelled using a single radiant temperature for each room.
- Outside environmental temperature includes an allowance for solar gain on opaque surfaces. Convective/radiant surface resistances may be modified by the user.
- The radiant fraction sensed by the thermostat is under the user's control.
- The cooling plant is assumed to be purely convective.
- Solar gain through glazing is accounted for through the use of solar gain factors.

Extensions to the 'Simple Model' are applied as follows:

External shading may be taken into account through the use of shading files generated by SunCast or SunCast Lite and calculations of local shading by window recesses and overhangs.

2.1.2 Solar Radiation
2.1.2.1 Meterological solar variables

The program generates design values of direct solar irradiance for clear sky conditions using the following parameters set in APlocate:

- Latitude & longitude
- Standard meridian (time zone) and local time correction
- Height above sea level

- Haze factor
- Precipitable water content

A detailed description of the method is provided in [Atmospheric Effects on Solar Radiation for Computer Analysis of Cooling Loads for Buildings at Various Location Heights, Journal of the Institution of Heating and Ventilating Engineers Volume 39 (Feb. 1972)].

Values of diffuse solar radiation are evaluated by the program as a function of solar altitude only, and correspond to clear sky basic diffuse irradiances in Table A2.25 of the CIBSE Guide A2 [CIBSE Guide A Environmental Design - The Chartered Institution of Building Services Engineers, London, 1999.].

2.1.2.2 Incident solar fluxes

The calculation of solar fluxes incident on external building surfaces follows the procedure used in Apache Simulation, with sky radiation treated as isotropic. See Apache Simulation Calculation Methods.

2.1.2.3 Treatment of solar radiation in Heat Gain

In Heat Gain, external shading factors read from a SunCast or SunCast Lite shading file are applied to the incident solar radiation beam. However there is no solar tracking in this program and no transference of diffuse radiation between rooms.

2.1.2.4 Shading

Shading of the beam component of solar radiation may be modelled in three ways in Heat Gain:

- Shading and solar tracking calculations performed by SunCast
- Shading calculations performed by SunCast Lite
- Shading calculations performed by APsim for construction-based shading devices SunCast and Suncast Lite shading applies to both glazed and opaque surfaces. Construction-based shading only applies to glazing.

2.1.2.5 SunCast and SunCast Lite shading files

Shading data generated by SunCast or SunCast Lite for the 15th day of selected months is stored on a shading file with extension '.shd'. The data for a given month comprises hourly data describing the exposure of exterior building surfaces to beam solar radiation. In the case of the SunCast file, internal solar tracking information is also stored on the file, but this data is ignored by Heat Gain. If the shading file is specified at run time, APsim reads the data and uses it to modify the beam component of solar radiation for shaded external surfaces.

2.1.2.6 Solar absorption & reflection by opaque surfaces

External opaque building surfaces absorb and reflect solar radiation according to their solar absorptance as assigned in APcdb. SunCast and SunCast Lite shading data is applied to external opaque surfaces.

2.3 Apache Heat Loss & Heat Gain: Results Review (APreview)
2.3.1 Heat Gain Results and Analysis

APreview offers the following facilities for viewing and analysing Heat Gain results:

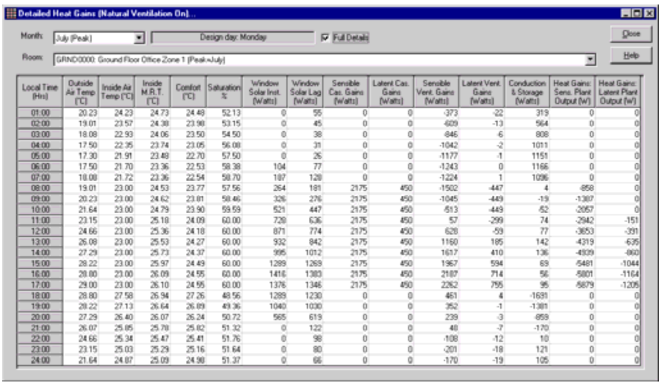
- Summarise all rooms
- Detailed table of results
- Graph results
- Peak total building loads
- Air-conditioning zones
- Calculate air-supply flowrate/conditions

2.3.1.1 Detailed Table of Results

The program asks which room is to be analysed and for which month. The menu cursor defaults to the month of peak cooling or maximum temperature for that room. Detailed results are displayed for each hour of the day.

The following options are given:

- Select a room (i.e. to change room)
- Select a month (i.e. to change month)
- Summary or Full details



Local Time (Hrs)	Outside Air Temp (°C)	Inside Air Temp (°C)	Inside M.R.T. (°C)	Comfort (°C)	Saturation %	Window Solar Inst. (Watts)	Window Solar Lag (Watts)	Sensible Cas. Gains (Watts)	Latent Cas. Gains (Watts)	Sensible Vent. Gains (Watts)	Latent Vent. Gains (Watts)	Conduction & Storage (Watts)	Heat Gains: Sens. Plant Output (W)	Heat Gains: Latent Plant Output (W)
01:00	20.23	24.23	24.73	24.48	52.13	0	55	0	0	-373	-22	319	0	0
02:00	19.01	23.57	24.38	23.98	53.15	0	45	0	0	-609	-13	564	0	0
03:00	18.08	22.93	24.06	23.50	54.50	0	38	0	0	-846	-6	808	0	0
04:00	17.50	22.35	23.74	23.05	56.08	0	31	0	0	-1042	-2	1011	0	0
05:00	17.30	21.91	23.48	22.70	57.50	0	26	0	0	-1177	-1	1151	0	0
06:00	17.50	21.70	23.36	22.53	58.38	104	77	0	0	-1243	0	1166	0	0
07:00	18.08	21.72	23.36	22.54	58.70	187	128	0	0	-1224	1	1096	0	0
08:00	19.01	23.00	24.53	23.77	57.56	264	181	2175	450	-1502	-447	4	-858	0
09:00	20.23	23.00	24.62	23.81	58.46	326	276	2175	450	-1045	-449	-19	-1387	0
10:00	21.64	23.00	24.79	23.90	59.59	521	447	2175	450	-513	-449	-52	-2057	0
11:00	23.15	23.00	25.18	24.09	60.00	728	636	2175	450	57	-299	74	-2942	-151
12:00	24.66	23.00	25.36	24.18	60.00	871	774	2175	450	628	-59	77	-3653	-391
13:00	26.08	23.00	25.53	24.27	60.00	932	842	2175	450	1160	185	142	-4319	-635
14:00	27.29	23.00	25.73	24.37	60.00	995	1012	2175	450	1617	410	136	-4939	-860
15:00	28.22	23.00	25.97	24.49	60.00	1289	1269	2175	450	1967	594	69	-5481	-1044
16:00	28.80	23.00	26.09	24.55	60.00	1416	1383	2175	450	2187	714	56	-5801	-1164
17:00	29.00	23.00	26.10	24.55	60.00	1376	1346	2175	450	2262	755	95	-5879	-1205
18:00	28.80	27.58	26.94	27.26	48.56	1289	1230	0	0	461	4	-1691	0	0
19:00	28.22	27.13	26.64	26.89	49.36	1040	1030	0	0	352	-1	-1381	0	0
20:00	27.29	26.40	26.07	26.24	50.72	565	619	0	0	239	-3	-859	0	0
21:00	26.07	25.85	25.78	25.82	51.32	0	122	0	0	48	-7	-170	0	0
22:00	24.66	25.34	25.47	25.41	51.76	0	98	0	0	-108	-12	10	0	0
23:00	23.15	25.03	25.29	25.16	51.64	0	80	0	0	-201	-18	121	0	0
24:00	21.64	24.87	25.09	24.98	51.37	0	66	0	0	-170	-19	105	0	0

This table gives the hourly internal room conditions and the heat gains for each hour of the design day in the current month. The table displayed on the screen does not contain information on the solar, ventilation and conduction/storage breakdown (this information can be reviewed by choosing Full Details).

Data is given in 'average over previous hour' format, therefore if the results indicate that at 15:00, the temperature is 26.0°C, it means that the average temperature over the period 14:00-15:00 is 26.0°C.

All heat is given in Watts of heat gain (cooling is therefore shown as negative).

2.3.1.1.1 Outside-air temperature

Is the average temperature of the outside air in °C.

2.3.1.1.2 Inside-air temperature

Is the average temperature of the room air in °C.

2.3.1.1.3 Mean surface temperature

Is the room average surface temperature in °C. It may be thought of as the area and emissivity-weighted average temperature of the internal wall and window surfaces.

2.3.1.1.4 Comfort temperature

Is the average room comfort temperature in °C. It is calculated as a weighted average of the air and mean surface temperatures, using the comfort radiant fraction entered on the Calculation-Options dialogue box to vary the weighting given to radiant temperature.

2.3.1.1.5 Inside-air percentage saturation

Is the percentage saturation of the internal air. It is approximately equal to the relative humidity for normal building operating conditions.

2.3.1.1.6 Window Instantaneous

Is the actual solar gain through the windows and absorbed by the room, including retransmitted radiation, but excluding solar gains re-reflected back out of the window. It therefore includes the effects of local and remote shading and the properties of the glazing system.

2.3.1.1.7 Window lagged

Is the window instantaneous solar gain with the short-wave portion lagged by up to an hour to give an effective solar effect on the room heat balance in accordance with the CIBSE Admittance Procedure.

2.3.1.1.8 Casual Sensible

Is the casual sensible gain from occupants, lighting, machines etc.

2.3.1.1.9 Casual latent

Is the casual latent gain from occupants, cooking etc.

2.3.1.1.10 Ventilation sensible

Is the sensible gain due to air entering the room at a different temperature to that of the room air.

2.3.1.1.11 Ventilation latent

Is the latent gain due to air entering the room at a different moisture condition to that of the room air.

2.3.1.1.12 Conduction + storage

Is the sum of gains from the construction (walls, partitions, ceilings, floors etc.) into the room. The data includes storage from the fabric. Note that in heavyweight buildings the storage can dominate, and the conduction + storage figure can be considerably lower than might be expected (See the Troubleshooting Section).

2.3.1.1.13 Sensible cooling

Is the heat gain from the cooling system required to meet the set point conditions set in the rooms data. Note that a negative gain is cooling.

2.3.1.1.14 Latent cooling

Is the latent-heat gain from the cooling system required to meet the set-point conditions set in the rooms data.

Appendix B3: Ecotect

1. Introduction

ECOTECT v5 is the most comprehensive and innovative building analysis software on the market today. It features a designer-friendly 3D modelling interface fully integrated with acoustic, thermal, lighting, solar and cost functions. What really sets ECOTECT apart is its support for conceptual design as well as final stage validation. Designers can use ECOTECT to generate vital design information before the building form has even been considered. Detailed climatic analysis can be used to optimise available solar, light and wind resources with the performance of simple sketch models quickly analysed and compared.

This information is critical at the earliest stages in order to reduce abortive work on inappropriate design options and yield significant operational cost savings for the client. Designing in this way means moving beyond traditional CAD systems to a tool that actually knows you're designing a building, not a gearbox. As ECOTECT deals with many different aspects of building performance, it needs a wide range of data to describe the building. To reduce the burden on the designer, ECOTECT uses a unique system of progressive data input. Initially only simple geometric details are needed. As the design model is refined and more accurate or detailed feedback is required, the user makes more choices and enters more data as it becomes important. This means that you can be analysing sun penetration, shading options and available light after only a few mouse clicks.

2. Features In Brief

You can use ECOTECT to do the following:

- Display and animate complex shadows and reflections,
- Generate interactive sun-path diagrams for instant overshadowing analysis,
- Calculate the incident solar radiation on any surface and its percentage shading,
- Work out daylight factors and artificial lighting levels either spatially or at any point,
- Calculate monthly heat loads and hourly temperature graphs for any zone,
- Generate full schedules of material costs and environmental impact,
- Trace the paths of acoustic particles and rays within any enclosures of any shape,
- Spray sound particles around an enclosure and watch the rate of decay,
- Quickly calculate statistical and raytraced reverberation times in any space,
- Export to VRML for interactive visualisation and presentation to clients,
- Export to the RADIANCE Lighting Program for physically accurate lighting analysis,
- Read and write a wide range of CAD and analysis file formats,

Thus ECOTECT offers a wide range of different analysis and simulation options that use simple but proven techniques. It makes informed assumptions about zonal relationships and material assignments as you enter your building so that you don't need to specify everything before you can get your first result. As your design develops and you refine the model, you progressively make more detailed choices as different issues become relevant. However, the range options provided means that you test different design options and assess their ramifications in many different areas, deriving as diverse a range of feedback as possible. To this end, the following simulation and analysis functions are included.

2.1 Solar Analysis

Solar radiation from the Sun can have a significant impact on a building. Whilst often a source of overheating due to inadequate controls, with some thoughtful design it can provide a cheap and abundant source of energy in your building. This energy can be used to heat spaces in winter, provide hot water, power appliances using photovoltaics, and even generate cooling ventilation in summer.

The following solar analysis functions in ECOTECT allow you to visualise and quantify the access you will have to solar radiation and the effects your building will have on the solar access of those around you.

2.1.1 Solar Radiation

In ECOTECT it is possible to calculate the precise amount of solar radiation incident on any surface in the model. This can be displayed as either instantaneous hourly values or as daily and monthly totals. This information has a wide range of applications, from determining the impact of a proposed building on solar access rights, to sizing and optimising photovoltaic panels. It is also fundamental to effective passive solar design.

2.1.2 Solar Exposure

Using hourly climate data and geometric analysis, the degree of solar exposure for any object in the model can be calculated, of any shape and at any angle.

3. Thermal Performance

3.1 Simulation Engine

ECOTECT provides a range of thermal performance analysis options. At its core is the Chartered Institute of Building Services Engineers (CIBSE) Admittance Method used to determine internal temperatures and heat loads. This thermal algorithm is very flexible and has no restrictions on building geometry or the number of thermal zones that can be simultaneously analysed. Most importantly, with only a few pre-calculations for shading and overshadowing, it is very quick to calculate and can be used to display a wide range of very useful design information.

3.1.1 The Admittance Method

The underlying assumption of the Admittance Method is that the internal temperature of any building will always tend towards the local 24-hour mean outdoor temperature. Any incident solar or internal heat gains will first act to raise internal air and surface temperatures, the effect of which is to increase conductive heat losses through the fabric and air infiltration losses through windows and other openings. When the total of all heat losses equals the total gain, the internal temperature stabilises. Once steady-state 24-hour mean conditions are calculated, cyclic variations about the mean are determined for each hour of the day, yielding a range of instantaneous temperature and heat load information. Steady-state conditions are governed by building geometry and the U-value of materials that make up its fabric. The dynamic response of the building is also affected by these factors, as well as the admittance value, thermal lag and decrement properties of those materials.

In the Admittance Method, the temperature and load calculations are two separate processes. As a first pass, the magnitude of potential heat gains and losses acting on the building are calculated for each hour of each day, from which average daily load factors can be determined. These are known as load factors because they are relative to mean conditions, not actual conditions. Variations in the instantaneous load factor against each daily average can then be used to determine the relative thermal stress each zone is subject to each hour of the day. These variations in stress result in cyclic fluctuations in internal temperature, from which hourly zone temperatures can be derived. Once detailed hourly internal temperatures are known, a second calculation is performed to determine the absolute heating and cooling loads. Given inside and outside temperatures for each zone, fabric, ventilation and infiltration loads can be accurately determined along with solar and internal loads.

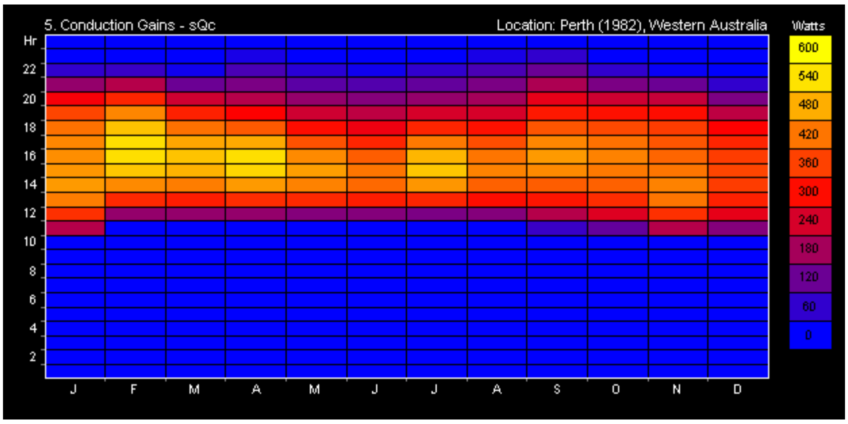
The Admittance Method encapsulates the effects of conductive heat flow through building fabric, infiltration and ventilation through openings, direct solar gains through transparent materials, indirect solar gains through opaque elements, and internal heat gains from equipment, lights and people. Using a two-pass algorithm, it also accounts for the effects of inter-zonal heat flow.

3.2 Thermal Simulation and Analysis

ECOTECT offers a wide range of thermal performance analysis features.

3.2.1 Annual Load Distribution

Heat load distribution graphs are quite different from temperature distributions. In these, loads are indicated by colour and the two axis show hours of the day vertically and months of the year horizontally. Loads are calculated for each hour of the day and the total for each month is then displayed. Thus it is possible to see at what time of the day maximum and minimum loads occur as well as which time of the year.



Using ECOTECT, you can isolate the distribution of each type of load:

3.2.1.1 Conduction loads through the fabric (sQc)

These loads refer only to the gains due to differentials in air temperature between inside and outside the space. Even though in reality it is impossible to distinguish between conduction and indirect solar loads (sol-air gains), computer analysis can and it is very important as you often deal with the two types of loads in different ways. For example, high conduction loads must be countered using either insulation (resistance) or thermal mass (capacitance), whereas you can simply paint a surface white to reduce indirect solar loads.

3.2.1.2 Indirect solar loads through opaque objects (sQss)

This refers to additional gains due to the effects of incident solar radiation on the external surface of exposed opaque objects. The solar radiation acts to raise the external surface temperature which in turn increases the conducted heat flow. As described in the previous point, it is impossible in reality to distinguish these from straight conduction gains, however it is very useful for a computer to do it as you can deal with them very differently.

3.2.1.3 Direct solar gains through transparent objects (sQsg)

These loads refer to solar radiation entering the space through a window, void or other transparent/translucent surface. It sould be noted that the Admittance method does not track these gains through the window and onto individual internal surfaces. It simply treats them as a space load (as opposed to a fabric load) and uses the admittance of the materials in each zone to diffuse and distibute the heat.

3.2.1.4 Ventilation and infiltration gains (sQv)

This refers to heat transfer due to the movement of air through through cracks and openings in the building fabric, such as windows, voids, etc. As the infiltration rate can be easily obtained for each zone, ventilation and infiltration are lumped together in this type of analysis.

3.2.1.5 Internal loads from lights, people and equipment (sQi)

These loads tend to be more contant and predictable than weather-based loads. However, you can often end up with quite complex load patterns in larger buildings when using many different schedules and object activations.

3.2.1.6 Inter-zonal loads from heat flow between adjacent zones (sQz)

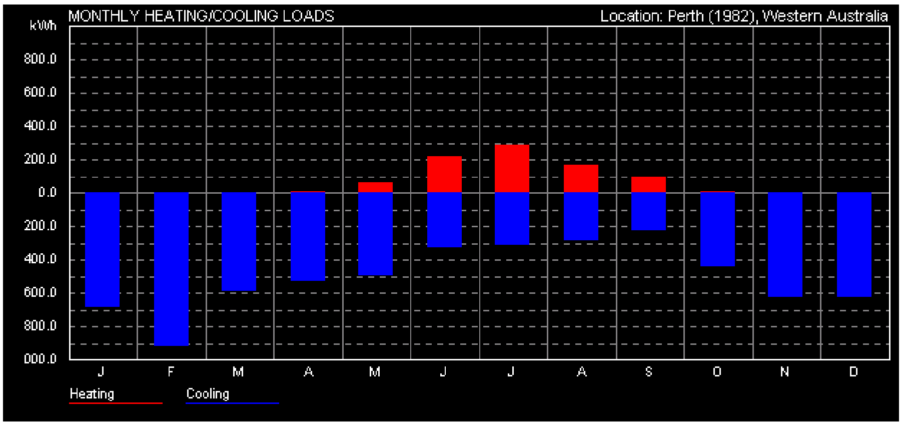
Interzonal gains result from the heat flows induced by temperature differences between zones. This flow occurs through areas where surfaces from different zones are adjacent to each other.

3.2.2 Hourly Heat Gain Graphs

Hourly heat gain graphs display the magnitude of all the different heat flow paths acting on visible thermal zones in the model over a 24-hour period. The graphs displays the magnitude of each type of heat load for each hour of the day. The magnitude is in either Watts or kW as it is an instantaneous load.

3.2.3 Heating and Cooling Loads: Monthly Space Loads /Discomfort

Monthly space load graphs display total heating and cooling loads for each zone. Heating loads are displayed in red and project above the centre line of the graph whereas cooling loads are blue and project below. The vertical scale is in either Wh, kWh or MWh (Watt-hours).



3.2.4 Discomfort Time

If a zone is not air-conditioned, a discomfort calculation is performed instead. In this case, the percentage of time the internal temperature of the zone spends outside the specified comfort band is calculated for each month, resulting in a graph similar to that shown below.

3.2.5 Annual Temperature Distribution

Instead of daily temperature graphs, which only show snapshots of the performance of a building, it is possible to display a statistical range of internal temperatures or heat loads over an entire year using a distribution graph.

Annual temperature distribution graphs show the number of hours a particular internal or external temperature was encountered over the entire year. The vertical axis shows the hour count while the horizontal axis shows the temperature. These graphs clearly show whether a building is consistently warmer or cooler than outside air conditions.

3.2.6 Hourly Temperature

Hourly temperature graphs display the internal temperatures of all visible thermal zones in the model over a 24-hour period. The graph displays a range of environmental information as well as internal zone temperatures. The outside air temperature and wind speed, as well as beam and diffuse solar radiation, is displayed as dashed lines within the graph. This makes it quite clear exactly what climatic factors the internal temperatures are responding to.