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**Effect of Building Form on the Thermal Performance of
Residential Complexes in the Mediterranean Climate of the
Gaza Strip**

تأثير شكل المبنى على الأداء الحراري للمجمعات السكنية في مناخ البحر الأبيض
المتوسط لقطاع غزة

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Abstract

Climate is one of the most important factors that affect both urban planning and architectural design. Energy consumption of a building is strongly related to the climatic surrounding it which has a major effect on its thermal performance. Residential buildings are considered the most architectural structures consuming energy in the world. This research comes in an attempt to study the thermal performance of residential buildings and its impact on thermal comfort. The research also seeks to study the impact of climatic factors on the urban configuration, especially with regard to the geometric shape and orientation of the housing unit. Also the research provides an overview of the residential complexes in the Gaza Strip and their design especially with regard to their form and orientation.

In this context, the research assumes that the geometric shape and orientation of the housing unit as well as the form and orientation of its urban configuration significantly affects the thermal performance of the housing unit, and thus the heating and cooling loads. Hence, the research seeks to evaluate the thermal performance of different geometrical shapes and orientations of the housing unit and within different urban configurations. The research is carried out using the analytical approach by using the computer programs ECOTECH and IES. The research aims to reach to the best possible configurations which present the high thermal performance in order to use it in residential buildings in the Gaza Strip. The results indicate significant thermal effects due to the form's proportions and orientation. The research concluded that the surface to volume ratio is considered the main responsible for the thermal response in different geometric shapes. The energy consumption increases at the same rate of increasing in the surface to volume ratio (S/V) in the Mediterranean climate of the Gaza Strip.

About 39% of energy consumption can be reduced by choosing the optimum width to length ratio (W/L) which is 0.8. The roof to walls ratio seemed to have a great influence on the thermal response. Using the (roof/ walls) ratio which ranges between 0.4 to 0.6 is more preferable for both cooling and heating requirements. The horizontal arrangements of residential apartments is better thermally than the vertical arrangements of the same (S/V) ratio. Convex shapes such as the court, L and U shape can be used as a more preferable option for building's arrangements than the rectangular shape of the same (S/V) ratio. A spacing ratio (L_1/L_2) equals 0.1 and aspect ratio (H/W) equals 0.5 is the preferable option in the (E-W) street in the Gaza Strip. However, the more preferable option in the (N-S) street has a spacing ratio (L_1/L_2) equals 1.2, and aspect ratio (H/W) equals 4. Therefore, the research recommends to apply passive solar design strategies, especially with regard to geometric shape and orientation in the first stage of the design process. Thermal simulation programs have to be used in order to evaluate the thermal performance of buildings. Building's proportions have to be determined with a full understanding to their relations with the urban morphology.

المخلص

يعد المناخ أحد العناصر الهامة والمؤثرة على كل من التخطيط الحضري والتصميم المعماري. هذا ويرتبط استهلاك الطاقة في المباني بالبيئة المحيطة وهو الأمر الذي من شأنه التأثير على الأداء الحراري بداخلها. وتحمل المباني النصيب الأكبر من استهلاك الطاقة إذ يبلغ استهلاكها ما يقرب من نصف متطلبات الطاقة، ولما كان القطاع السكني في صدارة المنشآت المعمارية استهلاكاً للطاقة في العالم بصفة عامة وفي قطاع غزة بصفة خاصة، يأتي هذا البحث في محاولة لدراسة الأداء الحراري بالمباني وتأثيره على الراحة الحرارية، كذلك يسلط البحث الضوء حول تأثير العوامل المناخية على التشكيلات العمرانية لاسيما فيما يتعلق بالشكل الهندسي والتوجيه للوحدة السكنية، ويتناول البحث بالدراسة المجمعات السكنية في قطاع غزة ويناقش نماذج لتصميماتها المعمارية خاصة فيما يتعلق بالشكل والتوجيه.

وفي هذا السياق يفترض البحث أن الشكل الهندسي الخارجي للوحدة السكنية وتوجيهها فضلاً عن شكل وتوجيه النسيج العمراني الناتج من تكرارها يؤثر تأثيراً كبيراً على الأداء الحراري للوحدة السكنية وبالتالي طاقتي التدفئة والتبريد. ومن هنا فإن البحث يسعى إلى تقييم الأداء الحراري للأشكال الهندسية والتوجيهات المختلفة للوحدة السكنية وضمن التشكيلات العمرانية المختلفة باستخدام المنهج التحليلي وبالاستفادة من برامج التحليل الحراري ECOTECT و IES، وصولاً إلى نموذج محقق لأعلى أداء حراري بحيث يصلح لاستخدامه في المباني السكنية بقطاع غزة. هذا ويخرج البحث بجملة من النتائج أهمها تأثير الأداء الحراري للبيئة السكنية واستهلاك الطاقة بالشكل والتوجيه. حيث توصل البحث إلى أن نسبة السطح الخارجي إلى الحجم هي المؤثر الأساسي في السلوك الحراري حيث يزيد استهلاك الطاقة بنفس معدل الزيادة في نسبة السطح إلى الحجم تقريباً وذلك في مناخ البحر الأبيض المتوسط لقطاع غزة.

كذلك تساهم نسبة العرض إلى الطول في تخفيض ما يقرب من 39% من استهلاك الطاقة. وتلعب نسبة السقف إلى الجدران دوراً بارزاً في التأثير على الأداء الحراري حيث وجد أن النسبة الأفضل لكل من طاقتي التدفئة والتبريد تتراوح ما بين 0.4 إلى 0.6، كما خرج البحث بنتيجة مفادها أن التكوينات الأفقية للوحدات السكنية أفضل حرارياً من نظيراتها الرأسية والتي تحوي نفس الحجم الداخلي ونفس نسبة السطح إلى الحجم. كما يقدم البحث نماذج لأشكال لجميع الوحدات السكنية كالأشكال المركبة (حرف U, L, والفناء) كنموذجاً بديلاً للشكل المستطيل بشرط احتوائها لنفس نسبة السطح إلى الحجم. هذا وتعد نسبة المسافات بين المباني إلى الطول الأمامي للوحدة السكنية والمساوية 0.1 ونسبة ارتفاع المبنى إلى عرض الشارع والمساوية 0.5 هي الخيار الأفضل حرارياً في الشوارع الشرقية- الغربية بقطاع غزة، فيما يتضمن الخيار الأفضل حرارياً في الشوارع الشمالية- الجنوبية نسب المسافات بين المباني إلى الطول الأمامي للوحدة السكنية والمساوية 1.2 ونسبة ارتفاع المبنى إلى عرض الشارع والمساوية 4. هذا ويوصي البحث بضرورة وضع التصميم الحراري كأولى اعتبارات التصميم المعماري الناجح، فضلاً عن استخدام برامج المحاكاة لتقييم الأداء الحراري للمنشآت المعمارية. كما يوصي البحث بضرورة تحديد النسب والأبعاد المعلقة بالمباني في ظل فهم كامل للعلاقة بينها وبين النسيج العمراني.

Dedication

This Research is lovingly dedicated to my parents who have been my constant source of inspiration. They have given me the drive and discipline to tackle any task with enthusiasm and determination. Without their love and support this Research would not have been made possible.

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List of Abbreviations

Abbreviations	Meaning
ACH	air changes per hour
a/b ratio	The ratio of the width of the shading facade to that of shaded facade (the depth ratio)
BPI	building performance index
Cf	Surface of the Envelope /Volume Living
DBT	dry bulb temperature
ETTV	Envelope Thermal Transfer Value
HVAC	Heating, Ventilation, and Air Conditioning
(H/W)	Aspect Ratio which is the ratio between the building height H to the width of the street W
IES	Integrated Environmental Solutions
IPCC	Intergovernmental Panel on Climate Change
L_{mas}	thermal mass thicknesses
L_1/L_2 Ratio	Spacing Ratio which is the ratio between the distance between adjacent buildings L_1 and the frontal length of building L_2
LPG	Liquefied Petroleum Gas
MOPWH	Ministry of Public Works and Housing
MWh	Megawatt Hour
OTTV	overall thermal transfer value
PET	Physiologically Equivalent Temperature
PMV	predicted mean vote
R	Thermal Resistance
R^2	The Square of the correlation coefficient, r
RC	Relative Compactness
RH	relative humidity
SHGC	Solar Heat Gain Coefficient
SRES	Special Report on Emissions Scenarios
S/V Ratio	surface to volume ratio

U	Thermal Transmittance
UCL	Urban Canopy Layer
WFR	Window to Floor Ratio
W/L Ratio	width to length ratio
WWR	Window to Walls Ratio

Chapter 1: General Introduction

1.1 Introduction

Climate is considered one of the most important elements affecting the building's design. Human has developed approaches to provide shelter, which can avoid the extreme climatic conditions. He developed the traditional house, which achieved thermal comfort depending upon the natural resources and passive solar design strategies. However, the modern house neglected aspects of climate in achieving thermal comfort. Instead, it depends on equipments, such as air-conditioning and mechanical ventilation systems, which use conventional energy. The world faces an energy problem, which appears as the depletion of conventional energy resources, as well as the global warming and the climatic changes as a consequence. Buildings are considered the main energy consumer, especially for the purposes of heating, cooling and lighting. The architectural design plays a fundamental role in achieving thermal comfort. Accordingly, a climate requires to be one of the most important design criteria in order to obtain building design, which can be energy efficient, environmentally friendly and an achievable to the highest degree of thermal comfort.

Building design in the Gaza Strip doesn't take sufficient account to the climatic considerations. That would increase the rates of non-thermal comfort in buildings and increase the heating and cooling loads as a consequence. Hence, the climate responsive sustainable building design appears as an essential factor in the first stage of the design process in order to achieve more comfortable indoor environment. Moreover, it will be a logical approach for architects to pay attention to local climatic conditions during the design process (Çakir, 2006). Building form, orientation and urban patterns are the most important design parameters affecting indoor thermal comfort and energy conservation in building scale (Leylian *et al.* 2010). Intelligent configuration and molding of the built form and its surroundings can considerably minimize the level of discomfort inside a building, and reduce the consumption of energy required to maintain comfortable conditions (Naya *et al.* 2006).

The Gaza Strip have different building forms and urban patterns, which affect the thermal performance inside them. It is noticed that geometric shapes such as rectangular and square can be considered the most popular used shapes, especially in residential buildings. Building orientation usually follow streets orientation in most situations. The detached configurations are the most common urban pattern except in the old town of Gaza, which contains compacted traditional buildings. Buildings ranges between low-rise (2-5 storey) and high-rise building (5-10 storey). It is noted that the selection of buildings geometrical shapes and orientations doesn't take into account the climatic factors such as solar radiation and wind. Also distances between buildings, buildings height and its relation to the street width are not usually determined in accordance with the standards of energy-saving buildings. Urban configurations don't pay sufficient attention to mutual shading between buildings which may be part of the solutions to the problem of energy consumption in the Gaza Strip. This situation can contribute in raising the rates of non-thermal comfort inside the indoor environment.

The research aims to highlight the situation of the climatic design in the housing sector in the Gaza Strip, especially with regard to the geometric shape and orientation of the housing unit as well as the form of urban configurations and streets orientations. Some cases of residential complexes such as El-Sheikh Zayed city and Tal El Hawa

housing project as well as some separated houses will be presented in order to highlight their geometric shapes, proportions, orientation and urban pattern. The research will use energy simulation software which appeared in recent years as useful tools in simulating buildings performance. They provide significant contribution in dealing with climate adaptation in regard to energy responsible planning (Karasu, 2010). A computerized simulation program called ECOTECH will be used as a tool for investigating the thermal performance of a building's forms and orientations. Then the Integrated Environmental Solutions (IES) program will be used as a validation tool. General geometric shapes, such as square, rectangular, circular, polygon, T shape, L shape, H shape, U shape and courtyard shape will be simulated and the heating, cooling and total loads will be determined in each shape in order to estimate the effect of geometrical shape on the thermal performance. Also, various configurations bases on form proportions such as the width to length ratio (W/L), the roof to walls ratio, the surface to volume ratio (S/V) will be simulated and the energy requirements and incident solar radiation will be determined. Various forms will be simulated in different orientations and with different urban configurations.

1.2 The Research Problem

Buildings consume large amount of energy in order to achieve thermal comfort for users. It is noted that building design in the Gaza Strip doesn't take sufficient account to the climate, environmental factors and the considerations of energy-saving in buildings, especially with regard to geometrical shape and orientation. Also the residential complexes take different patterns and their streets take different orientations without paying attention to the climatic factors, especially the solar radiation. This situations would increase the energy consumption for heating and cooling in buildings and affects comfort, health and efficiency.

1.3 The Research Hypothesis

The research assumes that the proper selection of geometrical shape and orientation, which take into account the environmental factors and the considerations of energy-saving in buildings have a significant impact on the thermal performance of building and energy consumption in the Gaza Strip. It assumes that the building proportions and ratio affect its thermal response. Also it assumes that the building configurations and the relation between the architectural proportions of building and the urban proportions of the built environments affect the indoor thermal performance of buildings. The form and orientation are able to modify the impact of the sun load and thus the heating and cooling loads. Hence the research attempts to evaluate these assumptions by simulating different forms of building in different configurations and with different orientations using ECOTECH and Integrated Environmental Solutions (IES) software programs.

1.4 Importance of The Research

There were several researches about overall energy saving methods for buildings and there are various researches about energy simulations focusing on various particular passive energy saving measures. However, there is a lack of such studies in terms of Gaza climate and built environment. So the research highlights the environmental design of residential buildings in the Gaza Strip in an attempt to find solutions for improving the residential environmental design and enhance the comfort conditions. In addition, the research will help to get better understanding about the interactive

relationship between the building's envelop shape and the surrounding environment. Also the research helps to provide reasonable results, as it depends on using simulation program in order to optimize building energy performance.

1.5 Objective of The Research

The main objective of this research is to investigate the impact of geometrical shape and building orientation on the thermal performance with regard to solar radiation. In this research the following aspects are highlighted:

- The energy situation in the Gaza Strip,
- The factors that affect thermal performance of building,
- The role of climatic factors on urban and architectural design,
- The climate responsive design strategies and passive solar design,
- The situation of climatic design in residential complexes in the Gaza Strip,
- The effects of geometrical shape of the building on indoor thermal comfort,
- The effects of building orientation on indoor thermal comfort,
- The role of the urban configuration of residential complexes in the thermal performance of buildings, and
- The effects of the street orientations and width on the indoor thermal comfort.

1.6 Methodology

The research is carried out using parametric analytic approach. An extensive literature review on the thermal performance and the climate responsive buildings design is carried out as theoretical background. It depends on theoretical sources such as researches, conference papers and previous studies. Also the research will carry out simulation processes using computerized program such as ECOTECH and Integrated Environmental Solutions (IES) which provides reasonable results. Residential buildings in the Mediterranean climate of the Gaza Strip with different geometrical shapes, proportions and orientations and in different urban configurations will be analyzed energetically. The heating and cooling loads will be calculated for each model. The results will be evaluated in order to optimize the thermal behavior of the models.

ECOTECH software is a comprehensive, concept-to-detail sustainable design analysis tool, providing a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs. Online energy, water, and carbon-emission analysis capabilities integrate with tools visualize and simulate a building's performance within the context of its environment. It calculates heating and cooling loads for models and analyze effects of occupancy, internal gains, infiltration, and equipment. Also, it visualize incident solar radiation on windows and surfaces, over any period. It displays the sun's position and path relative to the model at any date, time, and location (Autodesk Ecotect Analysis, 2010).

The Virtual Environment is an integrated analysis platform developed by Integrated Environmental Solutions (IES). It is a collection of building performance modeling and analysis modules leveraging a single integrated data model. The intent is to provide the high quality information required to design, build and operate better performing, more sustainable buildings without having to build a different model for each type of analysis (ex. energy, day lighting, etc.). It can be applied from the earliest stages of the design process, when greatest opportunity often exists for making improvements right through

to detailed design and even into operation of the building (Integrated Environmental Solutions, 2009).

1.7 The Research Limits

The research deals with the residential buildings in the Gaza Strip, which is located under the influence of the Mediterranean climate. It depends upon the simulation programs namely ECOTECH and IES. The following design parameters in the urban configurations will be analyzed:

- The geometric shapes, i.e. square, rectangular, circle, polygon, T shape, L shape, H shape, U shape, courtyard shape,
- Building width ratio W/L , relating the building width W to the building length L ,
- Surface -to- volume ratio: S/V
- Roof -to- walls ratio
- Building depth ratio in the convex shapes a/b , relating the width of the shading facade a to that of shaded facade b ,
- The building orientation, i.e. 0E (E-W), 10E, 20E, 30E, 40E,50E, 60E, 70E, 80E, and 90E (N-S),
- Spacing ratio L_1/L_2 , relating the distance between adjacent buildings L_1 to the frontal length of building L_2 ,
- Height-to-width ratio of the urban canopy layer (aspect ratio $H :W$), relating the building height H to the width of the street's open space W ,
- Plot ratio which is defined as the ratio of total floor area to site area,
- Site coverage which is the ratio of building footprints to site area,
- The street orientation, i.e. E-W, N-S, NE-SW, NW-SE.

Other limitations will be also made during defining the analytic study and these parameters will be described in more detail further on in the research.

1.8 Sources of information

The Research depends on several sources of information varied between the theoretical sources for the scientific information, the field study and computer simulation, these sources can be listed as follows:

- Journal papers.
- Conference papers.
- Books that deal with similar subjects.
- Internet.
- Related Reports and Statistics from governmental and private institutions.
- Field visits to collect information and data.
- Computer simulation of the selected models using the analysis program ECOTECH and IES.

1.9 Structure of the research

The research is presented in six chapters. The first chapter which is a general introduction is composed of the research problem, hypothesis, importance, objectives, sources of information, methodology and an overview of previous studies that dealt with the similar subjects.

Chapter 2 overviews the energy use in buildings and its environmental effects and its situation in The Gaza Strip. It describes the concepts of thermal performance, comfort and their relation to the urban and architectural design. It explains methods of heat transfer, solar radiation and factors that affect the thermal performance.

Chapter 3 summarizes climate factors and their effect on design elements especially on residential buildings. It includes climate responsive design strategies. It presents the situation of the environmental design of residential buildings in the Gaza Strip. It includes the climate characteristic of Gaza and presents the characteristic of residential buildings with regard to the form and orientation through some case studies.

Chapter 4 discusses the effect of geometrical shape and building orientation on its thermal performance by simulating different shapes of buildings then calculate the thermal performance of each model in terms of the heating and cooling loads to determine the desired shape, which will be simulated in different orientations.

Chapter 5 discusses the thermal performance of buildings in the urban fabric by simulating different urban pattern within different orientation of streets.

Chapter 6 concludes the research by summarizing its findings.

1.10 Previous studies

1. Ling *et al.* (2007). The Effect of Geometric Shape and Building Orientation on Minimizing Solar Insulation on High-Rise Buildings in Hot Humid Climate.

This study examines the effect of geometric shapes on the total solar insolation received by high-rise buildings. Two generic building shapes (square and circular) have been studied with variations in width-to-length ratio (W/L ratio) and building orientation using the computer simulation program ECOTECH V5.2. The results revealed that the circular shape with W/L ratio 1:1 is the most optimum shape in minimizing total solar insolation. The square shape with W/L ratio 1:1 in a north-south orientation receives the lowest annual total solar insolation compared to other square shapes. This optimum shape (CC 1:1) receives the highest amount of solar insolation on the east-orientated wall, followed by the south-, west- and north-orientated walls respectively. This study guides designers on choosing optimum geometric shape and appropriate orientation for high-rise buildings.

2. Shashua-Bar *et al.* (2004). Thermal Effects of Building Geometry and Spacing on The Urban Canopy Layer Microclimate in A Hot-Humid Climate in Summer.

A quantitative analysis is presented for evaluating the diurnal thermal impact of proposed building arrangements on the urban canopy layer (UCL) air temperature, in summer in a hot-humid region. Building configuration along an urban street is quantitatively specified in this study by the building dimensions, by the spacing of the units and by the width of the street. The generic model described here is representative of the actual form of residential buildings found mostly along urban streets in Israel's cities. Sixty different building configurations were studied. The diurnal air temperature pattern in summer was calculated for each configuration using the analytical Green CTTC model, and compared with that of a nearby representative meteorological station at an open site. The results indicate significant

thermal effects in the UCL due to the building form. The extent of the maximum impact is about 6.8 K at 1500h, namely ranging from 4.7 K above the value measured at the reference meteorological station (for shallow open spaces with wide spacing), to 2.1 K below this (for deep open spaces with narrow spacing). The statistical analysis of the results indicates the feasibility of assessing the expected maximum thermal effect of building designs of the generic form studied here, through a general linear relationship. This, thereby, provides a useful tool in judging the expected climatic impact of a proposed building design.

3. Behsh, (2002). Building Form as an Option for Enhancing The Indoor Thermal Conditions.

This study is an attempt to examine the thermal performance of the building form as related to Damascus climate. It aims to understand the relationship between surface and volume, roof and walls and between wall and wall in relation to different orientation. The computer simulation program DEROB-LTH was used. A number of building form with different shapes was analyzed. The forms were classified in three groups which include compact shapes, complex shapes and multi-story forms. The study concluded that the form with a rectangular shape showed better thermal performance than that with a square shape of the same volume and space area. Also the form with larger surface\ volume ratio (s\v ratio) show better thermal performance particularly during the summer period. In regard to the roof\ wall ratio, the form with a lower r\w ratio has better thermal response than a higher ratio of the same space areas and volume.

4. Daoud *et al.* (2009). Impact of form on the energy performance of buildings; Case of hot and dry climates Contribution to sustainable buildings.

This study aims to examine the relationship between the morphological characteristics of the form of buildings and the climatic parameters, in order to improve the thermal performance of buildings in the regions hot and dry. Knowing that the outside air temperature and solar radiation are the two main sources of discomfort, the numerical simulation is based on the study of the form factor influence ($C_f = \text{surface of the envelope} / \text{volume Living}$) on the coefficient of heat gain G (heat gain coefficient of the habitable volume), we have tested the interaction between the volume, geometry, the proportions of a hand and the two parameters above on the others. The results of this research have identified a significant improvement in thermal performance by varying parameters such as volume, geometry and proportions of the building. Finally, this study focuses on work related to the thermal performance on the consumption of energy in the building sector and the promotion of research in the field of energy efficiency.

5. Ali-Toudert (2005). Dependence of Outdoor Thermal Comfort on Street Design in Hot and Dry Climate.

This study deals with the dependence of outdoor thermal comfort on street design with emphasis on summer conditions in hot and dry climate in Ghardaia, Algeria. The effects of the height-to-width ratio (H/W) and street orientation, the asymmetry of the vertical profile, the use of galleries, overhanging facades, as well as the use of rows of trees were investigated. The study was conducted by means of the three dimensional model ENVI-met. Complex street geometries are compared

to simple urban canyons. Thermal comfort is assessed by means of the physiologically equivalent temperature PET. The results reveal that the vertical profile and orientation of the urban canyon have a decisive impact on the human thermal sensation at street level, as well as all other design details studied. This is mostly because affecting the sun exposure and so the heat gained by a human body. Wide streets ($H/W \leq 1$) are highly uncomfortable for both orientations. Yet, N-S streets have some advantage compared to E-W streets as the thermal conditions at their edges along the walls are thermally less stressful for people. Shading appeared as the most important condition of comfort in the summertime, which can be reached by an appropriate combination of all those urban design describers.

6. AlAnzi *et al.* (2008). Impact of building shape on thermal performance of office buildings in Kuwait.

This study provides a simplified analysis method to estimate the impact of building shape on energy efficiency of office buildings in Kuwait. The method is based on results obtained from a comprehensive whole building energy simulation analysis. The analysis takes into account several building shapes and forms including rectangular, L-shape, U-shape, and H-shape as well as building aspect ratios, window-to-wall ratios, and glazing types. The simplified method is suitable for architects during preliminary design phase to assess the impact of shape on the energy efficiency of office buildings.

7. Hachem *et al.* (2011). Parametric investigation of geometric form effects on solar potential of housing units.

This study presents a study of the solar potential of different shapes of two-story single family housing units, located in mid-latitude climate. Seven plan geometries are studied: square, rectangle, trapezoid, L, U, H and T shapes. The study investigates the effect of these shapes on two major response variables – Solar radiation incident on equatorial-facing facades and transmitted by the fenestration of such facades, and electricity production potential of building integrated photovoltaic (BIPV) covering roof surfaces with optimal solar exposure. The parameters, whose effects on the response variables are investigated, include, in addition to the basic shapes and roof design, variations to the geometry of L and U shapes and variations to the roof design. Shape variations include varying values of the relative dimensions of shading and shaded facades and variations to the angle enclosed by the wings of these shapes. Variations of roof design consist of modifications to the tilt and side angles of hip roofs. The results indicate that the number of shading facades in-self shading geometries and their relative dimensions are the major parameters affecting solar incident and transmitted radiation. Manipulation of the orientation of wings in L shape units can result in increased peak electricity generation potential, and in shifting the timing of the peak by up to 2 h either side of solar noon. The shift of peak load may be economically beneficial, facilitating more even distribution of electricity production over an assemblage of buildings. Judicious manipulation of unit shapes and window location can lead to optimization of solar radiation and its utilization for electricity generation and passive solar gain.

8. Hachem *et al.* (2011). Investigation of solar potential of housing units in different neighborhood designs.

This study presents a methodology for investigating the influence of three major parameters in the design of two-storey housing units in different neighborhood layouts, on solar energy utilization potential. The parameters are geometric shapes of individual units, density of units and site layouts. Rectangular and L shape with different values of the angle enclosed between the wings of this shape are studied. The density parameter is represented by detached and multiplexed units. The effect of parallel rows of units is also studied. Site layouts include a straight road and south and north facing semi-circular roads. The EnergyPlus simulation package is used to simulate 26 configurations consisting of combinations of the parameter values. Effects are evaluated as the change from reference configurations of the response parameters – incident and transmitted irradiation of facades and integrated PV electricity generation. The results indicate that the total electricity generation is governed by active roof surface area which is affected by both shape and orientation. Up to 50% increase in electricity generation can be achieved in some housing units of certain configurations, compared to the reference. Variation of surface orientation, particularly in curved layouts enables the spread of peak electricity generation over up to 6h.

1.11 Conclusion

This chapter presented the problem of discomfort built environment which appears as a result of the architectural design that neglected the climatic factors. The importance of this problem increases with the energy crisis which is linked with the ever increase in using heating and cooling energy. The chapter focused on the building form as it considered one of the first decision in the design process which determine the envelop morphology that links between the indoor and outdoor environment. It assumed that the building proportions and their relation with the urban morphology has a great influence on the thermal performance of the indoor environment and thus the energy consumption. So, simulation processes using the thermal analysis programs will be carried out to evaluate this assumption.

The chapter clarified some previous studies which dealt with similar aspects. It is concluded that there is a lack of studies which dealt with the Mediterranean climate of the Gaza Strip. This climate required a special requirements for both summer and winter periods. Also, the large portion of these studies handled with various geometric shapes with various surface to volume ratio. Form proportions such as width ratio and roof to walls ratio didn't studied in terms of energy consumption. Variations in the urban morphology according to variations in the building form didn't studied with regard to the indoor thermal performance and energy consumption.

Chapter 2: Energy Efficiency and Thermal Performance of Buildings

2.1 Introduction

The thermal performance of buildings is considered one of the most criteria of successful building design. It aims to provide the most comfortable environment for occupants and thus minimizing the energy demand for cooling and heating requirements. Its importance increased in conjunction with the energy crisis, the environmental pollution and the climate change which caused by the excessive use of energy in buildings. It deals with the heat flow between buildings and outdoor environment, which can be expressed as heat gain and heat loss. Building's components such as walls, windows and roofs and their materials affect these two mechanisms.

This chapter will display an overview of energy and its using in buildings and its related environmental problems. It will highlight the energy situation in the Gaza Strip. Also, it will explain the mechanism of heat transfer between the building and the environment, which include conduction, convection and radiation. It will overview the factors affect the thermal performance which are design variables, material properties, weather data and a building's usage data. In addition, It will deal with the building thermal balance by handling sources of heat gain and heat loss. Finally, it will discuss the thermal comfort as a measure of thermal performance.

2.2 Energy and Buildings

Energy is considered one of the main factors affecting human life. It plays a huge role in development and civilization. The architectural buildings are important component of human civilization, however they consume a large amount of energy as a result of technological development in order to achieve thermal comfort to their occupants. It's important to view some facts about energy and its uses in buildings and their environmental impacts.

2.2.1 Definition and Forms of Energy

Karasu (2010) stated that energy comes from the Greek word “energeia” and NEED (2011) mentioned that scientists define energy as the ability to do work. As they described, there are two main forms of energy, potential energy and kinetic energy. Potential energy which can be described as energy of position. It include gravitational, stored mechanical, nuclear and chemical energy. The other form is kinetic energy which can be described as energy of motion. It include motion, electrical, sound, radiant and thermal energy.

2.2.2 Energy Use in Buildings

One of the most important topics related to contemporary architecture is the energy using in buildings which contributes to achieve thermal comfort for occupants (Karasu, 2010). According to NREL (2006), commercial and residential buildings consume roughly 40% of the primary energy and 70% of the total electricity used each year in the United States. It is expected that Electricity consumption in the commercial building will increase 50% by 2025. Zain *et al.* (2007) mentioned that more than 45% of the total electricity consumption in Hong Kong is used to provide air-conditioning in commercial buildings.

The cooling requirements is estimated to consume about 65% of the electrical energy generated in the Kingdom of Saudi Arabia (Saeed, 1987). According to the European Commission (2005), the building sector is responsible for more than 40 per cent of EU energy consumption (Karasu, 2010). Figure (2.1) presents a breakdown of energy end-use in the residential sector for the United States and China. As shown in the figure, the space heating is the largest user of energy in both regions. It followed by water heating in China and other uses – primarily electric appliances in USA (Levine *et al.* 2007).

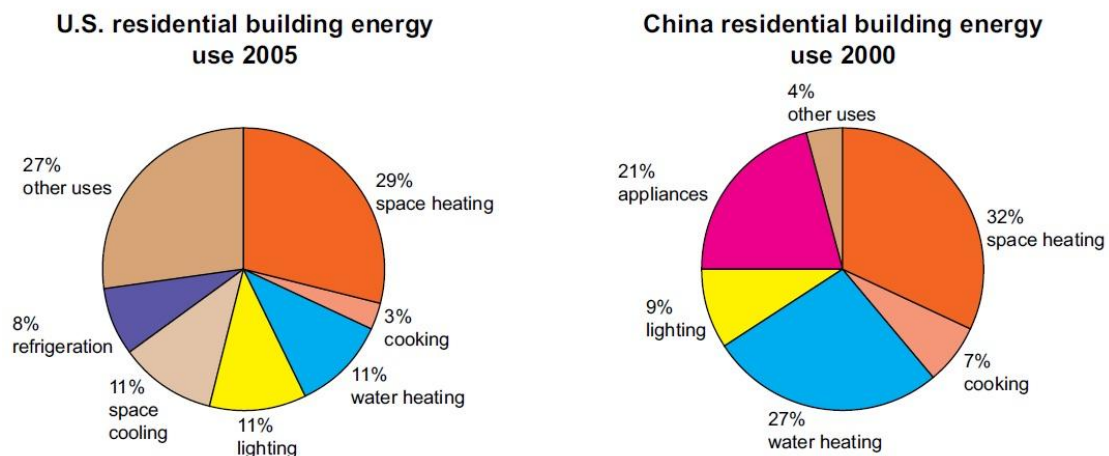


Figure (2.1): Breakdown of residential sector energy use in United States (2005) and China (2000)
Source: Levine *et al.* (2007)

2.2.3 Environmental Effects of Energy Use

One of the main central reasons for the current environmental pollution problem is the excessive use of energy in buildings. Burning fossil fuels to obtain electricity caused pollution of the air, water and soil. Also, it is considered the main responsible of global warming (Bearden, 2000). Climate change is another related issue and according to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC) (2001), The atmospheric concentration of carbon dioxide (CO₂) has increased by 31% since 1750. There has been a 2 to 4% increase in the frequency of heavy precipitation events in the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century. It is estimated that the globally averaged surface temperature will increase by 1.4 to 5.8°C over the period 1990 to 2100, see figure (2.2).

About 80% of the EU's total greenhouse gas emissions is related to energy (Oettinger, 2010). Also, according to U.S. Department of Energy (2001), buildings produce 35% of U.S. and 9% of global carbon dioxide (CO₂) emissions. Almost 48% of the increase in U.S. carbon emissions since 1990 is related to increasing emissions from the building sector (Zain *et al.* 2007). Carbon dioxide emissions increased annually at a rate of 2% from 1971 to 2004 with an annual increase of 1.7% for residential buildings. The Developing Asia was found to have the largest increase in CO₂ emissions for residential buildings which reach 42%, followed by the Middle East with 19%. Show figure (2.3) which illustrates the results for the buildings sector of the CO₂ emissions scenarios produced for the IPCC Special Report on Emissions Scenarios (SRES) (Levine *et al.* 2007).

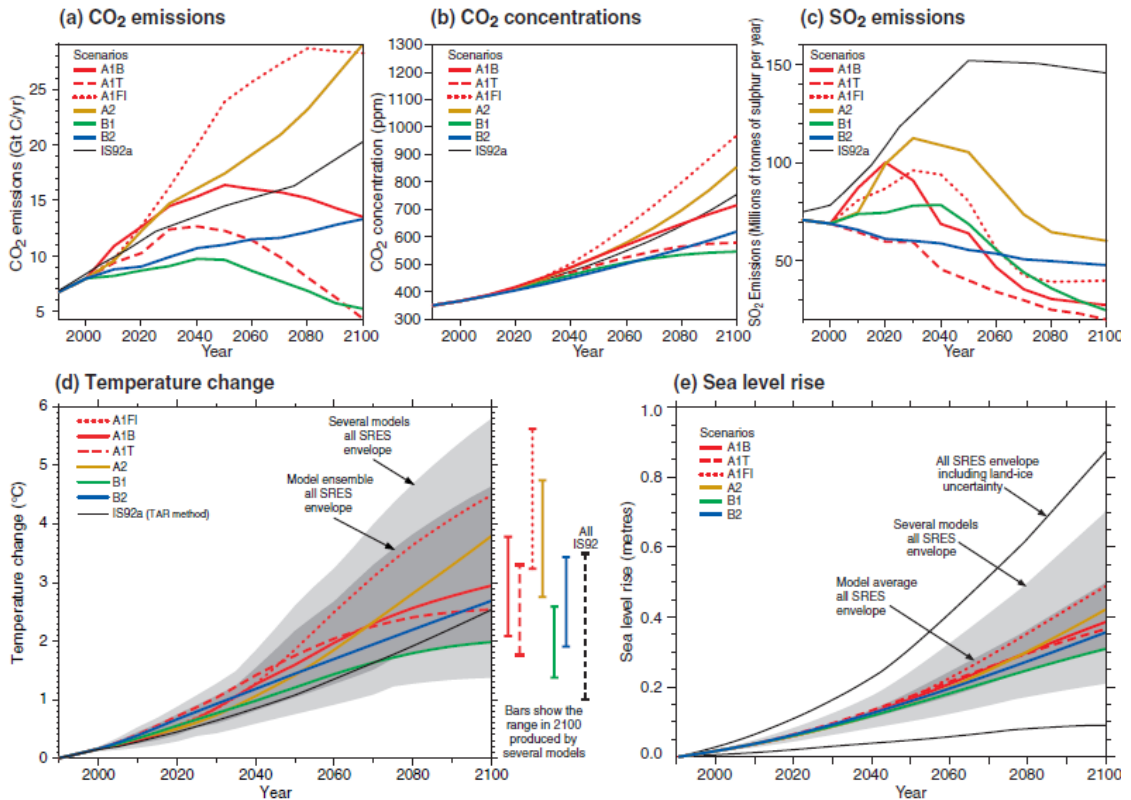


Figure (2.2): The global climate of the 21st century
Source: IPCC, (2001)

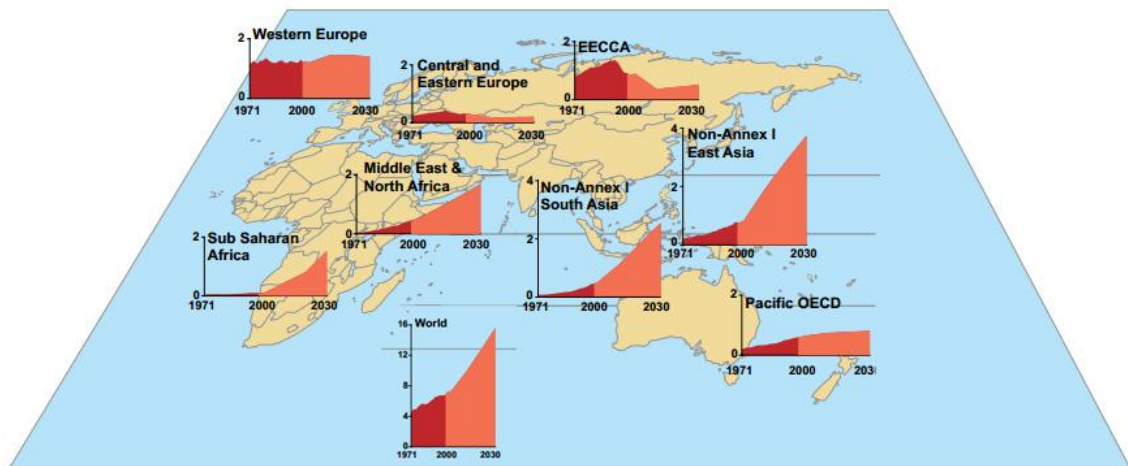


Figure (2.3): CO₂ emissions from the buildings sector
Source: Levine *et al.* (2007)

2.2.4 Energy Shortage Problem

The world is facing a large challenge due to energy shortage which is now driving the economies of the world nations. There is an increasing need for electrical power which depends on fossil fuels. It's expected to increase the demand for oil year by year. The prices of some of the petroleum products in some U.S. areas rises at more than \$2.50 per gallon (Bearden, 2000). About 90% of the energy consumed in the world is supplied from fossil sources such as coal, petroleum, and natural gas (Ddkmen and Gultekdn, 2011). It is estimated that the earth's remaining fossil fuel reserves can probably provide us with energy with another 1 or 2 centuries (Ibrik, 2009). According to Oettinger (2010), more than a third of the EU electricity generation capacity will be

lost by 2020 due to the limited life time of its installations which depends on low-carbon energy sources, mainly nuclear and hydropower.

2.2.5 Using Renewable Energy

The renewable energy refers to electricity generated from one of natural resources such as wind, solar, geothermal and biomass. These resources can be utilized by applications such as wind-powered turbines, photovoltaic (solar cell) arrays and burning of agricultural, forestry, and other byproducts including landfill gas, digester gas, and municipal solid waste (U.S. Department of Energy, 2001). It is important to have a significant increase in using the renewable energy in order to achieve sustainable development and economic growth and to prevent climate change (Karasu, 2010).

The world witnesses an increase in the sharing of renewable energy. In the EU for example, using renewable energy has risen to account 10% of gross final energy consumption in 2008. Renewable sources especially solar and wind accounted 62% of newly installed electricity generation capacity in the EU in 2009 (Oettinger, 2010). In Turkey, renewable energy accounted between 37– 43 % of its energy production and between 15–22 % of its energy consumption for the 1988–1998 period (Karasu, 2010). Table (2.1) shows for example a recent EPIA estimate of the BIPV potential in Europe, US and Japan.

Table (2.1): Potential of BIPV

Source: Montoro, (2008)

Available Roof Surface					
	Net Available Solar Surface (Km ²)	Installable PV "Potential" (GW)	Estimated Electricity production (Twh/year)	Residential Electricity consumption 2006 (TWh/year)	% of PV
Europe (75%: Germany, France, UK, Italy, Spain)	3.723	465,4 (8m ² /Kwp)	511,9	859	59%
		161,9 (23m ² /KWp)	178,1		20%
USA	4.563	570,4 (8m ² /Kwp)	570,4	1351	42%
		198,4(23m ² /KWp)	198,4		14%
Japan	1.050	131,3 (8m ² /Kwp)	118,1	229	51%
		45,7 (23m ² /KWp)	41,1		18%

2.2.6 The Energy Situation in the Gaza Strip

The Gaza strip depends completely on Israel's energy since it was occupied in 1967. After establishing Gaza company for electricity generation in 2003, the company provides Gaza with 40% of its needed electricity. Gaza imports the fossil fuel required for electricity generation from Israel with high prices which results in high price electricity which estimated to be \$0.125 per kWh (Baalousha, 2006). This situation increases the burden of the Palestinian citizen, especially under the difficult economic conditions. Moreover, Muhaisen (2007) mentioned that the electricity demand for the

Gaza strip increase annually in the rate of 10-15 MW as a result of population growth, see figure (2.4). He also mentioned that the domestic sector consumes 70% of the total annual electricity as shown in figure (2.5).

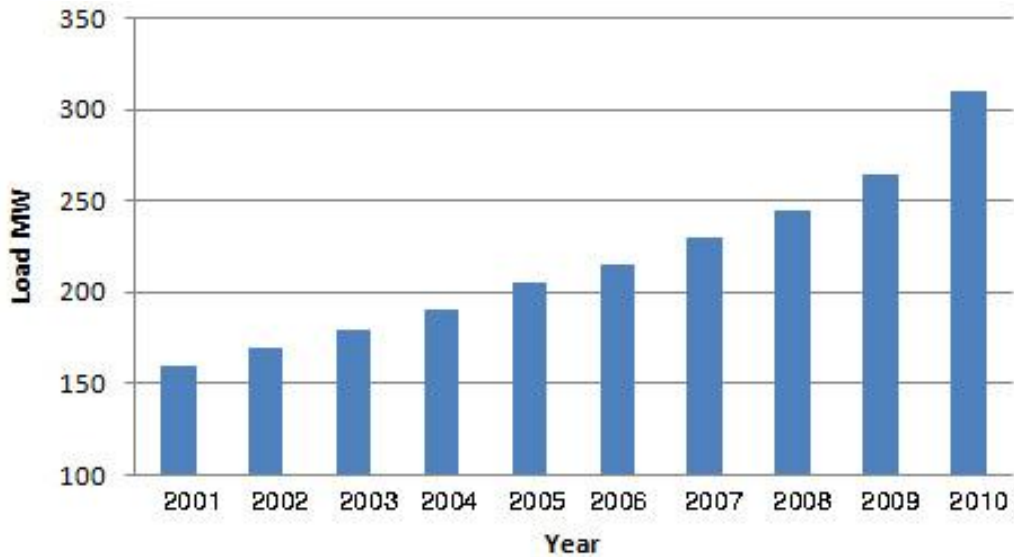


Figure (2.4): The electricity load required for Gaza Strip until year 2010
Source: Muhaisen, (2007)

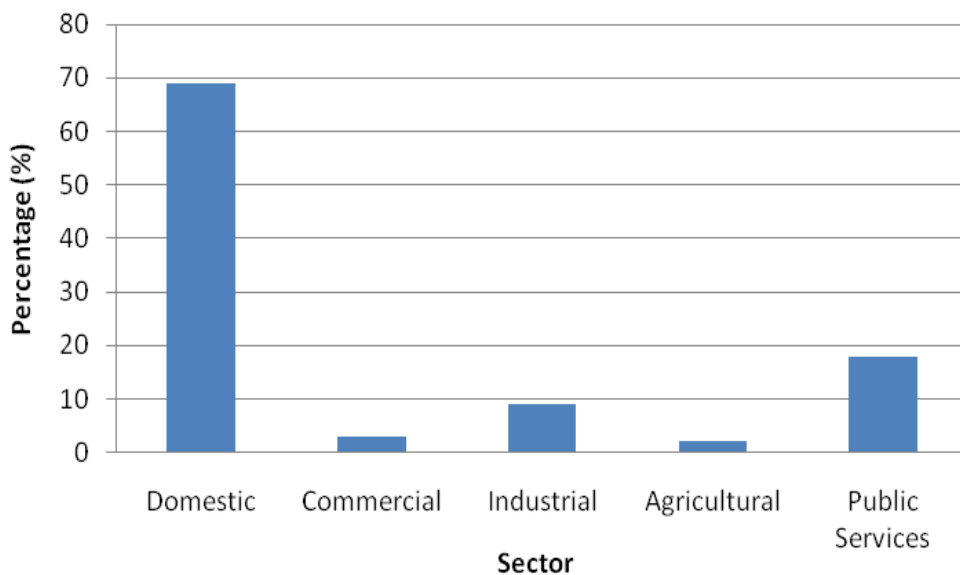


Figure (2.5): The electricity load consumption of different sectors in year 2006
Source: Muhaisen, (2007)

About 86% of households use a space heating facility while 80.7% of families used electrical devices for air conditioning and fans (Abu Alkhair, 2006). Ibrik (2009) stated that the energy consumption increased by 2% from 2001 to 2002, and by 9% from 2002 to 2003. The electricity consumption of the Gaza Strip was increased by 80% during the period 1999 to 2005, and at about 10% average annual increasing rate (Abu-Hafeetha, 2009). The Gaza Strip consumes other forms of energy such as LPG, kerosene, gasoline and diesel. As shown in table (2.2), the Gaza Strip consumes 216 KWh of electricity. It seems to be a large quantity comparing with other Palestinian territory regions although the small area of the Gaza Strip. This is due to the High population density. As well as, the Gaza Strip consumes a large amount of wood as an Alternative resource of energy under the electricity crisis.

Table (2.2): Average Household Consumption of Energy from the Households that Use Energy in the Palestinian Territory by Region, July 2011
Sources: Palestinian Central Bureau of Statistics, (2011)

Region	Average Household Consumption of Energy					
	Electricity (KWh)	Wood (kg)	LPG (Kg)	Kerosene (Liter)	Gasoline (Liter)	Diesel (Liter)
Palestinian Territory	243	49	15	6	49	66
West Bank	257	42	15	20	80	74
North of West Bank	241	36	15	25	91	89
Middle of West Bank	318	21	15	15	91	83
South of West Bank	214	96	17	25	57	55
Gaza Strip	216	58	15	5	26	23

2.2.7 Renewable Energy in the Gaza Strip

Solar energy is considered the main renewable source of energy available in the Gaza Strip because its geographic location near the hot dry climate. Figure (2.6) shows the average duration of solar radiation in Gaza City. It is noticed that the mean sunshine duration range between (8-11) hours in summer period and between (5-7) hours in winter period which is useful for many applications. Solar heaters which are used to heat water are the most applicable application in Gaza houses. According to the Palestinian central bureau of statistics (2011), about 60.5 % of housing units in Gaza Strip use solar heaters.

Photovoltaic units aren't used in Gaza buildings due to its initial high cost which results in a high cost of electricity which estimated to be 3-5 times more than that obtained from the grid. Wind energy is another renewable source in Gaza Strip. The low annual average wind speed which is 3.8 m/s can't be used for considerable generation of electricity. However, it may be suitable for small wind turbines to be installed in residential buildings (Muhaisen, 2007). Also, the biomass energy (wood and agricultural waste) is only used in cooking and heating in rural areas (Ibrik, 2009).

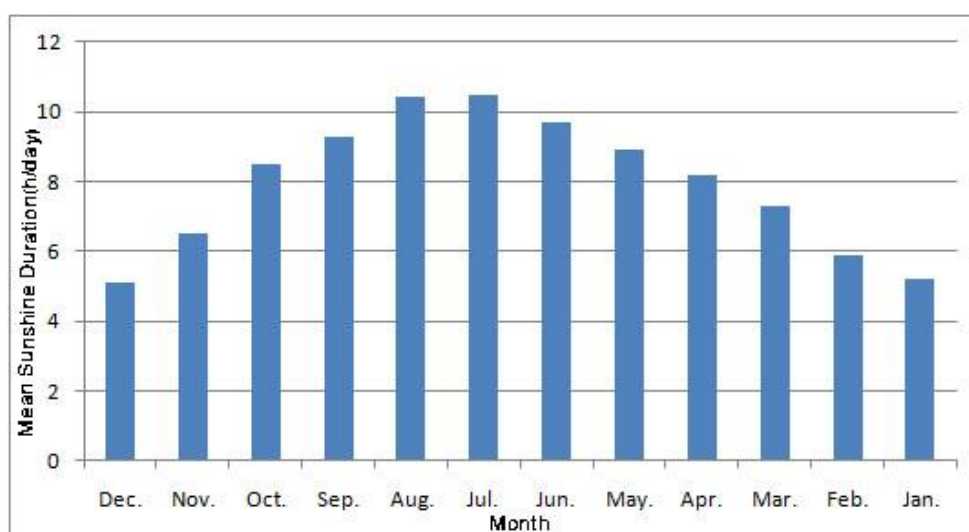


Figure (2.6): The average duration of solar radiation in Gaza City in year 2011
Source: Palestinian Meteorological Department, (2011)

2.2.8 Energy Efficient Buildings

Energy-efficient buildings depends on reduction the energy demand by increasing thermal-performance level, including reduction of air permeability. Energy consumption for heating buildings can be reduced by increasing the level of insulation, using of energy-efficient windows, selecting the optimal orientation of buildings with the goal of passive use of solar energy and using sources of renewable energy (Matrosov *et al.* 2007). Energy efficiency refers to the effectiveness of a building's ability to influence, control and facilitate user control over the movement of heat energy within a building and between the building and its surroundings (Ateed, 2012).

Heat flow must be controlled in order to make buildings more energy efficient. It is possible to slow the rate of energy exchange through conduction, convection and radiation by increasing the thermal performance of building envelopes (Building Science, 2012). The next section will illustrate the thermal performance of buildings and the mechanisms of heat transfer in order to get a better understand of these process and their relation with the energy consumption.

2.3 Overview of Thermal Performance

The thermal performance is considered one of the most important aspect of energy utilization in buildings. The prediction of the buildings thermal performance through heat transfer mechanisms is essential for enhancing the indoor conditions using HVAC and estimation of heating and cooling loads (Zain *et al.* 2007). This section will display a general review of thermal performance and its impact on energy consumption and the mechanisms of thermal transfer.

2.3.1 Definition of Thermal Performance

Nayak and Prajapati (2006) defined the thermal performance of a building as "the process of modeling the energy transfer between a building and its surroundings". The difference of temperature between the building and the outdoor environment is the main engine for energy flow throughout a building. It is also proportional to the thermal quality of the building enclosure (Utzinger and Wasley, 1997).

2.3.2 Impact of Thermal Performance on Energy Consumption

Ghisi and Massignani (2007) stated that the energy consumption of buildings is associated with their thermal performance. The heat transfer through the building components, such as walls, windows and floors, in a mean of heat gains or losses adding to the internal heat gains and ventilation gains are considered the most important factors affecting the thermal performance. In turn, this thermal response determines the required heating and cooling energy in order to maintain acceptable thermal conditions for occupants (Aye *et al.* 2005). Yu *et al.* (2011) concluded that the most influential factor on both cooling and heating energy consumption is the heat transfer coefficient of wall, followed by the building shape coefficient.

2.3.3 Thermal Transfer Mechanism

Heat is considered one of the forms of energy which transferred between objects due to the difference in temperature. It always moves from the hotter object to the cooler one (Roos, 2008). Three heat mechanisms which are conduction, convection, and

radiation are utilized in the passive solar buildings in such way to control the process of distributing heat throughout the living space (NREL, 2001).

a. Conduction

Conduction is the way heat moves between molecules through materials. Heat causes vibrations to the molecules close to the heat source and these vibrations spread to neighboring molecules, thus transferring heat energy (NREL, 2001). Conduction requires the physical contact of two objects. It occurs through the different component of building envelop where heat is conducted from the warmer side to the cooler one (Roos, 2008). The quantity of heat transferred through a material is proportions with its thermal conductivity. The basic equation of heat conduction is shown in appendix (1) (Nayak and Prajapati, 2006).

b. Convection

Roos (2008) defined convection as "heat transfer due to fluid (gas or liquid) or airflow". That explains why warm air rises or cool air falls on a wall's inside surface. Air convection can be used in the passive solar homes to carry solar heat from a south wall into the building's interior (NREL, 2001). Convective thermal transmission occurs from air outside of the building to the outer surface of the wall and the inner surface of the wall to the air inside of the building (Mahlia *et al.* 2007). It can be divided into natural convection which occur due to a temperature difference between zones, and forced convection which occur due to the movement of air by mechanical means. In these two cases convection is responsible for the distribution of heat within the occupied space and between zones (Barakat, 1985). Building's materials have an important role in convective. A modern lightweight material with permeable thermal insulation is sensitive to the convective heat transfer (Svoboda, 2000). The basic equation of heat convection is shown in appendix (1).

c. Radiation

Radiation is heat transfer between two surfaces as a mean of electromagnetic waves, such as light, infrared radiation, UV radiation or microwaves with nothing between them. Radiation takes place in the sun-exposed surfaces of buildings and its value increases where there are large temperature differences (Roos, 2008). Materials properties such as transparency and colors play a significant role in determining the percentage of solar radiation absorbed, reflected, or transmitted, depending on certain properties of that object. The solar radiation which transmitted through the glass and absorbed by the home is radiated again from the interior surfaces as infrared radiation (NREL, 2001). The basic equation of heat radiation is shown in appendix 1.

2.4 Factors Affecting Thermal Performance of Buildings

The thermal performance of a building depends on a large number of factors. Nayak and Prajapati (2006) summarized these factors as design variables, material properties, weather data and a building's usage data.

2.4.1 Design Variables

Buildings are considered the main responsible for indoor thermal conditions because they form the main contact between indoor and outdoor environment. Many variables must be considered through the building's design will be displayed.

a. The Form of Buildings

The building's form, spacing and configuration in its neighborhood affect both the solar and wind factors. They play a large role in determining the amount of solar radiation received by the building's surface and the airflow around it (Nayak and Prajapati, 2006). As the building surface is the exposed component to the outdoor environment, a small ratio of building surface to the volume which is the main characteristic of compact forms is helpful to maintain thermal balance (LEARN ,2004), see figure (2.7).

The building form can affect the thermal performance as it determines the size and the orientation of the exterior envelope exposed to the outdoor environment. Also, cost and aesthetics are affected by the building form. Selecting the optimum shape, orientation, and envelope configuration can reduced the energy consumption by about 40% (Wang *et al.* 2006). Another component of the building form is the roof form. The convection heat transfer area and coefficient for the curved roofs such as cylindrical and dome are higher than flat roofs of the same base. Another issue related to roof form is the ceiling height which affects the building's volume (Rosenlund, 2000).

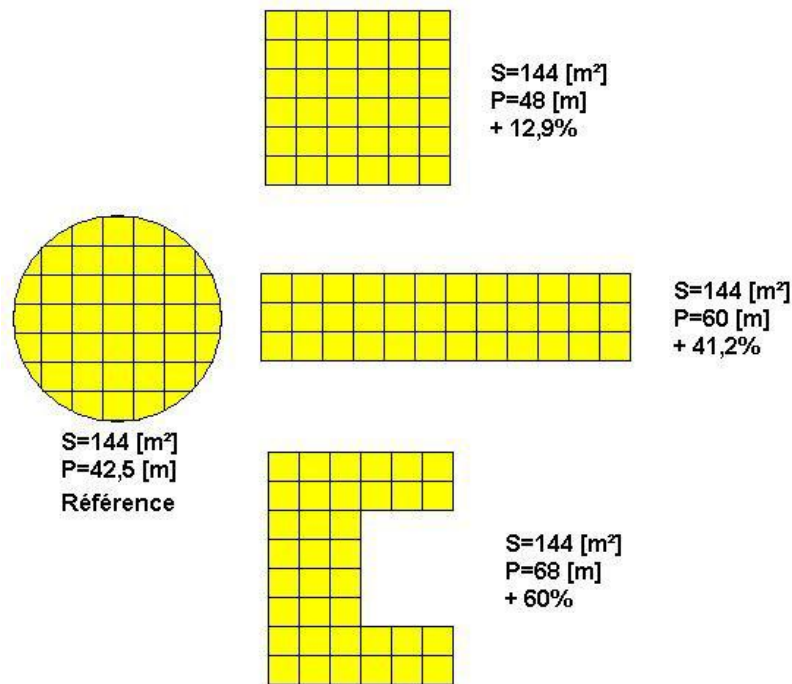


Figure (2.7): Plan to surface area ratios for different shapes of building
Source: LEARN ,(2004)

b. Building Orientation

The building orientation can affect the building thermal performance by minimizing the direct solar radiation into the buildings envelop either building openings or opaque walls (Al-Tamimi *et al.* 2010). Many factors must be taken into consideration during the selecting of building orientation. They include the expected shading impact and the sun movements according to latitude, time of day and time of year (Goulding *et al.* 1992).

c. The Envelope of the Building

Building envelope has a great influence on both indoor and outdoor space condition (Goulding *et al.* 1992). It is one of the main components affects the total heat gain and

overall heat transfer coefficient. It's found that the building envelope accounts for 36%, 25% and 43% of the peak cooling load in Hong Kong, Singapore and Saudi Arabia respectively (Al-Tamimi *et al.* 2010). So it is important for the building envelopes to have a level of thermal resistance and a minimum of thermal bridges in order to avoid the penetration of water vapor inside the buildings (Matrosov *et al.* 2007).

d. Shading Devices

Shading devices have a useful impact especially in Mediterranean and semi-desert climates. The period of the year, the time of the relative transparency of the materials can affect the shading (Goulding *et al.* 1992). In a study of Abd El-Monteleb and Ahmed (2012), it is showed that the vertical louvers with a protrusion of 38 cm or more result in a decrease of 2° C in indoor temperature in the hot arid climate of Egypt. Also, in a study of Al-Tamimi and Fadzil (2011), it is concluded that selecting the best shading devices can improve the number of the comfortable hours by about 26% and 4.7% in unventilated and ventilated conditions, respectively in the tropics.

2.4.2 Material Properties

Material properties of buildings components play a fundamental role in controlling the process of heat transfer. The most important thermal properties which are thermal conductivity, thermal resistance, thermal transmittance and density will be outlined.

a. Thermal Conductivity λ

The thermal conductivity is a property of the material, which represents “the quantity of heat per unit time in watts, that flows through a 1m thick even layer of material with an area of 1m², across a temperature gradient of 1 K (Kelvin) in the direction of the heat flow” (CSR Hebel Technical Manual, 2006). The lower value thermal conductivity is the less thermal transmission will be (Mahlia *et al.* 2007).The basic equation of thermal conductivity is shown in appendix (1).

b. Thermal Resistance of a Material, R

The thermal resistance of a material is the resistance to heat flow between two surfaces at different temperatures. It can be expressed as the R-value which is a function of the material thickness and the reciprocal of its thermal conductivity (CSR Hebel Technical Manual, 2006). The basic equation of thermal resistance is shown in appendix (1). It may be defined as “the time required for one unit of heat to pass through unit area of a material of unit thickness when unit temperature difference exists between opposite faces” (Code on Envelope Thermal Performance for Buildings).

c. Thermal Transmittance, U

The thermal transmittance, U is a direct measure of the thermal insulating ability of a given building component air to air. It is obtained by reciprocating the total thermal resistance of the building component, R (i.e., $U = 1/ R$) (CSR Hebel Technical Manual, 2006). It can be defined as “the quantity of heat that flows through a unit area of a building section under steady-state conditions in unit time per unit temperature difference of the air on either side of the section” (Code on Envelope Thermal Performance for Buildings).

d. Density, Porosity

The density, ρ (kg/m³), is “the mass of a unit volume of the material, comprising the solid itself and the gas-filled pores” (Harmathy, 1988). The density plays a great role for the thermal properties: the lighter the material the more insulating and the heavier the more heat storing (Rosenlund, 2000).

2.4.3. Climatic Factors

The climatic factors can affect the design operation of buildings envelop in order to achieve comfort and save energy. It's important to understand the general climate of the region and the microclimate (Ridley, 1990).

a. Solar Radiation

Nayak and Prajapati (2006) defined the solar radiation as "the intensity of sunrays falling per unit time per unit area and is usually expressed in Watts per square meter (W/m²)". They determined some factors affect the radiation incident on a surface which are geographic location (latitude and longitude of the place), orientation, season, time of day and atmospheric conditions. Solar radiation is the most weather variable influences the air temperatures. It consists of direct radiation (ID) and diffuse radiation (Id which are varying with the sky conditions. Another variables affect the total solar radiation are reflections from the ground and adjacent buildings, shading from adjacent buildings and vegetation (Rosenlund, 2000).

b. Humidity

Air contains a certain amount of vapor, which is called air humidity (Rosenlund, 2000). ASHRAE Standard 55P (2003) defined the relative humidity RH as “the ratio of the partial pressure (or density) of the water vapor in the air to the saturation pressure (or density) of water vapor at the same temperature and the same total pressure”. The acceptable rate of humidity differ according to the climate. While a low rate of humidity is preferable in dry climates, it causes discomfort in tropical climate regions (Biket, 2006), See figure (2.8).

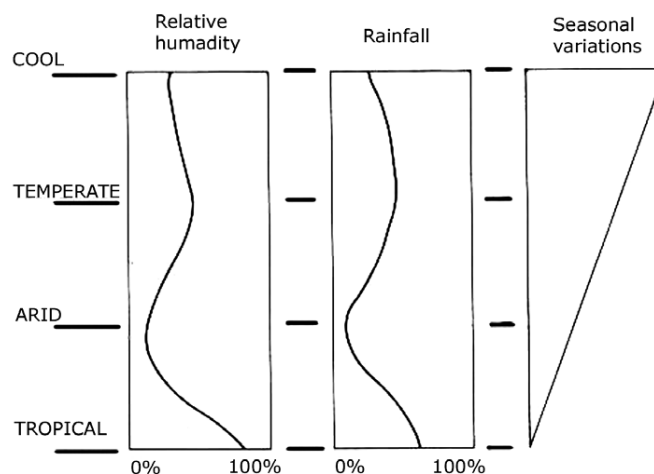


Figure (2.8): Relative Humidity and Rainfall in various climate regions

Source: Biket (2006)

There are an inverse relationship between relative humidity and air temperature. It decreases as the air temperature rises. The decrease in the relative humidity towards

midday tends to be the largest in summer. Also, high humidity levels reduces the transmission of solar radiation due to the atmospheric absorption. Moreover, high humidity decreases evaporation of water and sweat and thus causes high ambient temperature and discomfort (Nayak and Prajapati, 2006). Humidity affects the rate of perspiration evaporation which affects the ability of the body to dissipate heat at higher ambient temperatures (Ridley, 1990).

c. Pressure and Winds

Wind has a great influence on buildings design and their thermal performance. It affects the convective heat exchanges of a building envelope and the air infiltration (Nayak and Prajapati, 2006). It's necessary to avoid the effect of winter wind which increase the infiltration heat loss and utilizing the summer wind in encouraging ventilation (Ridley, 1990). Many factors affect the wind at the local level such as topography, vegetation and buildings configuration (Rosenlund, 2000). Also, it is important to take wind factor into consideration during the urban planning and architectural design. Buildings height and distances between them can affect the formation of pressure zones which is inevitable in the direction of the wind. Various climate regions require different wind requirement (Biket, 2006). Show figure (2.9) which clarifies the desirable wind direction in various climate regions.

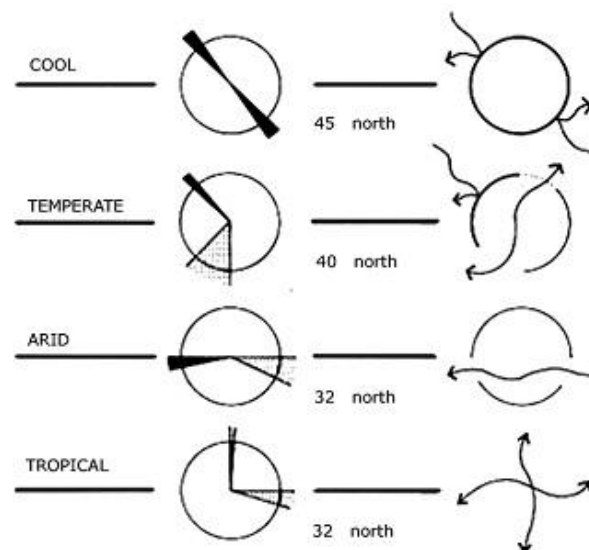


Figure (2.9): Desirable wind direction in various climate regions
Source: Biket, (2006)

2.4.4 Building Occupancy and Operations

Buildings usage produce heat from their occupancy, lights and equipments. Occupation densities and types of activities affect the total heat gain. It can be significant in crowded spaces (Goulding *et al.* 1992). People give off the heat of metabolism to maintain a constant body temperature. Electric lights and equipment give off heat to the building equal to the electrical energy they consume (Utzinger and Wasley, 1997).

2.5 Thermal Balance of Buildings

The main principle in the term of buildings thermal balance is the heat transfer between buildings and environment. This term can be expressed as the overall thermal

transfer value OTTV which is considered as a measure of the heat transfer from outside to the indoor environment through the external envelope of a building. It take into consideration three components of the heat gain which are conduction through an opaque surface, conduction through glass window and solar radiation through glass window (Nikpour *et al.* 2011). Another two sources of heat gain as mentioned by Utzinger and Wasley (1997) are the internal heat gains and the air exchange via ventilation or infiltration. In order to achieve thermal balance in a building, sources of heat gain (conduction, ventilation, solar and internal gain) must equal to heat loss, see figure (2.10). This section will display these sources.

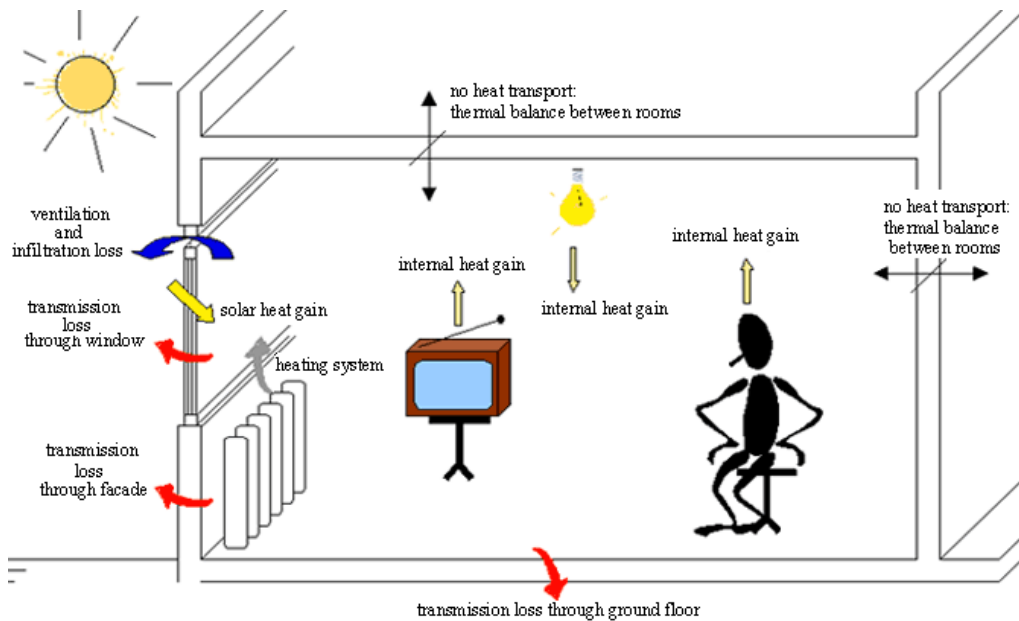


Figure (2.10): Sources of heat gain and heat loss in buildings
Source: CLEAR comfortable low energy architecture, (2011)

2.5.1 Envelope Thermal Transfer Value (ETTV)

One of the most important components affecting the total heat gain and the overall heat transfer coefficient is the building envelope (Al-Tamimi *et al.* 2010). The ETTV represents the thermal performance of the whole envelope. For the purpose of energy conservation, the maximum permissible ETTV has been set at 50 W/m^2 . The ETTV takes into consideration the three basic components of heat gain through the external walls and windows of a building which are: heat conduction through opaque walls, heat conduction through glass windows, and solar radiation through glass windows (Code on Envelope Thermal Performance for Buildings). Heat transfer through the building envelope affected by the area of its components and the thermal conductance of their materials. In order to comprise between buildings, heat transfer rates per unit floor area of the building has to be estimated (Utzinger and Wasley, 1997).

a. Heat Transfer Rate Through the Building Walls

Ling (2007) estimated that vertical wall in high rise buildings received 86.6% of the annual solar insolation. Heat transfer rate through opaque walls is equal to the product of the wall area, A_w , and the wall heat transmission coefficient, U_{WALL} . To allow comparison of different sized buildings, the heat transfer rate through the walls is divided by the floor area A_f giving the heat transfer rate through opaque building walls per unit floor area, \hat{U}_{wall} , see appendix (1) (Utzinger and Wasley, 1997).

b. Heat Transfer Rate Through the Building Roof

One of the major component of building envelop is the roof as it affect the building heating, ventilating and air conditioning. Dominguez *et al.* (2010) stated that increasing the roof albedo from 0.09 to 0.75 on a building without insulation resulted in energy savings of 28%. Heat transfer rate through the building roof is equal to the product of the roof area, A_r , and the roof heat transmission coefficient, U_{ROOF} . As in the estimate of \hat{U}_{wall} , the heat transfer rate through the roof is divided by the floor area A_f giving the heat transfer rate through the building roof per unit floor area, \hat{U}_{roof} , see appendix (1) (Utzinger and Wasley, 1997).

c. Heat Transfer Rate Through the Building Glazing

Glazing have a large influence on the building thermal balance. Heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration. It is up to 40 % in hot summer and cold winter zone. Glazing material, orientation and its ratio to the wall help to cause cooling effects and avoid the increasing in the indoor air temperature (Al-Tamimi *et al.* 2010). Heat transfer rate through the building glazing is equal to the product of the glazing area, A_g , and the glazing heat transmission coefficient, U_{GLZG} . This heat transfer rate is divided by the floor area A_f giving \hat{U}_{glzg} . See appendix (1) (Utzinger and Wasley, 1997).

d. Heat Transfer Rate Through the Ground

The process of buildings heat transfer through the ground occurs along the building perimeter. The heat transfer rate from the building through the ground to the environment is equal to the product of the building perimeter in contact with the ground, Perimeter, and the rate of heat flow through the ground per foot of perimeter for a given building construction type, U_{GRND} . Dividing this rate by the floor area A_f giving \hat{U}_{grnd} , see appendix (1) (Utzinger and Wasley, 1997).

2.5.2 Heat Transfer Rate via Ventilation or Infiltration

Natural ventilation can be defined as the flow of outdoor air to the indoor through openings under the influence of wind and thermal pressures. It has the ability to control temperature to provide cooling particularly in hot and humid climate and thus enhance the building thermal performance. The natural ventilation can improve the thermal comfort in a range between 9% and 41% in a tropical climate and between 8% and 56% in a temperate climate (Al-Tamimi *et al.* 2010).

The Air infiltration through wall's cracks can causes a heat loss. Buildings tightness is important for maintaining the indoor temperatures. It is measured in the number of air changes per hour (ACH). It is important to avoid the problems of increasing the building tightness which can affects the indoor air quality and moisture buildup. A good, comfortable, energy-efficient house will have approximately 0.35 to 0.50 air changes per hour under normal winter conditions (Balcomb, 1995).

2.5.3 Building Solar Heat Gains

The building solar heat gain is responsible for the large amount of cooling load and is considered as the most parameter affected the overall thermal transfer value OTTV (Nikpour *et al.* 2011). When solar radiation falls on glass and other partially transparent material some of the incident energy is reflected, some is absorbed by the material, and

the rest is transmitted to the inside of the building. For ordinary windows the absorption is quite a small fraction and transmission much the largest part (Stephenson, 1963).

Solar transmittance is given as a Solar Heat Gain Coefficient (SHGC). This refers to the ratio of solar heat gain entering a space through a window compared to the total incident solar radiation falling on the outside surface of that window. This includes both directly transmitted solar heat and the solar radiation actually absorbed by the glass, which is then re-radiated, conducted or convected into the space (Marsh, 2006).

2.5.4 Building Internal Heat Gains

This term represents all the sources of heat inside the building, namely the occupants, lights, appliances and other equipment, see appendix 1 (LEARN, 2004). All three paths for internal heat gains are given in Btu of heat added to the building per hour per square foot of floor area (Uttinger and Wasley, 1997).

Blum *et al.* (1989) mentioned that the internal heat gains can be summed to the auxiliary heat used, then dividing by the actual number of degree days and the square footage of the house to give the building performance index (BPI), in $\text{kJ/m}^2 \cdot ^\circ\text{C}\cdot\text{day}$. It is considered the performance factor which characterizes the overall heating energy efficiency of the building and normalized for the effects of climate, occupancy, and size.

2.5.5 Evaporative Heat Loss

Evaporation is the process of removal of water by vaporization which is accompanied by heat loss which leads to a cooling effect. Many factors affect the rate of evaporation which are the temperature, the wind, the exposed surface and the pressure. The rate of evaporation increases with increase in temperature, wind speed and the exposed surface while it decreased with high pressure (Nayak and Prajapati, 2006).

2.6 Thermal Comfort in Buildings

ASHRAE Standard 55P (2003) defined thermal comfort 'that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation'. Many factors affect thermal comfort such as air temperature, radiant temperature, relative humidity, air velocity, activity and clothing (Darby *et al.* 2005). Air temperature and air humidity are the most commonly factors addressed in the conventional design process. However, they affect only 6% and 18% of thermal comfort, respectively. Another factors such as the temperature of surrounding surfaces and the air velocity account for 50% and 26% of thermal comfort perception, respectively (Mikler *et al.* 2008). Thermal comfort is an essential parameter in passive solar buildings in which solar energy is collected, stored and distributed (Goulding *et al.* 1992). It is not be possible for a group of people exposed to the same climatic conditions of the same room, to feel comfort at the same time due to the physical variance (Çakir, 2006). This section will deal with comfort zone, bioclimatic charts and thermal comfort models.

2.6.1. Comfort Zone

According to Çakir (2006), the comfort zone may be defined as "a thermal condition in which little or no effort is required by occupants to adjust their bodies to surrounding environmental conditions". A number of scales were developed for comfort zone, and some are shown in Table (2.3). Each scale determines a range of comfort factors which

previously mentioned. Gagge's DISC index expresses degrees of discomfort rather than comfort. If 80% of people is feeling comfort, that's mean that the comfort zone is DISC ± 0.5 . The Standard Effective Temperature (SET) is another index which describes a comfort environment with 50% relative humidity, air speed of 0.125 m/s, activity level of 1 met (sitting) and clothing of 0.6 clo ('indoor clothes') (Rosenlund, 2000).

Table (2.3): Thermal sensation scales
Source: Rosenlund, (2000)

	ASHRAE	Fanger	Rohles & Nevins	Gagge's DISC	SET (°C)
Painful			+5	+5	
Very hot			+4	+4	37.5-
Hot	7	+3	+3	+3	34.5-37.5
Warm	6	+2	+2	+2	30.0-34.5
Slightly warm	5	+1	+1	+1	25.6-30.0
Neutral	4	0	0	0.5	22.2-25.6
Slightly cool	3	-1	-1	-1	17.5-22.2
Cool	2	-2	-2	-2	14.5-17.5
Cold	1	-3	-3	-3	10.0-14.5
Very cold			-4	-4	

Another scale of comfort zone is ASHRAE which has defined a comfort zone for winter and summer season. This definition is only depends on relative humidity and temperature (Sensirion, 2010), see figure (2.11). Evans (2007) shows that there are different comfort zones defined in five successive ASHRAE standards. They show the difficulty of defining a desirable comfort zone, with significant variations proposed over a period of thirty years.

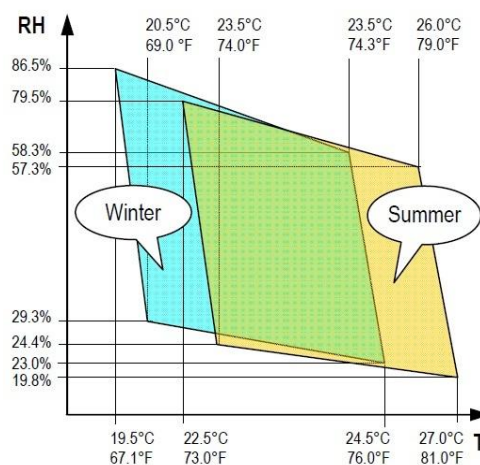


Figure (2.11):Relative humidity (RH) / temperature (T) diagram based on comfort zone according to ASHRAE 55-1992

Source: Sensirion, 2010

Fanger's effort in developing comfort index results in the predicted mean vote 'PMV' which indicates the average comfort vote of a typical population on a scale from -3, Cold, to +3, Hot, with 0 as thermal neutrality (Evans, 2007). Charles (2003) found that the PMV model is not always a good predictor of actual thermal sensation, particularly in field study settings due to the difficulties inherent in obtaining accurate measures of clothing insulation and metabolic rate. His review also suggested that bias in PMV predictions is more accurate in air-conditioned buildings than in naturally ventilated ones, in part because of the influence of outdoor temperature, and opportunities for adaptation.

2.6.2. Bioclimatic Charts

The most commonly used bioclimatic charts are Olgyay and Givoni's Bioclimatic Chart. Olgyay expresses the comfort zone in graphic form taking into consideration two climatic variables which are the dry bulb temperature DBT on the vertical axis and the relative humidity RH on the horizontal. The comfort zone is laying in the aerofoil-shaped zone at the centre of this graph. The higher lines above this comfort zone indicate the effect of air movement on extending the upper boundary of the comfort zone. The lower lines below the comfort zone indicate various levels of radiation that would compensate for the lower than comfortable temperatures (Auliciems, *et al*, 2007). Figure (2.12) illustrates Olgyay's Bioclimatic chart. Another chart is presented by Givoni who used a diagram, with dry bulb temperature on the horizontal scale and absolute humidity on the vertical scale. This diagram can contain a number of zones to indicate conditions that require different bioclimatic design resources (Evans, 2007), see figure (2.13).

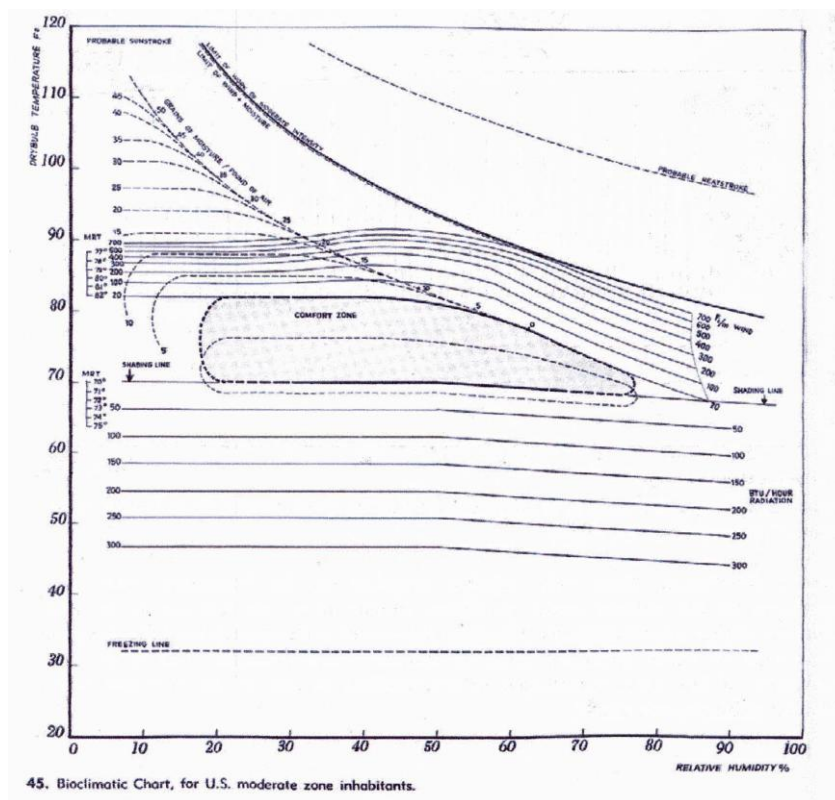


Figure (2.12): Olgyay's Bioclimatic chart
Source: Auliciems *et al.* (2007)

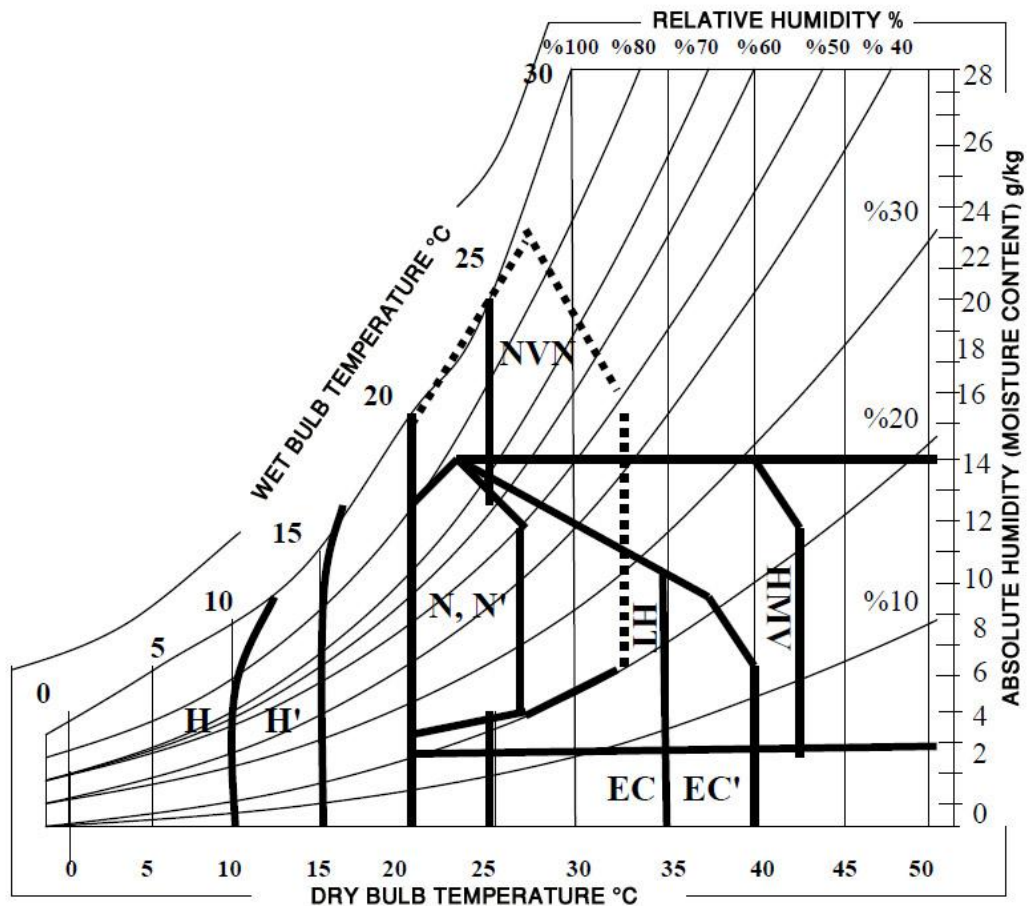


Figure (2.13): Givoni's Bioclimatic chart
Source: Labdi, (2009)

2.6.3. Thermal Comfort Models

In spite of the difficulties of defining acceptable comfort conditions, there are several models for measuring thermal comfort. The most commonly used models are the heat-balance approach (the Fanger model) and the adaptive models (Mikler *et al.* 2008).

a. The Heat-Balance Approach (The Fanger Model)

This approach combines the theory of heat transfer with the physiology of thermoregulation to determine a narrow range of comfort temperatures which occupants of buildings will find comfortable (Darby *et al.* 2005). The range is determined by a 'PMV' (predicted mean vote) which defines comfort in terms of air temperature and humidity because these parameters are easy to measure and control (Mikler *et al.* 2008).

b. The Adaptive Approach

The adaptive approach to thermal comfort starts from the observation that human can take a range of actions in order to maintain they temperature within close limits and thus achieve thermal comfort (LEARN ,2004). The Adaptive Model is the most suitable approach to the passive solar buildings as it defines comfort with a wider range of thermal parameters and correlates variable outdoor conditions with indoor conditions and, (Mikler *et al.* 2008).

De Dear (1997) suggests that human thermal adaptation is comprised of three interrelated processes– behavioral, physiological and psychological. Behavioral adaptation includes actions such as adjusting clothing, activity and modifying the surroundings themselves such as opening/closing windows. Physiological adaptation is broken down into genetic adaptation and acclimatization, whilst psychological adaptation describes the extent to which habituation and expectation alter thermal perceptions.

2.7 Conclusion

This chapter addressed the issue of thermal performance in buildings and its relation with energy consumption. It focused on the energy use in building in order to enhance thermal performance and achieve thermal comfort to its occupants. The situation of energy demand and potential of renewable energy in Gaza strip was also discussed. The chapter outlined the factors affecting thermal performance and ways to achieve building thermal balance between heat gain and heat loss. Hence, this chapter highlighted the impact of building thermal performance on energy consumption and environmental pollution. It also determined the roles of architectural design of building elements and its envelop material on achieving thermal balance. Also, the scales of thermal comfort the building has to achieve were clarified.

The chapter concluded that it is necessary to utilize renewable energy sources in buildings in order to mitigate the environmental problems and the ever increase in using the conventional sources of energy. It is important to eliminate the thermal transfer rate between the building envelop and surrounding environment in ways of conduction, convection and radiation in order to maintain the thermal balance. This required the control of architectural elements and a building's material properties with respect to the climatic factors. It is also required to utilize passive solar design strategies. For this purpose the next chapter will displays the climate responsive buildings design. It will outline the climate classification and the passive heating and cooling strategies.

Chapter 3: Climate Responsive Buildings Design and its situation in the Gaza Strip

3.1 Introduction

The ever increase in using energy appears as one of the most important related issue of building design in the present era. The traditional architecture has developed a number of climatic treatments, which contributed significantly in protection the human from the negative effects of climate. It succeeded in exploiting the natural energy sources in order to enhance the thermal comfort. The architectural design of buildings and the passive solar strategies play a significant role in their thermal performance and energy consumption. Architectural design must respect the climatic factors in order to achieve thermal comfort.

This chapter will display the climate responsive buildings design. Also, it will overview the passive solar design strategies which include passive heating strategies and passive cooling strategies. It will focuses on buildings forms and orientation according to climate change. After that this chapter will discuss climate responsive design strategies in Mediterranean region. It will display the climate characteristics in Mediterranean region and the passive solar design strategies in it. Finally, it will highlight the potential of passive solar design in Gaza Strip especially in residential buildings.

3.2 Overview of Climate Responsive Buildings Design

It was obvious that there is a large relationship between the built environment and other problems such as environmental pollution, climatic change and energy consumption. The reason for this is due to the excessive use of heating and cooling equipments in order to enhance the indoor environment. The world aware of these problems and seem to move towards the climate-responsive design as one of the means that can contribute to solving these problems. This section will display a general review of climate responsive buildings design and its important on energy consumption. As well as it will clarify the concept of climate classification in order to clearly identify the suitable passive solar design strategies for each climate.

3.2.1 Definition of Climate Responsive Buildings Design

Mikler *et al.* (2008) defined Passive design as "an approach to building design that uses the building architecture to minimize energy consumption and improve thermal comfort. The building form and thermal performance of building elements are carefully considered and optimized for interaction with the local microclimate". He added that the passive design aims to achieve thermal comfort with a minimum need of active mechanical systems which results in a large amount of fossil fuel-based energy consumption. Passive solar techniques utilize the natural energy available in the environment by means of collecting, storing and distributing. They make use of heat transfer's principles in order to control thermal energy flow between buildings and outdoor environment (Nayak and Prajapati, 2006).

3.2.2 Importance of Climate Responsive Design

One of the main important aspects associated with Climate responsive design of buildings in addition to energy saving is its role in preserving valuable resources in the

planet (Al-Tamimi *et al.* 2010). According to the Passive Solar Industries Council (1994), the passive solar homes generally require an average of about 30% less energy for heating than conventional houses, with some houses saving much more. Reyes *et al.* (2007) stated that a well-designed passive solar home can reduce energy bills by 75% while adding up to 10% in construction costs. It has been estimated that 13% of the heat demand of buildings is covered by passive solar energy use. Figure (3.1) shows an example of the compounding effect of combining various passive elements on a typical building in Vancouver in Canada as thermal comfort is held constant. The baseline meets the minimum requirements of ASHRAE Standard 90.1. As each additional element is incorporated, the annual energy consumption is further reduced.

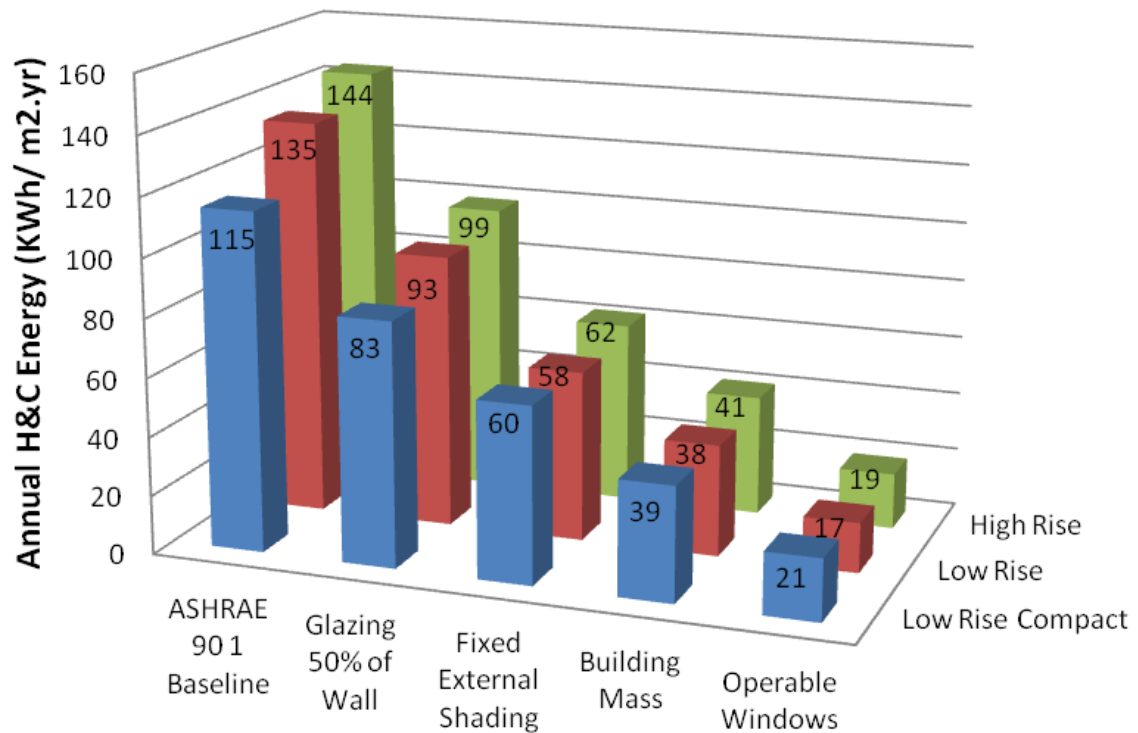


Figure (3.1): Effect of Passive Design on Energy Intensity
Source: Mikler *et al.* (2008)

3.2.3 Climate Classification

One of most commonly used classification system for describing the climate is Köppen's. The Köppen system recognizes five major climate types based on the annual and monthly averages of temperature and precipitation. Each type is designated by a capital letter. A second letter in the classification considers the precipitation and a third letter the air temperature (Kottek *et al.* 2006), See table (3.1) and figure (3.2).

a. Warm-Humid Climate (Moist Tropical)

The most important characteristic of this climate is the high temperatures and the heavy rain. Minimum average monthly temperature is above 18°C. Humidity and cloudiness increase the importance of diffuse solar radiation while they decrease the potential for radiative sky cooling. Rainfall and winds are the main determinant of seasons (Rosenlund, 2000). Köppen specifies three A climates which are Wet equatorial climate (A_f), Tropical monsoon and trade-wind littoral climate (A_m) and Tropical wet-dry climate (A_w).

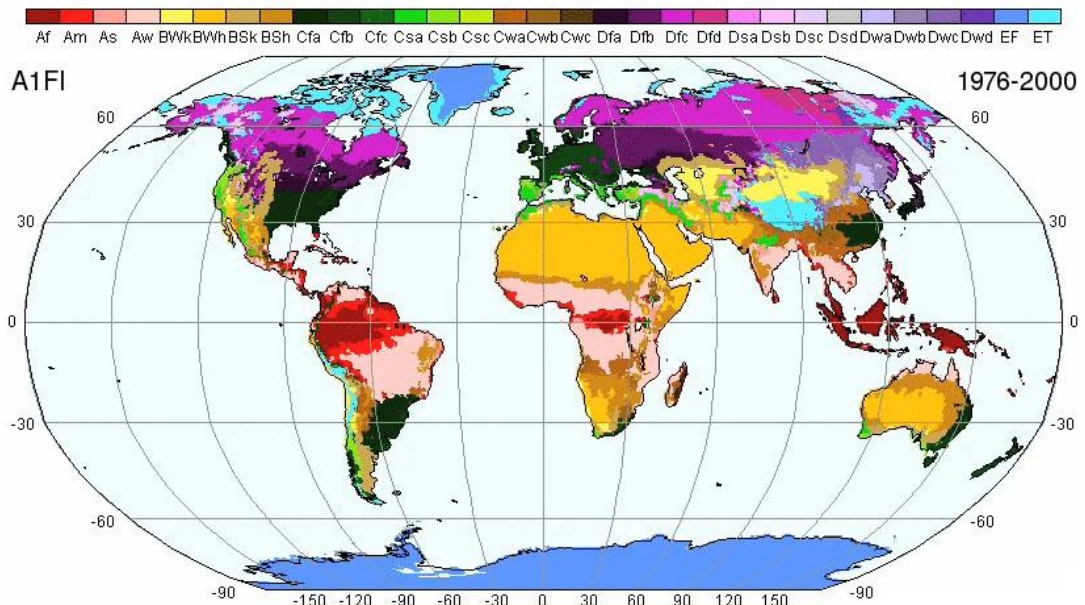


Figure (3.2): World Map of Köppen-Geiger climate classification
Source: Kottek *et al.* (2006)

b. Hot-Arid Climate

A little rain and a huge daily temperature range are the main characteristic of this climate. The winter average temperatures are higher than 0°C and above 18°C in summer. A hot-arid climate has a strong sunshine with a large portion of direct radiation (Rosenlund, 2000). Köppen's classification recognizes three B climates which are Tropical and subtropical desert climate (B_{Wh}, part of B_{Wk}), Mid-latitude steppe and desert climate (B_{Sh}) and Tropical and subtropical steppe climate (B_{Sk}, part of B_{Wk}).

c. Temperate Climates (Humid Middle Latitude)

These climates have warm, dry summers and cool, wet winters. The average temperatures ranging from 0–18°C for the coldest, and 10–22°C for the hottest month. Solar heating potential may be high, but overheating problems may be important during the hot season (Rosenlund, 2000). Köppen's classification identifies six C climates and eight D climates which are Humid subtropical climate (C_{fa}, C_{wa}), Mediterranean climate (C_{sa}, C_{sb}), Marine west coast climate (C_{fb}, C_{fc}), Humid continental climate (D_{fa}, D_{fb}, D_{wa}, D_{wb}) and Continental subarctic climate (D_{fc}, D_{fd}, D_{wc}, D_{wd}).

d. Cold Climates (Snow)

The average temperature of the coldest month is below 0°C and the summer averages may reach 22°C. The potential for solar heating may be limited (Rosenlund, 2000). Total precipitation is not very high and seasonal temperatures vary widely (Kottek *et al.* 2006).

e. Polar Climates

These climates are part of areas where permanent ice and tundra are always present. Only about four months of the year have above freezing temperatures. Köppen's two E climates and the H climate are Tundra climate (ET), Snow and ice climate (E_F) and Highland climate (H).

Table (3.1): Description of Köppen climate symbols and defining criteria
Source: Peel *et al.* (2007)

1st	2nd	3rd	Description	Criteria*
A			Tropical	$T_{\text{cold}} \geq 18$
	f		- Rainforest	$P_{\text{dry}} \geq 60$
	m		- Monsoon	Not (Af) & $P_{\text{dry}} \geq 100 - \text{MAP}/25$
	w		- Savannah	Not (Af) & $P_{\text{dry}} < 100 - \text{MAP}/25$
B			Arid	$\text{MAP} < 10 \times P_{\text{threshold}}$
	W		- Desert	$\text{MAP} < 5 \times P_{\text{threshold}}$
	S		- Steppe	$\text{MAP} \geq 5 \times P_{\text{threshold}}$
		h	- Hot	$\text{MAT} \geq 18$
		k	- Cold	$\text{MAT} < 18$
C			Temperate	$T_{\text{hot}} > 10$ & $0 < T_{\text{cold}} < 18$
	s		- Dry Summer	$P_{\text{sdry}} < 40$ & $P_{\text{sdry}} < P_{\text{wwet}}/3$
	w		- Dry Winter	$P_{\text{wdry}} < P_{\text{swet}}/10$
	f		- Without dry season	Not (Cs) or (Cw)
		a	- Hot Summer	$T_{\text{hot}} \geq 22$
		b	- Warm Summer	Not (a) & $T_{\text{mon}10} \geq 4$
		c	- Cold Summer	Not (a or b) & $1 \leq T_{\text{mon}10} < 4$
D			Cold	$T_{\text{hot}} > 10$ & $T_{\text{cold}} \leq 0$
	s		- Dry Summer	$P_{\text{sdry}} < 40$ & $P_{\text{sdry}} < P_{\text{wwet}}/3$
	w		- Dry Winter	$P_{\text{wdry}} < P_{\text{swet}}/10$
	f		- Without dry season	Not (Ds) or (Dw)
		a	- Hot Summer	$T_{\text{hot}} \geq 22$
		b	- Warm Summer	Not (a) & $T_{\text{mon}10} \geq 4$
		c	- Cold Summer	Not (a, b or d)
		d	- Very Cold Winter	Not (a or b) & $T_{\text{cold}} < -38$
E			Polar	$T_{\text{hot}} < 10$
	T		- Tundra	$T_{\text{hot}} > 0$
	F		- Frost	$T_{\text{hot}} \leq 0$

*MAP = mean annual precipitation, MAT = mean annual temperature, T_{hot} = temperature of the hottest month, T_{cold} = temperature of the coldest month, $T_{\text{mon}10}$ = number of months where the temperature is above 10, P_{dry} = precipitation of the driest month, P_{sdry} = precipitation of the driest month in summer, P_{wdry} = precipitation of the driest month in winter, P_{swet} = precipitation of the wettest month in summer, P_{wwet} = precipitation of the wettest month in winter, $P_{\text{threshold}}$ = varies according to the following rules (if 70% of MAP occurs in winter then $P_{\text{threshold}} = 2 \times \text{MAT}$, if 70% of MAP occurs in summer then $P_{\text{threshold}} = 2 \times \text{MAT} + 28$, otherwise $P_{\text{threshold}} = 2 \times \text{MAT} + 14$). Summer (winter) is defined as the warmer (cooler) six month period of ONDJFM and AMJJAS.

3.3 The Climatic Design Strategies

The climatic design strategies depend on utilizing the opportunities and capabilities of the local climate. Some of these strategies remain the same in different climates (Passive Solar Industries Council *et al.* 1994). The layout, form and orientation of the buildings in addition to spacing between them are the most important strategies affecting indoor thermal comfort. Also, building envelope has a great influence as it separates the outdoor and indoor environment (Leylian *et al.* 2010). This section will clarify the most important strategies. Also, some passive heating and cooling strategies can be applied to enhance the thermal response of buildings. Appendix (2) will display this main strategies.

3.3.1 Building Form

The main principle in selecting the building form is the ability to maximize solar collection and to minimize heat losses through the envelop, where the most important requirement is heating. This can be achieved through increasing the area available for solar collection and decreasing the remaining external surface areas. Also, reducing the ratio between surface area and volume can enhance thermal performance (Goulding *et*

al. 1992). See figure (3.3). Many factors affect the building shape such as planning considerations, building type and use, feasibility and initial cost. In all cases it has a large influence on reducing the building energy intensity, see figure (3.4) (Mikler *et al.* 2008).

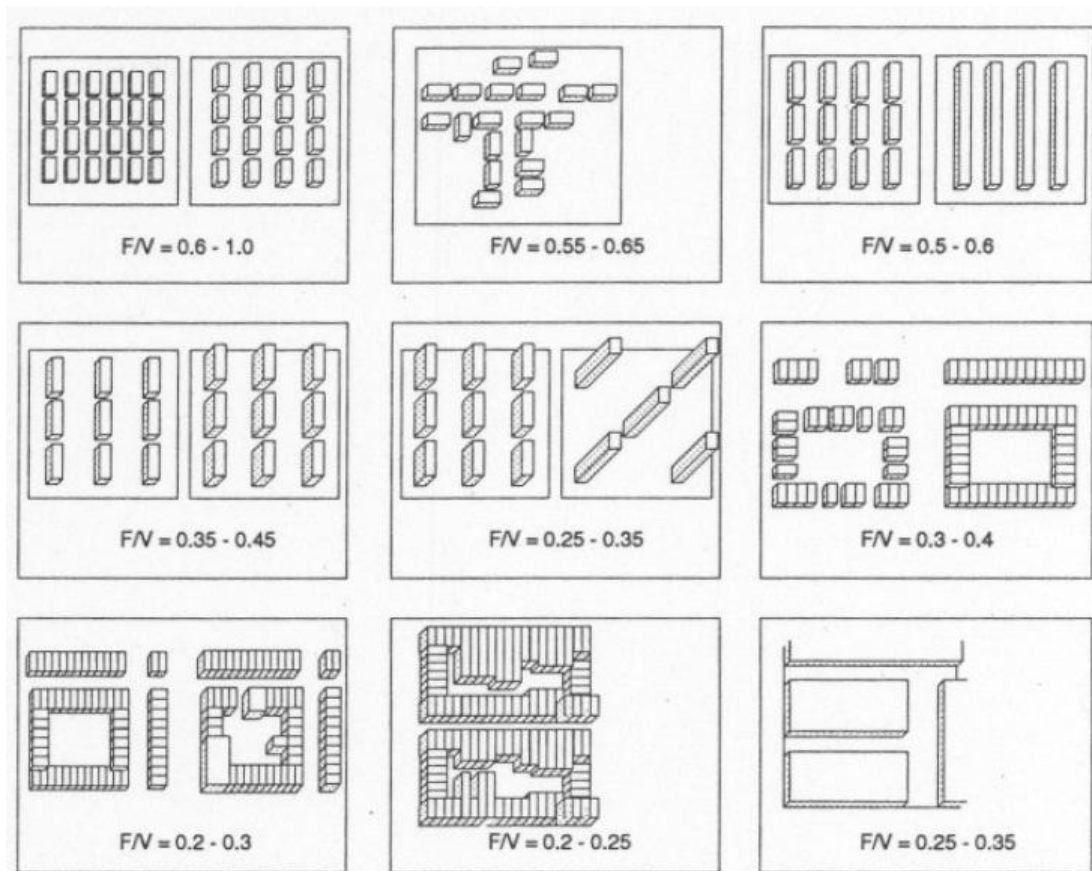


Figure (3.3): Site layouts showing different surface area (F) to volume (V) ratios
Source: Goulding *et al.* (1992)

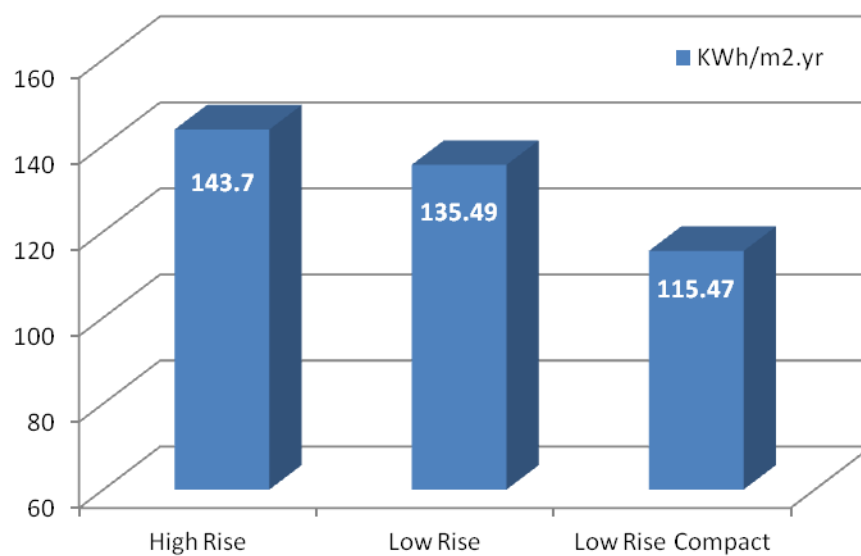


Figure (3.4): Energy Intensity and Building Shape
Source: Mikler *et al.* (2008)

Moreover, some forms such as H-type or L-type can provide self-shading of surfaces which can decrease the direct solar radiation (Nayak and Prajapati, 2006). Self-shading of building usually depends on the building shape and layout arrangement (Chan, 2012). Also, the building form affects on wind channeling and air flow patterns, and the opportunities for enhancing the use of natural daylight (Goulding et al. 1992). Generally, geometry variables including length, height, and depth usually control the objective values such as the area and volume of the building (Yi and Malkawi, 2009).

Building with larger floor space is smaller energy efficiency. Larger volume buildings tend to be more efficiency. Taller and narrower buildings are more energy efficient. According to Capeluto (2002) self shading geometry forms provide the best solution for improvement energy performance in buildings. According to Lam (2005) the amount of heat coming through the building envelope is proportional the total gross exterior wall area. Self-protected form is one of possible ways against the impact of solar radiation in high rise buildings. It's clear that self-shading strategies reduce solar insolation on vertical surfaces (Nikpour *et al.* 2011). Figure (3.5) illustrate the relationship between building form and heat loss.

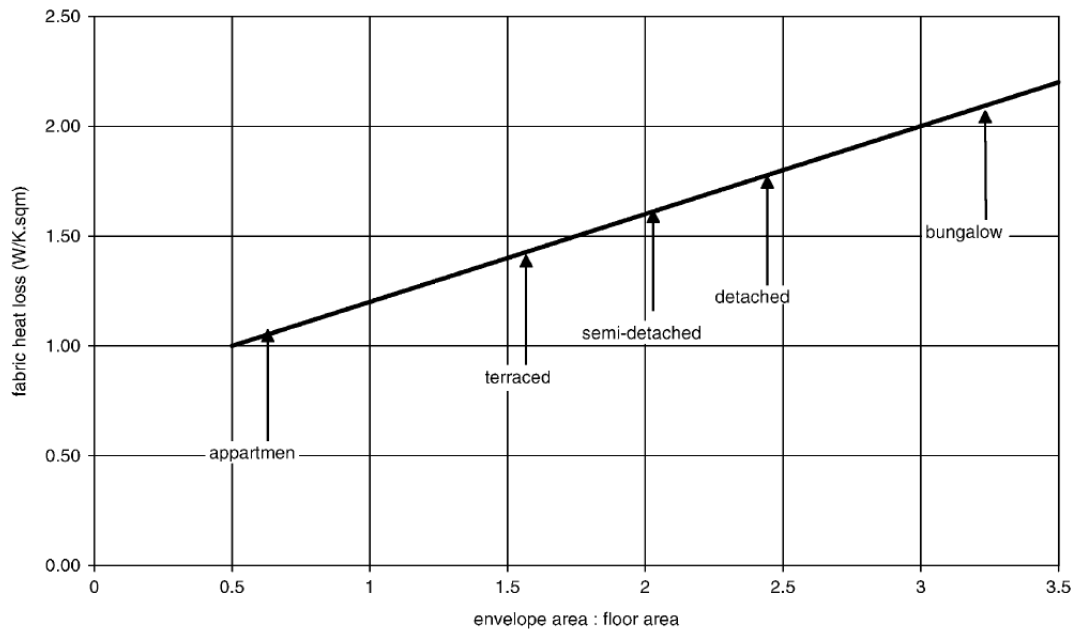


Figure (3.5): Relationship between building form and heat loss
Source: Steemers, (2003)

The geometry of buildings can affect the microclimatic conditions in the urban canopy layer (UCL) of open spaces of urban streets and courtyards which play an important role in the city's overall climate as shown in figure (3.6) (Shashua-Bar *et al.* 2004). The relationship between the building's height and the street's width (aspect ratios H/W) can affect shading at street level during daytime which has a side effect on nighttime cooling and natural ventilation as night winds are more restricted with higher aspect ratios (Krüger *et al.* 2010).

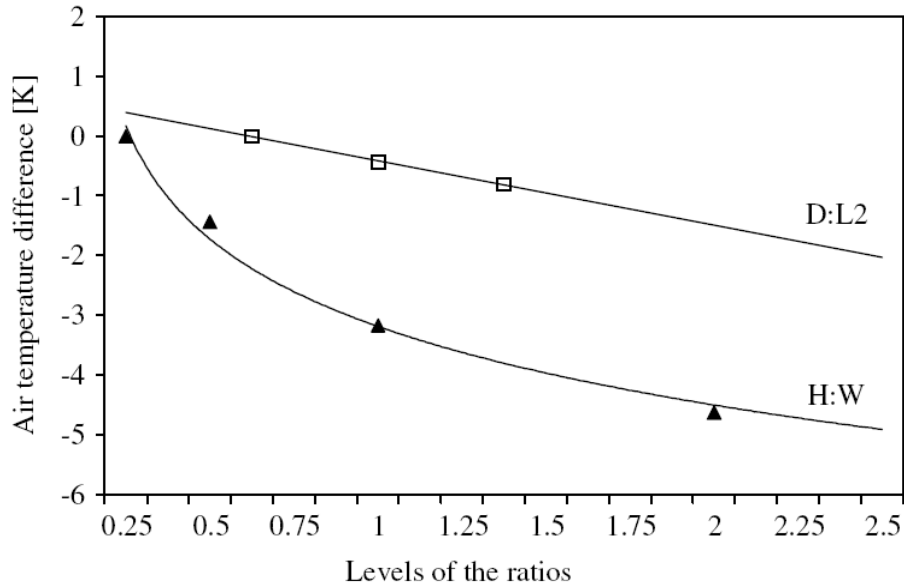
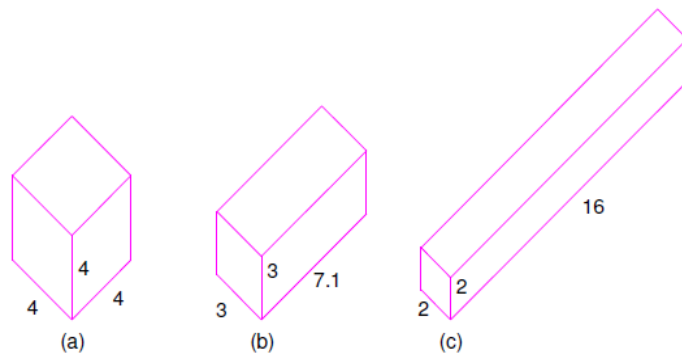


Figure (3.6): The effects of the building depth ratio (D : L2) and the aspect ratio (H :W) on the UCL air temperature in Tel-Aviv
Source: Shashua-Bar *et al.* (2004)

The main proportions affects the geometric shape is the surface-to-volume ratio and the width to length ratio. Behsh (2002) mentioned that forms with different geometric shapes of the same contained volume have different surface area. This is usually expressed by surface to volume ratio. The surface to volume ratio is a rough indicator of urban grain size, representing the amount of exposed ‘skin’ of the buildings, and therefore, their potential for interacting with the climate through natural ventilation, day lighting, etc. However, the counter-indication to a high surface to volume ratio is the increase in heat loss during the winter season and heat gain due to exposure to solar radiation during the summer season (Ratti *et al.* 2003), see figure (3.7) and figure (3.8).



SOLID SHAPE	SURFACE AREA 'S'	VOLUME 'V'	SURFACE AREA/ VOLUME RATIO 'S/V'
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Figure (3.7): Surface area to volume ratio (S/V ratio) for a few building shapes
Source: Nayak and Prajapati, (2006)

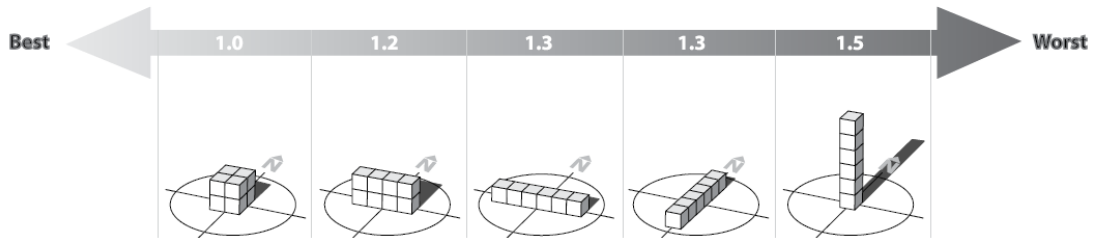


Figure (3.8): The effect of envelope to volume ratio on energy efficiency
Source: Mikler *et al.* (2008)

The building volume was found to have a strong influence on the air change rate of the building. The ratio of external surface to building volume is likely to decrease for increasing volumes. Therefore less external surface, where leaks can occur is available and the surface area to volume ratio is more favorable (Antretter *et al.*, 2007).

Ling *et al.* (2007) mentioned that the exposed surface-to-volume ratio (S/V ratio) for geometric shape depends on the width to length W/L ratio. Geometric shapes with higher value of W/L ratio contained lower value of S/V. He indicated that main factors that determine the relationship between solar insolation level and building shape are W/L ratio and building orientation. Karasu (2010) examined the effect of length/width ratio in the hot-dry climates of Bodrum in Turkey as shown in figure (3.9).

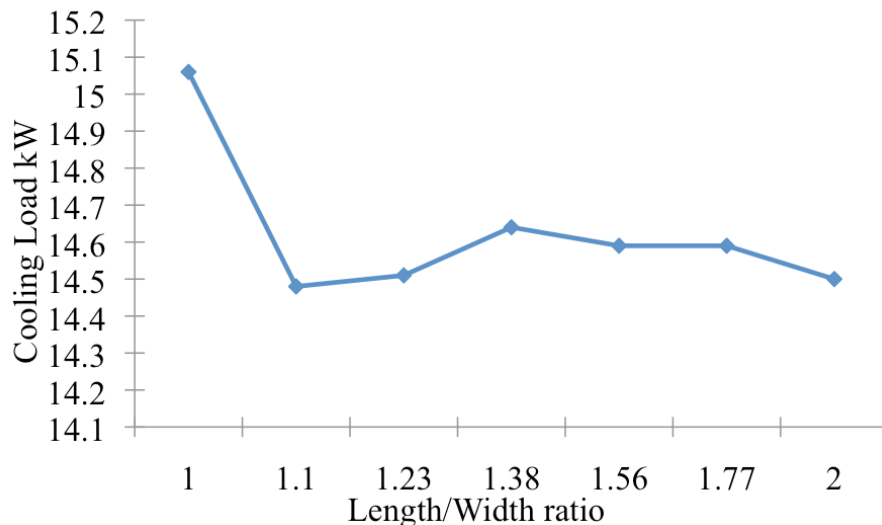


Figure (3.9): Effect of the length/width ratio on the cooling load
Source: Karasu, (2010)

The optimum shape differ according to different climate regions but In general, it's the shape which has a minimum heat gain in summer and the maximum heat gain in winter (Gut *et al.* 1993). The most important considerations in designing the building's form in different climate will be displayed.

a. The Cold Climate

A minimized and well-insulated building envelope that reduces heat losses is most adequate. Pitched roofs are suitable for rain protection. Snow loads may have to be considered (Rosenlund, 2000).

b. The Temperate Climate

Buildings are preferably rather compact. However, because of the conflicting climatic conditions, several solutions are possible, depending on local topographical conditions and functional requirements (Gut *et al.* 1993). One solution could be to design an insulated and heated central winter unit, with open, shaded or glazed spaces around this courtyard for seasonal use (Rosenlund, 2000). Building formation should prevent wind and allow sun in the coldest period and be wide surfaced and prevent sun during the hottest period (Biket, 2006).

c. The Hot-Arid Climate

The shape and volume of buildings should be compact, yet somewhat elongated along the east-west axis; (e.g. the optimum shape is 1:1.3), because large, compact building volumes gain less heat. Under winter conditions an elongated form is ideal; under summer conditions a square shape is better. A courtyard house type is therefore preferable. Adjoining houses, row houses, and group arrangements (all continuous along the east-west axis), which tend to create a volumetric effect, are advantageous, as are high massive buildings (Gut *et al.* 1993).

d. The Warm-Humid Climate

The most suitable form in this climate is the open elongated shape in order to provide air movement which is considered the only way of achieving thermal comfort (Koenigsberger *et al.* 1974). The height of the buildings should, in general, not exceed 3-storys. Since the higher buildings receive too much radiant heat and give wind obstruction to neighboring buildings, building's height shouldn't exceed 3-storys (Gut *et al.* 1993). Pitched roofs with wide overhangs or verandas create shade and rain protection (Rosenlund, 2000).

3.3.2 Orientation

Givoni (1969) pointed out that the amount of radiation received by the building is determined by orientation. Karasu (2010) showed that orientation has a significant influence on the cooling load. In areas where comfort is acquired mainly by air movement, it is important to orient the building according to prevailing winds. In regions where ambient temperature has greater influence on comfort than ventilation, orientation with respect to the sun is important. A north-south orientation of the main facades is preferable, since the summer sun penetrates facades and openings only marginally in these directions, while in winter when the path of the sun is lower, there is possibility of solar access (Rosenlund, 2000).

Goulding *et al.* (1992) displayed some strategies for the building's orientation. These strategies aim to maximize the potential for solar collection through the orient of the longest side of building to face south. Also, he discussed the effect of facades orientation in multi-family housing. He mentioned that apartments with more than one external wall will have greater heat losses than those with only one external wall. The losses from an apartment situated at the northwest corner of the top floor of a conventional block can be up to twice those of an apartment in the middle of the south façade as shown in figure (3.10).

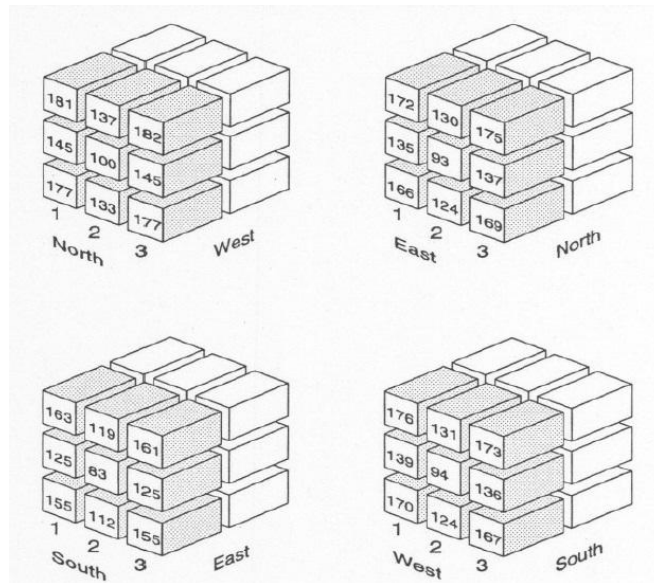


Figure (3.10): Heat losses from rooms with different positions and orientations
 Source: Goulding *et al.* (1992)

Building facade orientation is one of the key elements for many passive design strategies. Façade orientation affects the energy and comfort implications of solar shading, window to wall area ratio, window position and performance and choice of exterior color. Building facades, which can have a significant window to wall area ratio, receive sun in various amounts. The south facade will capture desirable solar gains during winter when the sun angle is low, making it ideal for passive solar heating during winter. On the other hand, window should be carefully placed on the east and west facades since they receive the second highest radiation intensities. Excessive solar heat gains on the west side can be particularly problematic as maximum solar intensity coincides with the hottest part of the day (Mikler *et al.* 2008). Nayak and Prajapati, (2006) noticed that in warm climates, the maximum load corresponds to the northwest-southeast orientation (the glass curtain wall facing southwest). Hence, such an orientation of the building should be avoided, see figure (3.11).

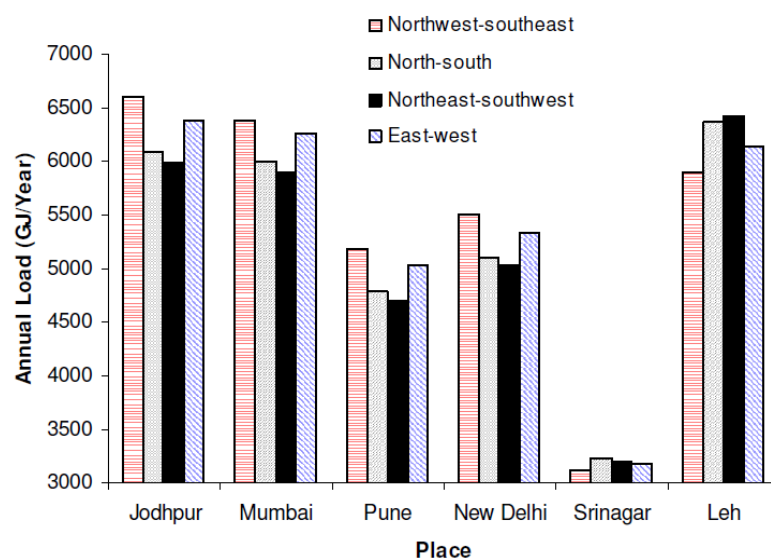


Figure (3.11): Effect of orientation on the annual load of a conditioned building in various Indian cities
 Source: Nayak and Prajapati, (2006)

Appropriate orientation can control the amount of solar radiation and wind entering a building (Nayak. and Prajapati, 2006). Proper orientation and location of buildings allow for sun and wind protection and controlled wind channeling (airflow) (Gut et al. 1993). The most important considerations in selecting the building's orientation in different climate will be displayed.

a. The Cold Climate

Orientation for solar access is important, especially in the winter. Double or triple glazing is required. Large glazed areas may require shading in some directions if the summer is hot. Windows in direction opposite from the equator should be minimized (Rosenlund, 2000). A building must be oriented to receive maximum solar radiation into the living areas for warmth on one hand, while keeping out the prevailing cold winds on the other. (Nayak and Prajapati, 2006)

b. The Temperate Climate

Normally, buildings should have an elongated shape along the east-west axis. The southern front can easily be designed for proper utilization of the winter sun and for protection against the summer sun. Windows on the eastern side receive substantial heat during the morning, which may be highly appreciated in winter time. Usually, larger windows on the west side are to be avoided, as the solar heat gain through these would coincide with the highest air temperatures.

Buildings should be arranged so that they benefit from summer winds because this season is usually humid and a proper cross-ventilation is required for cooling. Shelter should be provided from the winter winds (Gut et al. 1993). In this kind of climate regions, the orientation in 17.5 degrees east from the south provides the balance in heat dispersion. Orientation of high buildings should be determined according to the wind effect (Biket, 2006).

c. The Hot-Arid Climate

Orientation according to the sun is most important, and north-south orientation of the main facades is preferable. If there is a cooler season, correctly placed and oriented windows may improve indoor comfort during winter. Solar protection is important, especially towards the west where afternoon sun coincides with high air temperatures (Rosenlund, 2000). Buildings are best arranged in clusters for heat absorption, shading opportunities and protection from east and west exposures. In general, the best orientation is north-south with 25o south easterly direction. Main walls and windows should face the prevailing (cool) wind direction in order to allow maximum cross-ventilation of the rooms (Gut et al. 1993).

d. The Warm-Humid Climate

Since there is less direct sunshine, it is important to orient the building according to prevailing winds. There should be special care to admit desired winds and to protect from cold winds if there is a cooler season (Rosenlund, 2000). Sun orientation: Shading of the east and west elevations is difficult because of the low sun, and may require special devices; whereas the south and north sides can easily be protected by an overhanging roof. Thus the best orientation for protection from the sun is along the east-west axis.

With regard to wind, long-shaped buildings across a predominant wind direction is preferable. So as a general rule, with low rise buildings, where the walls would not receive much radiation, orientation according to the wind direction is more advisable. With high-rise buildings the opposite holds true and protection from sun radiation should be the decisive factor (Gut *et al.* 1993).

3.3.3 Glazed Fenestration Systems

The glazed system is an important strategy in passive solar design as it can cause the large portion of building's heat gain. The heat gain through the exterior window accounts for 25–28% of the total heat gain, and added to the infiltration, it makes 40% of the total while exterior wall heat gain represents 23–24% (Yu *et al.* 2008). Window's material, orientation and its area ratio to the wall WWR are the main factors affect the performance of the glazed system. The effective utilization of these factors with applying natural ventilation can enhance the thermal comfort by decreasing the negative effect of solar radiation (Al-Tamimi *et al.* 2010). The main influencing factor of the previous factors is the overall window to wall area ratio. On east, south, and west exposures, greater window areas will admit more solar gain during winter (Mikler *et al.* 2008).

3.3.4 Insulation

Insulation has the ability to control the process of heat transfer between the buildings and the outdoor environment. This can be expressed by the term of U-value. Insulation has a great influence on reducing the amount of heat gain in summer and the heat loss in winter. This can maintain the indoor air temperature within the thermal comfort thus reducing the heating and cooling requirements (Bahrami, 2008).

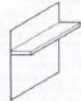


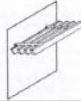
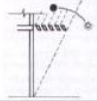


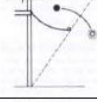
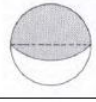



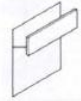
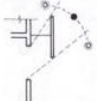


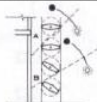

3.3.5 Thermal Mass

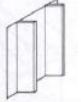


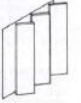



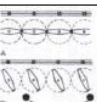
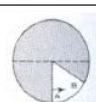
The thermal mass in a passive solar system is usually a conventional construction material such as brick, poured concrete, concrete masonry or tile and is usually placed in the floor or interior walls (Balcomb, 1995). In order to have an effective thermal mass, its material must have a high heat capacity with a moderate conductance, a moderate density, and a high emissivity. Night insulation enhances the efficacy of thermal mass during the heating season (Haglund *et al.* 1996). It is found that maximum savings in yearly cooling and heating transmission loads are about 17% and 35%, respectively, as a result of optimizing thermal mass thicknesses L_{mas} for same R_n -value in Saudi Arabia (Al-Sanea *et al.* 2012). A study of Kosny *et al.* (2001) showed that whole building energy savings of up to 18% (heating and cooling) and 8% (heating only) is possible when comparing lightweight buildings to heavyweight buildings.

3.3.6 Shading

The main principle in shading strategy is to avoid the penetration of direct solar radiation into the building through its opening and heat absorbing materials. Trees and roof overhangs act as a shading system (Scottsdale's Green Building Program). Also, solar shading devices such as overhangs, awnings and blinds which are a lightweight ventilated shading panels attached to walls and roofs can utilized to avoid unwanted solar radiation in summer and allowing it in winter. The most critical point in designing shading devices is the different solar radiation angles during summer and winter

(Bahrami, 2008). Figure (3.12) illustrates the basic shading devices, classified as horizontal, vertical, and eggcrate types.

Horizontal Types			
Shading Device	Side View	Shading Masks	Comments
			Straight overhangs are most effective on southern exposure.
			Louvers parallel to wall allows hot air to escape and are most effective on southern exposure.
			Awnings are fully adjustable for seasonal conditions and most effective on southern exposure.
			Horizontal louvers hung from solid overhangs cuts out the lower rays of the sun. Effective on south, east and west exposures.
			Vertical strip parallel to wall cuts out the lower rays of the sun. Effective on south, east and west exposures.
			Rotating horizontal louvers are adjustable for daily and seasonal conditions. Effective on south, east and west exposures.

Vertical Types			
Shading Device	Plan View	Shading Masks	Comments
			Vertical fins are most effective on the near-east, near-west and north exposures.
			Slanted vertical fins are most effective on east and west exposures. Slant toward north and separation from wall minimizes heat transmission.
			Rotating vertical fins are the most flexible and adjustable for daily and seasonal conditions. Most effective on east and west exposures.


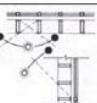

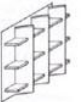
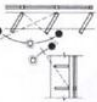




Eggcrate Types			
Shading Device	Plan & Side View	Shading Masks	Comments
			Eggcrate types are combinations of horizontal and vertical types. Most effective in hot climates on east and west exposures.
			Eggcrate with slanted vertical fins (slant toward north). Most effective in hot climates on east and west exposures.
			Eggcrate with rotating horizontal louvers. Most effective in hot climates on east and west exposures.

Figure (3.12): Types of shading devices
Source: Scottsdale's Green Building Program

3.4 Climate Responsive Design Strategies in the Mediterranean Region

The Mediterranean region is the area around the Mediterranean sea. It includes the southern part of Europe and the northern part of Africa and the western part of Asia. Its climate is affected by the Mediterranean Sea, which can be considered as an important heat reservoir and source of moisture for surrounding land areas. The region is characterized by a complex topography which plays a significant role in steering air flow. According to its location in a transitional zone, both mid-latitude and tropical variability is important and competes against each other. The Mediterranean climate is exposed to the South Asian Monsoon in summer and the Siberian high-pressure system in winter (Giannakopoulos *et al.* 2005).

3.4.1 Climate Characteristics of the Mediterranean Climates

The Mediterranean climate may occur on the west side of continents between about 30° and 40° latitude (Giannakopoulos *et al.* 2005). The sun is considered the most important parameter in the Mediterranean region (Behsh, 2002). It has two main seasons: hot dry summers and cool wet winters (Evans, 2007). The average conditions are not extreme and in general, the sky temperature ranges between 6°C and 30°C below the ambient temperature (Colombo *et al.* 1994). The incongruent variations in winter and summer temperatures, daily temperature variations, solar radiation and relative humidity require different solutions for different locations (Schnieders, 2009). Figure (3.13) shows Köppen climate types in the Mediterranean region.

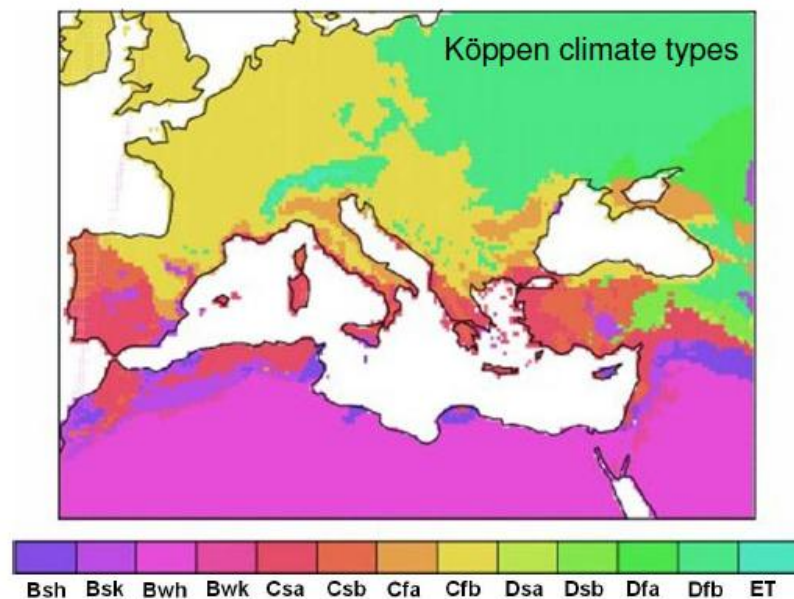


Figure (3.13): Köppen climate types in the Mediterranean region
Source: Lionello *et al.* (2011)

3.4.2 Responsive Building Strategies

The main principles in passive design strategies is to avoid unwanted heat gain in summer and increasing the heat gain and avoid heat loss in winter (Evans, 2007). Heat gain can be maximized in winter in an easily manner, however it is difficult to avoid it during summer. The presence of large amounts of water vapor in summer period in most Mediterranean areas is considered a challenge as it decrease the availability of night cooling in summer and produce mild night temperatures in winter (Colombo *et al.*

1994). The more important passive strategies in Mediterranean climate will be introduced.

a. Urban Morphology

One of the main strategies of the urban morphology is the building density which mainly determines the relative surface of the roofs. Increasing the roof areas can play a significant role in increasing the radiative exchanges. This strategy can be utilized in the Mediterranean or semi desert climates which characterized by high density housing in narrow streets. The solar radiation received by roofs can be reflected away to the sky using appropriate materials in order to minimize the air temperature in external spaces especially near the ground (Goulding *et al.* 1992).

b. Plan shape

The optimum shape can be defined as the shape that achieve a large amount of heat gain in winter and a small amount in summer. In the Mediterranean climate, south walls are the best solar collectors during winter time, while the roof and east-west walls become at the top in summer time. Therefore, the rectangular shape with the long axis running east to west is the optimum shape. The large area of south wall can increase the solar radiation in winter as it receives three times more energy than the east or west. Also, the problems associated with the west wall can be enhanced by reducing its area to the minimum. Natural ventilation can be utilized in this shape as in any other.

The square shape's performance is worse than the rectangular and the rectangular shape with the long axis, running north to south is considered the worst. Another important issue in the building shape is the height. Two story building is considered more preferable than a single one because of a small roof area which decrease heat gain in summer and heat loss in winter. Also, increasing building's height can increase the area of south walls and enhance solar access and heat gain. It's more easily to control solar radiation with vertical surfaces (Colombo *et al.* 1994).

c. Orientation

The optimum orientation for the Mediterranean climate is which provide both heating and cooling. The solar access is the most important parameter for heating requirements. Hence, it will be appropriate to orientate the building +22.5 from the south. This south-west orientation would be worse in summer, instead the building have to orientate to provide breeze and shading. It is necessary to make sure there are no obstruction affect the solar access between 9AM and 3PM solar time in winter period (Colombo *et al.* 1994).

d. Material and Insulation

It's obviously that the need for cooling is an important as the need for heating in the Mediterranean climate. Unfortunately, the summer temperature do not drop very much at night for cooling requirements. Therefore the best solution is to reduce the mass to be cooled down at night by using a light construction with internal insulation layers. Building envelope includes these elements (Colombo *et al.* 1994):

- **Windows:** Glass is responsible for the larg portion of heat loss in winter and heat gain in summer. This is due the low resistance of glass elements as well as

air infiltration. In mediterranean climate, double glazing should be adapted in buildings. However, triple glazing is an unreasonable choice at present cost.

- **Roofs:** In the south Mediterranean climate, the summer situation is even worse. Roofs expose large amount of solar radiation and this heat can transfer to the interior space. So its necessary to use pale colours on flat roof-top. Its preferable to have a vented gab between the roof and the ceiling insulation in the case of sloping roofs. Shading and vegetation will have effective impact.
- **Walls:** West walls must have a special concern in selection there materials and insulation in the Mediterranean climate. However, super insulation in other walls is unnecessary and uneconomic (Colombo *et al.* 1994). Un insulated but high thermal capacity walls allow for the evacuation of the heat stored in the building during the day, leading to the reduction of air-conditioning need (Znouda *et al.* 2007).
- **Ground Contact Zones:** It's not preferable to use insulation in the floor slab in the Mediterranean climates as it reduce the opportunity for cooling during the hot summer months.

e. Shading

Shading is an essential parameter in all climate especially in Mediterranean climates to avoid overheating at midday on sunny days. The critical period for the Mediterranean summer season is the afternoon when the sun is still hot, yet low in the sky. Shading must be provided to the west walls by trees, evergreen vegetation, trellises or overhanging roofs. It's advisable to integrate shading with insulation of the west walls. Exterior shading devices should be provided to the west windows with some air flow between the glass and the protection device, in order to maximize the benefit from internal shading systems (Colombo *et al.* 1994). The shadowed portion of the glazed area should be as large as possible in summer and as low as possible in winter (Znouda *et al.* 2007).

3.5 Potential of the Climatic Design of Residential Buildings in the Gaza Strip

The Gaza Strip (365 km²) is a coastal area in the west-southern part of Palestine. It extends 40 km along the eastern Mediterranean Sea and its wide range between 6 to 12 km (ARIJ, 2003). The geographical coordinates of the Gaza Strip are 31° North, and 34° East (The Palestinian Guidelines for Energy Efficient Building Design, 2004). The area consists of a littoral zone, a strip of dunes from the Quaternary era, and more to the east, gently sloping alluvial and loess plains (Baalousha, 2006). See figure (3.14).



Figure (3.14): Geographical location of the Gaza Strip
Source: Medri *et al.* (2008) Adopted by author

3.5.1 Climatic Zones of the Gaza Strip

According to ARIJ, (2003) the Gaza Strip forms a transitional zone between the sub-humid coastal zone of Palestine in the north, the semiarid loess plains of the northern Negev Desert in the east and the arid Sinai Desert of Egypt in the south. According to the Koppen system for climatic zoning, Gaza has a Mediterranean subtropical climate with dry summer and mild winters. This climate is classified as C_{sa} indicating that the warmest month has a mean temperature above 22°C . There are two main climatic zones in Gaza that are influenced by other surrounding zones. These zones are:

1. The climatic zone 1: which extends along the coast including most of the northern, middle and southern parts of Gaza has climate properties of the sub humid coastal zone with mean annual rainfall of 459 mm and mean annual temperature average of 18°C . This zone has a population of 971330 persons that is about 97.2 % of the total population of Gaza.
2. The climatic zone 2: it can be categorized under the semiarid loess plains of the northern Negev Desert in the east with 316 mm mean annual rainfall and population of 28467 persons comprising 2.8 % of the total population in Gaza.

3.5.2 Weather Characteristics in the Gaza Strip

The solar radiation is considered the most important parameter in the climate. The Gaza Strip receives a variable amount of solar radiation during the year. In winter, the mean monthly values of solar radiation reaches one third of the summer months' values. This fluctuation in the solar radiation is responsible for the variations in the average daily mean temperature which ranges from 25°C in summer to 13°C in winter as shown in figure (3.15). Daily relative humidity fluctuates between 65 % in the daytime and 85

% at night in the summer, and between 60 % and 80 % respectively in winter, see figure (3.16).

The daily average maximum wind velocity reaches 3.9 m/s in the afternoon of summer months while it reaches to the half of this value at night. In winter the average wind velocity is about 4.2 m/s, see figure (3.17). The prevailing winds during the summer come from the northwest while the most frequent direction is southwest in winter. The amount of rainfall reaches to about 450 mm per year in the north and decreases to 200 mm per year at Rafah in the south (ARIJ, 2003).

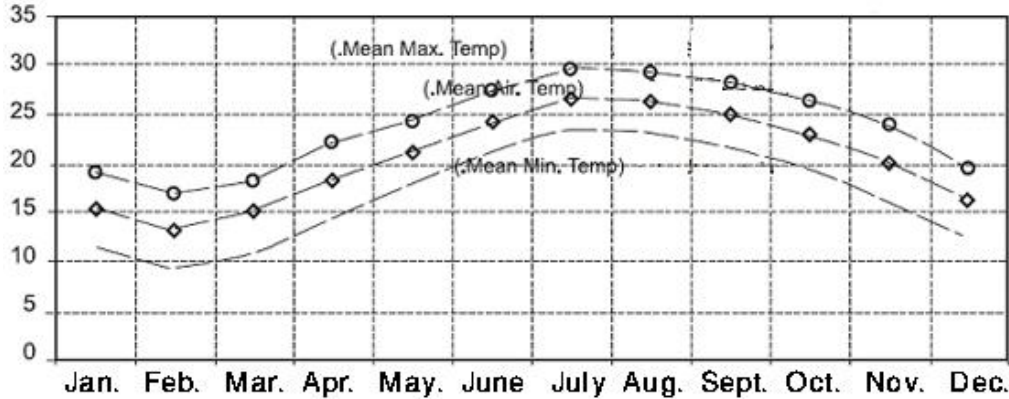


Figure (3.15): The maximum and minimum temperature in Gaza City
Source: The Palestinian Guidelines for Energy Efficient Building Design, (2004)

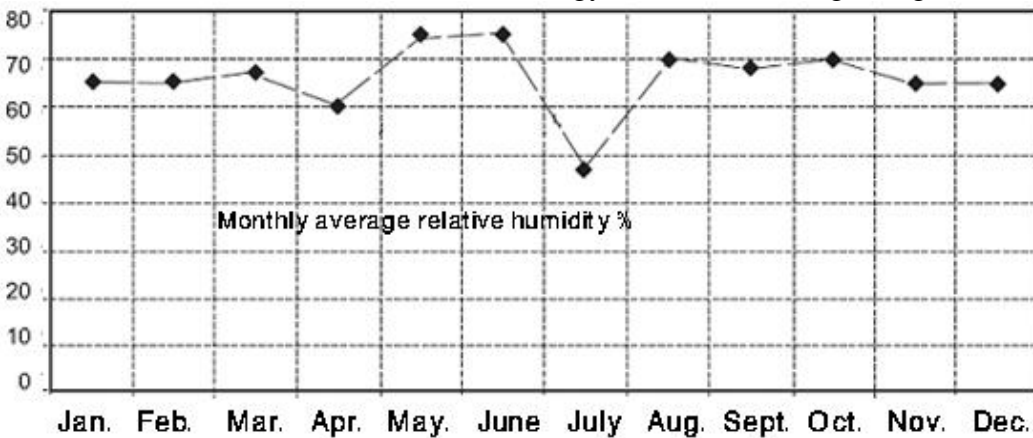


Figure (3.16): The Monthly average relative humidity in Gaza City
Source: The Palestinian Guidelines for Energy Efficient Building Design, (2004)

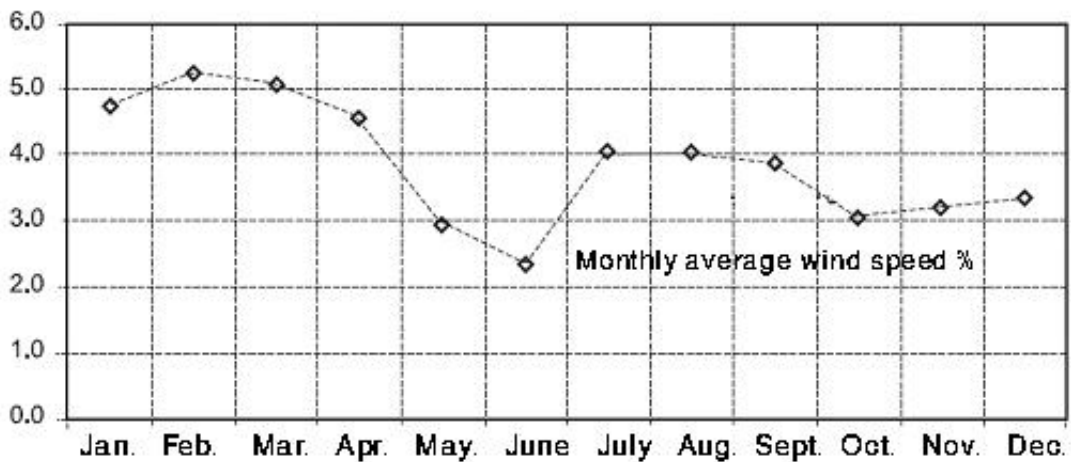


Figure (3.17): Monthly average wind speed in Gaza City
Source: The Palestinian Guidelines for Energy Efficient Building Design, (2004)

3.5.3 Residential complexes in the Gaza Strip

Residential buildings are considered the main sector in Gaza buildings. Detached buildings are the most commonly used style in residential complexes. The attached style is only found in the old town in Gaza city and it doesn't used in the present architecture of the Gaza Strip. Building's density, height, area and spacing between them are determined according to the zoning district regulations. The maximum built site coverage ranges between 50% in multi story buildings and 60% in zoning district (b) and 80% in zoning district (c). The minimum area of parcel range between 250 m² in zoning district (b) and (c) and 1000 m² in multi story buildings. Spacing between buildings is determined according to the side and rear setback. Table (3.2) illustrates the main zoning district regulations in the Gaza Strip (Alkahlout, 2006).

Table (3.2): Zoning district regulations in the Gaza Strip
Source: Alkahlout (2006)

Area	The maximum built site coverage	Number of floors	TOP	The minimum area of parcel	The front setbacks	The side and rear setbacks
Zoning district (b)	60%	5	3	250	3 m	2/2/2 m
Zoning district (c)	80%	5	4	250	2 m	1/1/1 m
Multi-storey buildings	50%	1.5* street's width	0.5*1.5* street's width	1000	3 m	Side back= 10% of height and 15% of height

According to Hadid, (2002) residential buildings can be classified into two main types which are separate house and apartment building:

a. Separate House

The separate house is a popular style in the cities, towns and campus of the Gaza Strip. The area of this style can be determined according to the owner ability and to accommodate the main functions which are 2-3 bedrooms, 1-2 bathrooms, kitchen, guest room, setting room, and balconies. Simple forms are using and the main materials are the concrete and hollow blocks walls, which are plastered and painted from both sides with light colors. Ventilation is the most characteristic of this style as the building is exposed to the environment from the four facades. Due to the absence of insulation, the upper floor usually gains much heat in summer time and losses heat in winter. A villa house is another type of this style for rich families. The area of such type is variable starting from 200 m² up to 500 m². Different forms can be utilized to create shades on the elevations.

b. Apartments Buildings

Residential apartment is a new concept in the Palestinian society. The needs of housing increased especially in cities and some villages. The areas for building purposes is small comparing to the demand of housing needs, especially in cities. This is another reason for the vertical expansion in apartments which can be classified as low-apartment building and tower-apartment. The areas of apartments vary from 80m² up to 180 m² with the same functions as in the separate house functions.

The design and form varies depending on number of apartments in the same floor. In most of the low-apartment buildings, 1, 2, or 3 apartments in the same level is the typical example, while the number of floors can reach 6 floors. Each apartment has three facades open to the natural environment in the best cases for ventilation and natural lighting. The building material is concrete. The number of floors can reach more than 15 floors in the tower apartments. Generally, The tower buildings are cool (with humidity) and windy (open to the west – the sea) in summer time, and cold in winter. Figure (3.18) shows a view of residential building in Gaza city.



Figure (3.18): View of residential building in Gaza city
Source: Hadid, (2002)

3.5.4 Climatic Design of Residential Buildings in the Gaza Strip

According to the survey of Hadid (2002), he found that there are several design parameters in buildings of the Gaza Strip which can be utilized as a passive design elements in order to achieve thermal comfort. Balconies, shading devices, opening, insulation and colors are examples of these parameters. However, these elements were not selected according to thermal calculations. orientation of the buildings and their openings doesn't take sufficient account of sun movement. Also, shading devices are putting into different oriented facades with the same form and dimensions. They can be used as a decorative elements in many cases. As a result, buildings don't achieve the acceptable level of thermal comfort. Instead, people tend to use the active systems such

as air conditioning and mechanical ventilation which consume a large amount of energy.

3.5.5 Analytical Study of Residential Complexes Form in the Gaza Strip

Gaza city is considered the main city in the Gaza Strip. The view to the west is one of the determinant elements in orientation of buildings in the Gaza Strip. Orientation in some houses was taken into consideration in town, but in some cases the access to the lot of land affected the orientation. As shown in figure (3.19), streets take the orientation parallel and perpendicular to the coast (north eastern- south western) and (north western- south eastern). Land plots take the same orientation of the streets. Also, buildings take the same orientation of land plots due to the decrease in land area. So buildings orientation don't take into consideration the climatic factors especially the solar parameter.

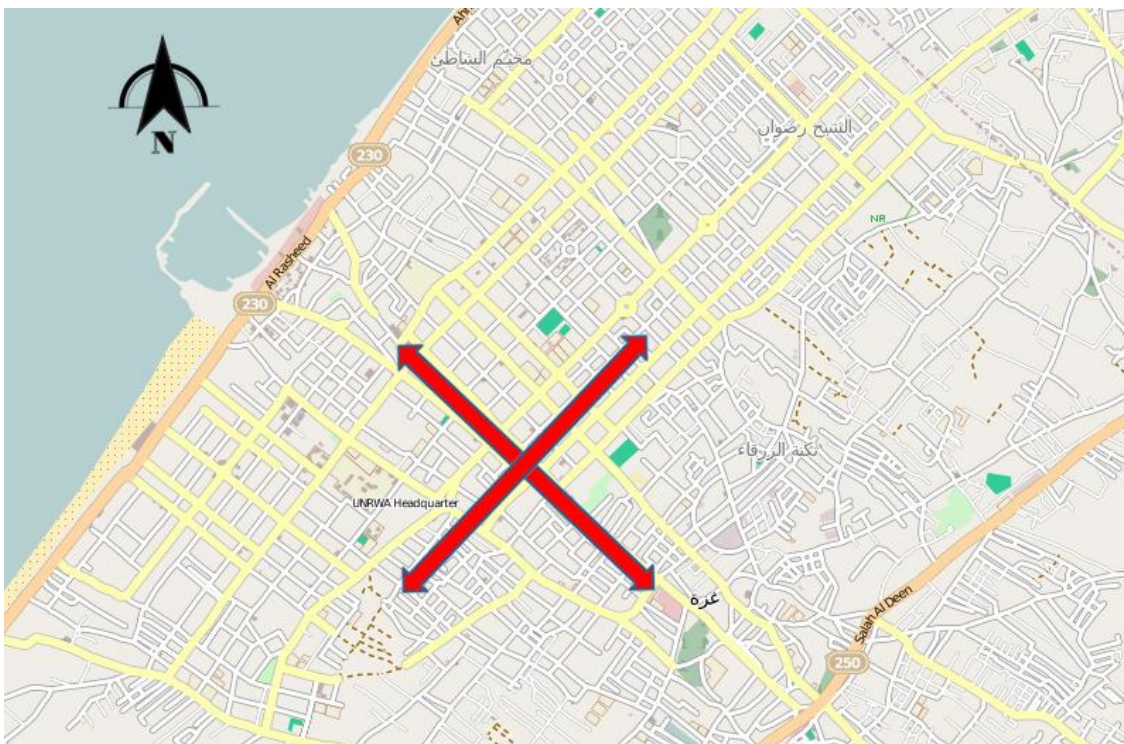


Figure (3.19): streets and parcel's orientation in Gaza city
Source: Open street map, (2011)

The main form of buildings range between the cube (square in plan) and cuboid (rectangular in plan) as the rectangular shape is the most popular geometric shape in parcels, see figure (3.20). There are other forms such as circular, L shape and U shape but in small percentage. As discussed in the previous section, residential buildings range between 1-15 floor. Also, there areas range between 80- 500 m² according to their type. Figure (3.21) show the average area of housing units in the Gaza Strip.



Figure (3.20): Aerial photo of Gaza city showing the common form of buildings
 Source: Google earth, (2011)

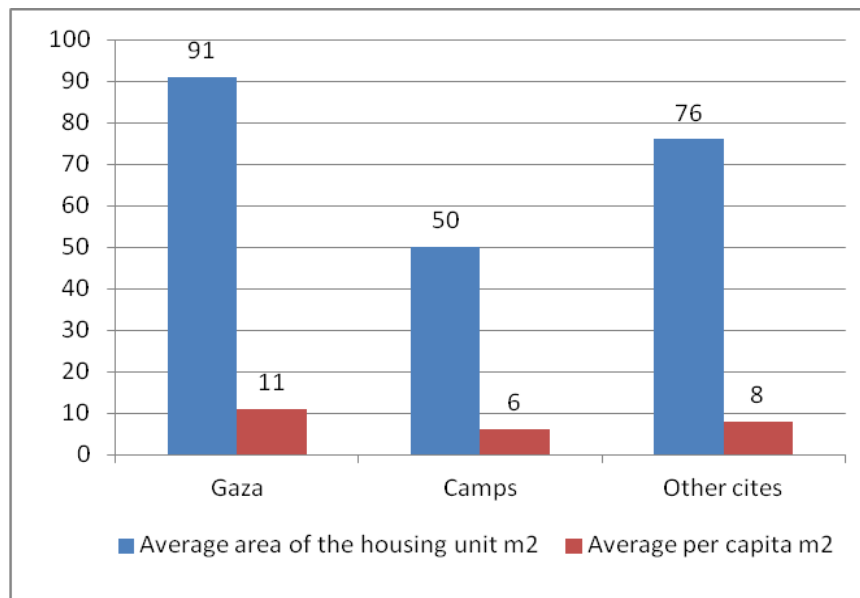


Figure (3.21): The average area of housing units in the Gaza Strip
 Source: Al-Esawi, (2008)

However the rectangular shape is the most popular shape, the shape proportions such as surface to volume ratio and width/ length ratio and roof/ walls ratio is differ largely as there is no standers to design shapes with the ideal proportions with regard to solar radiation and thermal performance. In order to overview the potential of residential complexes form in the Gaza Strip, it's necessary to identify some case studies. El-Sheikh Zayed residential complex and Tal El Hawa housing project will be studied as they are recent projects and contain typical apartment buildings that can easily studied. In addition, some cases of separate houses will be studied.

a. El-Sheikh Zayed Residential Complex

The project is located in the town of Beit Lahiya, in the northern of Gaza Strip, with a total land area of 527,000 square meters. The project accommodate approximately 3,500 housing units, ranging between apartment buildings and towers as shown in figure (3.22). The apartment buildings consists of 70 building. Each building consists of 5 floors and each floor consists of 2 apartment with an area of 108 m², see figure (3.24). The towers buildings consists of 82 tower of 12 floor for each tower and 3 apartment for each floor. The apartment area range between 116- 118 m² as shown in figure (3.25). (MOPWH, 2011). The complex take the style of detached buildings and groups of buildings clustered around an outdoor courtyard as shown in figure (3.23). The complex street take the (north eastern- south western) and (north western- south eastern) orientation and the buildings take the same orientation. The buildings take the rectangular shapes with the main proportions which define the geometric shape of the apartments are shown in table (3.3) and figure (3.32).



Figure (3.22): El-Sheikh Zayed city
Source: MOPWH, (2011)

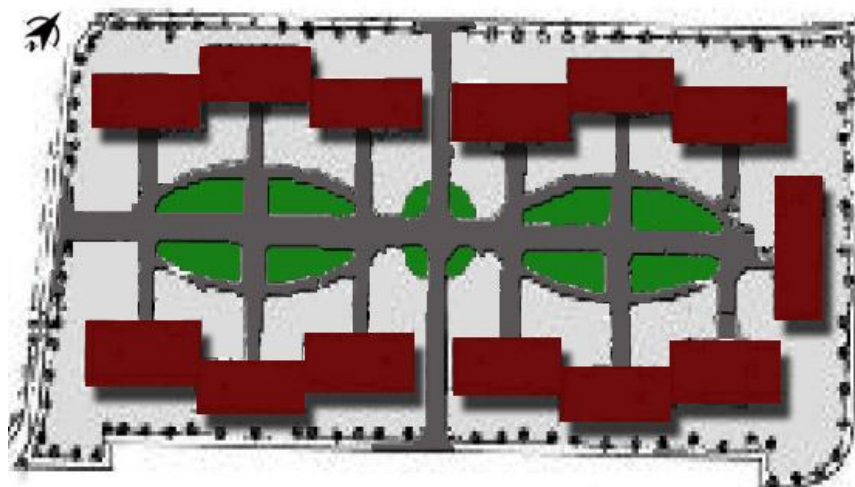


Figure (3.23): Residential block in El-Sheikh Zayed city
Source: MOPWH, (2011)

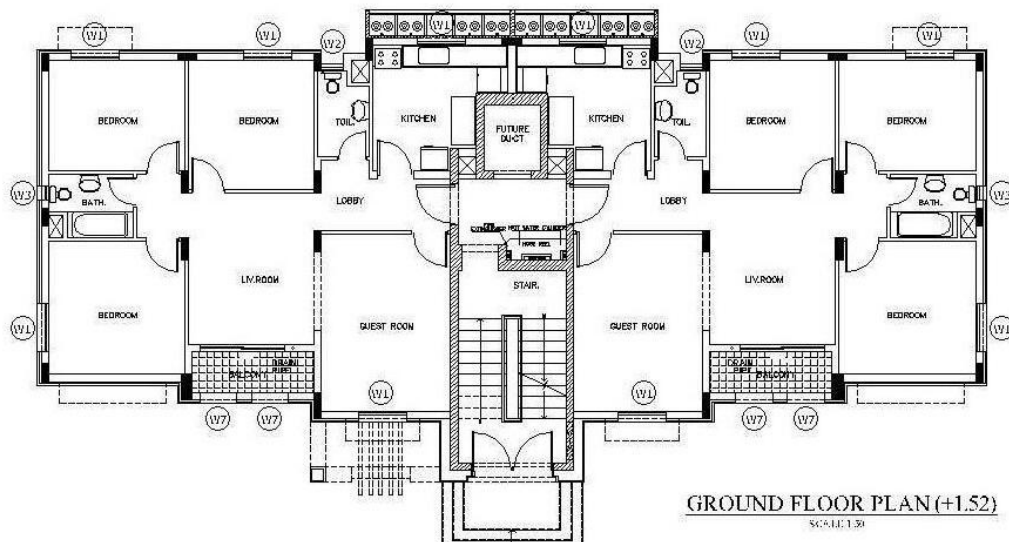


Figure (3.24): Plan of the 5 story apartment buildings in El-Sheikh Zayed city
Source: MOPWH, (2011)

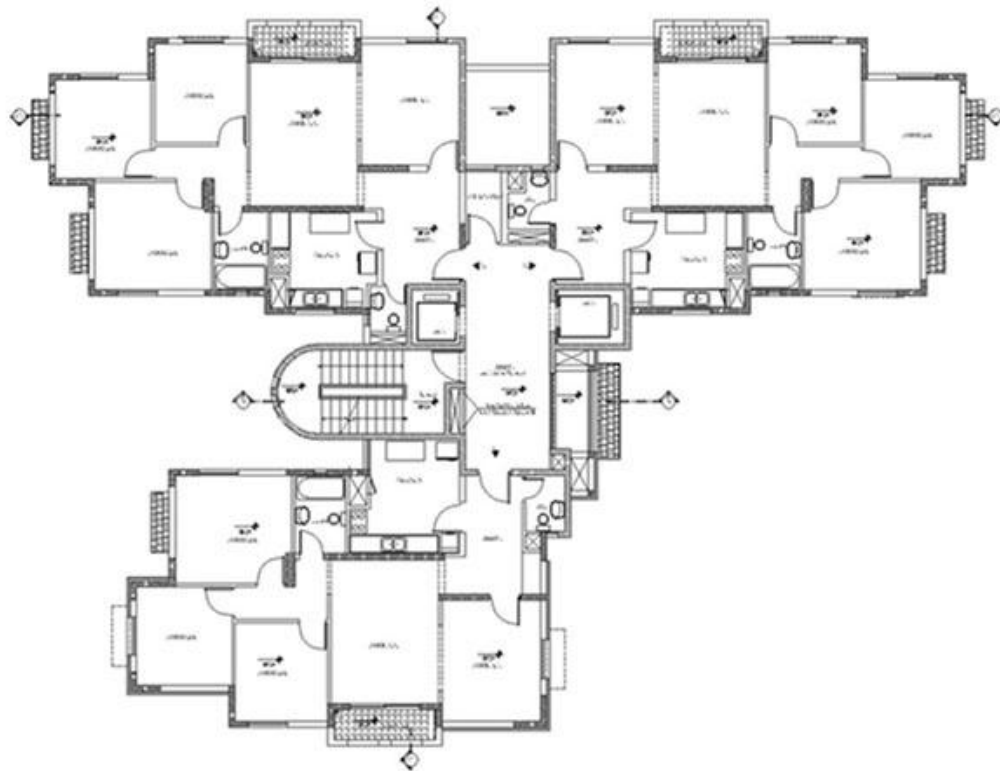


Figure (3.25): Plan of the 12 story apartment buildings in El-Sheikh Zayed city
Source: MOPWH, (2011)

b. Tal El Hawa Housing Project

The project is located in the west of Gaza city, with a total land area of 430,000 square meters. The area can be classified as zoning district (b) with a density of 47 person for 1000 square meters, see figure (3.26). The project contains approximately 72 apartment buildings. Each building consists of 7 floors in addition to the ground floor. The first model consists of 4 apartment for each floor with an area of 140 m² as shown in figure (3.27). The second model consists of 3 apartment for each floor with an area of

189 m² as shown in figure (3.28) (Palestinian Ministry of Public Works and Housing, 2011). The detached buildings are the main style in the project. Groups of buildings clustered in a form of L shape and two L groups clustered around an outdoor courtyard. The complex street take the (north eastern- south western) and (north western- south eastern) orientation and the buildings take the same orientation. The apartments take the rectangular form with the main proportions which define their geometric shape are shown in table (3.3) and figure (2.32).



Figure (3.26): Tal El Hawa housing project
Source: Google earth, (2012)

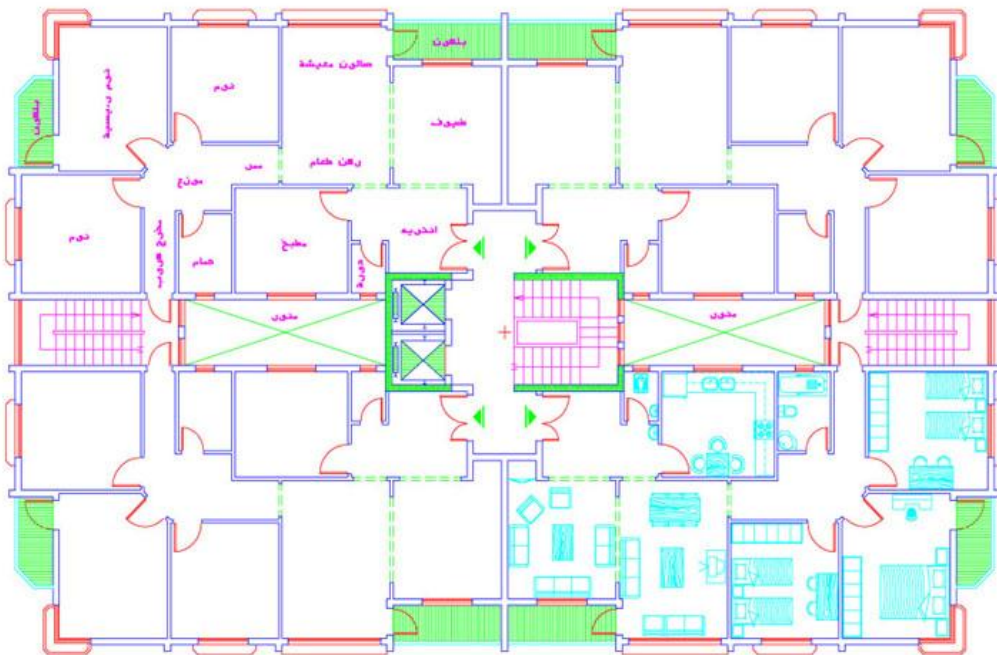


Figure (3.27): Plan of the first model with 4 apartment for each floor
Source: MOPWH, (2011)

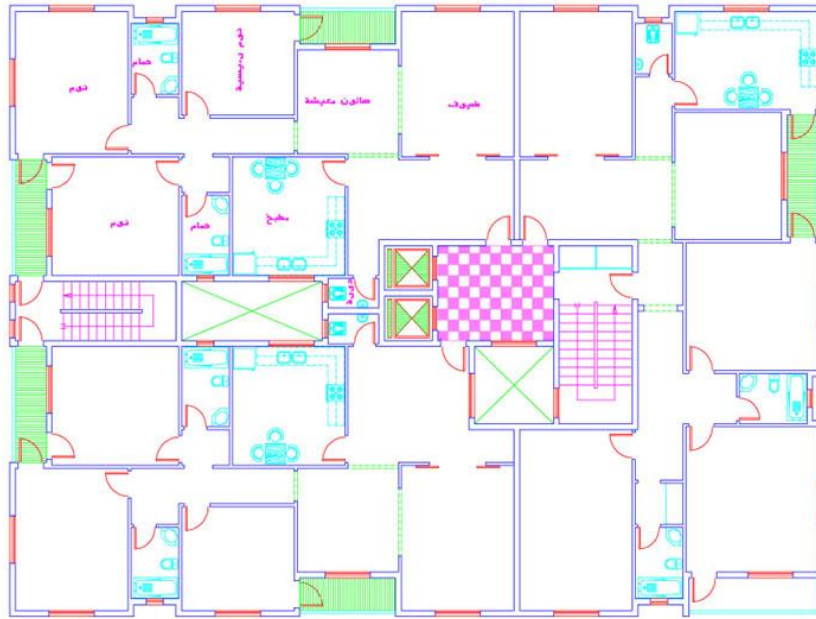


Figure (3.28): Plan of the second model with 3 apartment for each floor
Source: MOPWH, (2011)

c. Separate House

As mentioned previously, the separate houses are the most popular style in the Gaza Strip residential buildings. They usually take the rectangular shape in different proportions and ratios. In order to overview the variability of these ratios, three cases of separate houses will be displayed in figure (3.29), (3.30) and (3.31). The main proportions which define the geometric shape of these cases are shown in table (3.3) and figure (3.32).



Figure (3.29): Plan of 2 floor separate house with 2 apartment in each floor
Source: Al-Rabwa Engineering Consultant- Khan Younis, (2012)

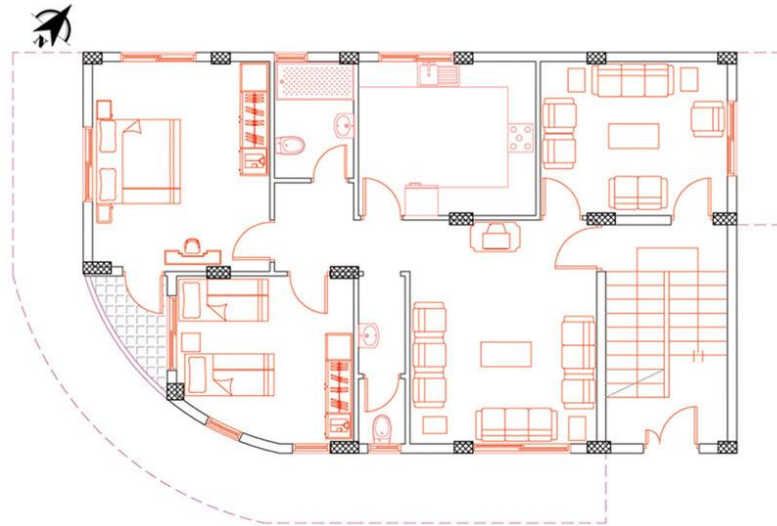


Figure (3.30): Plan of 2 floor separate house in Gaza city
Source: Home Engineering Unlimited Consultant- Gaza, (2012)

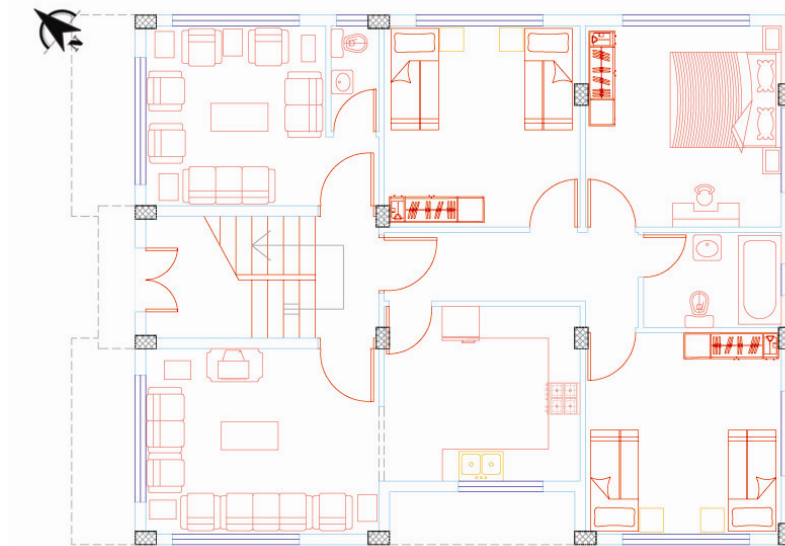


Figure (3.31): Plan of 1 floor separate house in Gaza city
Source: Home Engineering Unlimited Consultant- Gaza, (2012)

Table (3.3): The main proportions of residential buildings in the Gaza Strip
Source: The researcher, (2012)

	Number of floors	Area (m ²)	width/length ratio	surface/volume ratio	Roof/walls ratio	Perimeter/area ratio	Perimeter/height ratio
El-Sheikh Zayed city	5	294	0.4	0.34	0.24	0.27	5.4
	12	773		0.264	0.117	0.236	5.08
Tal El Hawa housing project	8	677	0.64	0.22	0.22	0.18	5.08
	8	769	0.75	0.216	0.22	0.176	5.64
Separate houses	2	228	0.64	0.45	0.59	0.28	10.7
	2	115	0.61	0.54	0.44	0.37	7.2
	1	120	0.8	0.72	0.86	0.39	15.6

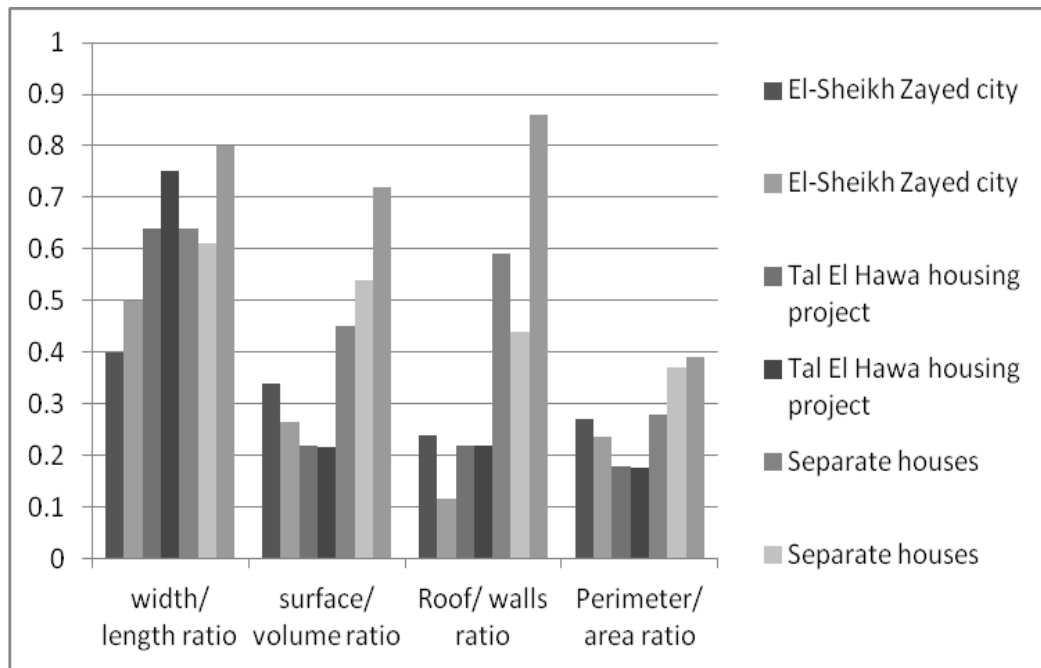


Figure (3.32): The main proportions of residential buildings in the Gaza Strip
 Source: The author, (2012)

3.6 Conclusion

This chapter handled an important issue in the architectural design. It dealt with the climate responsive design and its importance in energy consumption. It outlined the climate classification in order to determine the basic climate characteristic for passive design. Basic passive strategies such as shading, insulation and thermal mass have been clarified with a special concern to building's form and orientation. The Mediterranean region has a special climate which require a special concern in both heating and cooling seasons. Hence, this chapter highlighted the climate characteristic of this region and the climate responsive strategies Appropriate to it. In addition, the climatic design in residential complexes of the Gaza Strip have been studied with a special concern to the form.

This chapter concluded that the climate responsive design can be utilized to achieve thermal comfort and reduce cooling and heating requirements. Sufficient account must be taken in the Mediterranean climate especially to the building's form and configuration as the solar radiation is the most important parameter in this climate. It is also concluded that the residential complexes in the Gaza Strip don't pay a special attention to the climatic factors. Several shapes and proportions were found in the buildings which affect the amount of solar radiation. Therefore, the next chapter will display a parametric study of geometric shapes effect on the thermal performance and the energy requirements in residential units in the Mediterranean climate of the Gaza Strip using three dimensional modeling programs.

Chapter 4: Investigation of the thermal performance of various geometric shapes

4.1 Introduction

The building form is one of the main parameters which determines the building envelope and its relationship with the outdoor environment. Hence, It can affect the received amounts of solar radiation, the rate of air infiltration and as a result the indoor thermal conditions. It is found from all the previous studies that the surface to volume ratio is the main responsible for the thermal response in different geometric shapes. However, the impact of different geometry with the same (S/V) ratio has not been discussed extensively to investigate the effect of self shading obtained by these geometries. Also, the specific shape can have different (S/V) ratio by changing its proportions such as the width to length ratio (W/L) (also called the aspect ratio) and the roof to walls ratio. Building height is another important issue in determining the thermal response of the same (S/V) ratio. In order to provide a full understanding to these integrated parameters, this chapter can be divide into 3 sections. The first section will introduce a study of 12 different geometries with different (S/V) ratio in order to examine the correlation between increasing in the (S/V) ratio with the increasing in both heating, cooling and total loads comparing with the more compact geometry (reference form).

The second section will study the rectangular shape in more details, as it considers the more popular shape in residential buildings. The study will correlate the effect of changing the width to length ratio (W/L) on changing the (S/V) ratio and the roof to walls ratio and thus the total heating and cooling loads. It evaluates the effect of changing the building height with the same (S/V) ratio on the energy efficiency. Each study will also examine the effect of changing orientation and glazing ratio to the floor area on changing the thermal response of different ratios. The third section will be dedicated to study the effect of self shading of a compact geometry such as the rectangular and complexes geometry such as L, U and court shapes. The study will based on a fixed (S/V) ratio with different (W/L) and roof to walls ratio.

4.2 Previous Studies

Different studies have dealt with the form aspects. AlAnzi *et al.* (2008) have developed a simplified method to predict the impact of shape on the annual energy use for office buildings in Kuwait. Basically, the study depends on the relative compactness (RC) of the building and correlates it with the annual energy use. The relative compactness based on the ratio between the volume of a built form and the surface area of its enclosure compared to that of the most compact shape with the same volume. Pessenlehner and Mahdavi (2003) have criticized the use of relative compactness in evaluation the energy efficiency as it does not capture the specific three-dimensional massing of a building's shape which can affect the thermal performance via self-shading for example. Also, changing orientation and distribution of glazing which changes the building morphology, shading potential and its thermal performance without changing the relative compactness. Pessenlehner and Mahdavi (2003) examined the annual heating load and overheating index for 12 different shapes with 3 glazing area options and 5 glazing distribution options and 4 orientations as a function of the relative compactness (RC).

Hachem *et al.* (2011) have studied the effect of different geometries on the solar radiation incident on equatorial-facing facades and transmitted by the fenestration of such facades. The study focused on the optimal solar exposure shape for the purpose of electricity production by the building integrated photovoltaic (BIPV). From the thermal point of view, the high solar exposure shape may not achieve the acceptable comfort conditions and energy reduction especially in summer period. Also, Ling *et al.* (2007) studied the effect of geometric shapes on the total solar insolation received by high-rise buildings in Malaysia. The study based on variations in the width to length ratio (W/L) and orientation for two generic building shapes (square and circular). The study didn't correlate the percentage of increasing in the width ratio with the percentage of decreasing in the surface to volume ratio (S/V) and the percentage of decreasing in the total solar insolation. As well as the solar insolation studies depends on selecting specific days in the year which doesn't provide with a clear understanding of the thermal performance of the various building shapes throughout the year.

Behsh, (2002) assumed that the surface to volume ratio (S/V) can be used as indicator for the thermal performance of compact forms. However, he assumed that this ratio doesn't provide a clear understanding of the thermal response of the complexes shapes. He suggested the relation between the roof area and walls area and the relation between the walls areas according to their orientation to be effective in evaluating the thermal response of different forms. Nevertheless, he simulate complexes shapes and multistory shapes with different (S/V) ratio which make this ratio to be the main dominate for the thermal response. As well as he depends on the air temperature difference between forms in the cooling period. Catalina *et al.* (2011) studied the impact of the building form on the energy consumption. Their study based on using the building shape factor (L_b) (also called building characteristic length) which is defined as the ratio between the heated volume of the building (V) and the sum of all heat loss surfaces that are in contact with the exterior, ground or adjacent non-heated spaces. They examined the heating demand of several shapes with various building shape factor and in different climates.

4.3 Tools and Validity

ECOTECH is a software package with a unique approach to conceptual building design. It couples an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information displays. ECOTECH offers a wide range of internal analysis functions which can be used at any time while modeling. These provide almost instantaneous feedback on parameters such as sun penetration, potential solar gains, thermal performance, internal light levels, reverberation times and even fabric costs (Marsh, 2003). ECOTECH has the ability to calculate the total amount of solar radiation falling on selected surfaces for each month of the year. Geometric overshadowing, reflective effects and available radiation are calculated separately for each day within the month, see figure (4.1).

ECOTECH based on the CIBSE steady state methods. The steady state method used to design the building analyzed is based on the CIBSE admittance method. This method uses idealized (sinusoidal) weather and thermal response factors (admittance, decrement factor and surface factor) that are based on a 24-hour frequency. The admittance method was originally intended to calculate peak internal temperatures in buildings to ensure that it would not become uncomfortably hot during sunny periods. The admittance

method is also used for the estimation of air conditioning plant capacity to maintain constant air temperatures in buildings (Beattie and Ward, 2012).

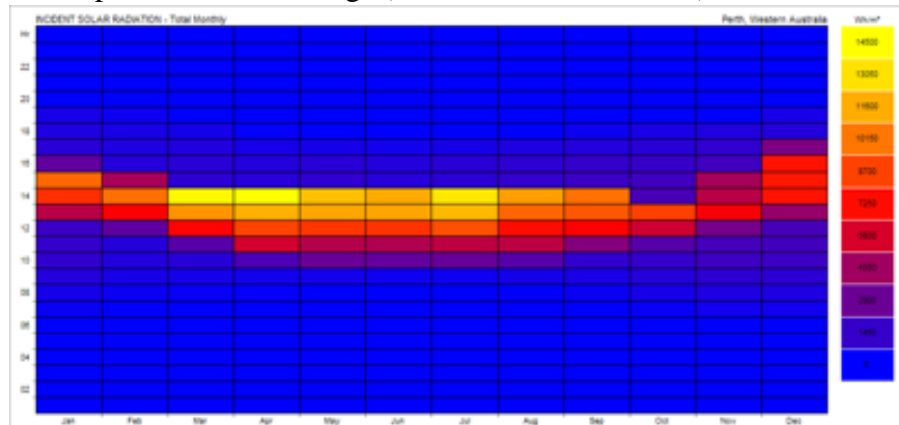


Figure (4.1): Full Monthly Solar Exposure in ECOTECT
Source: Ecotect Tutorial

The <Virtual Environment> is an integrated suite of applications linked by a Common User Interface (CUI) and a single Integrated Data Model (IDM). This means that all the applications have a consistent “look and feel” and that data input for one application can be used by the others. Modules such as “ApacheSim” for thermal simulation, “Radiance” for lighting simulation, and “SunCast” for solar shading analysis. “ModelIT” is the application used for input of 3D geometry used to describe the model (VE-Pro User Guide- IES Virtual Environment 6.4, 2011), see figure (4.2).

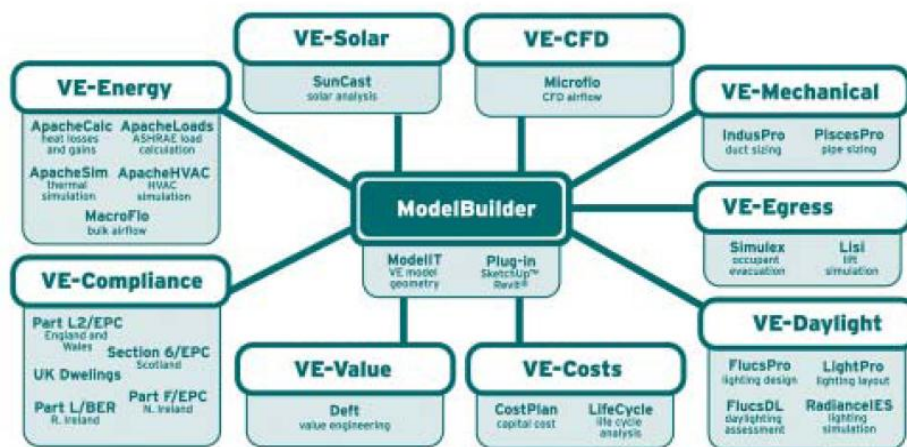


Figure (4.2):Workflow from Revit to IES<VE>
Source: IES <Virtual Environment> Integrated Environmental Solutions / Revit (2010)

Simulations were carried out El_Arish weather file during the months of January–December. Local latitude is 31.08 N, longitude 33.82 E and the elevation is approximately 32 m above sea level. The HVAC system was assumed to be full air conditioning with the heating and cooling set point were assumed to be 18.0°C and 26.0°C respectively. Using of buildings (hours of operation) was assumed to be On continuously. As the study focuses on the incident solar radiation as one of the most important variables in the Mediterranean climate affecting the heating and cooling energy consumption, the internal heat gain from occupancy and appliances as well as the ventilation heat gain weren’t considered in the study.

External walls have a U-values of $1.77 \text{ W/m}^2 \cdot \text{K}$ in ECOTECT and $1.9487 \text{ W/m}^2 \cdot \text{K}$ in IES. The roof U-values are $0.896 \text{ W/m}^2 \cdot \text{K}$ in ECOTECT and $0.9165 \text{ W/m}^2 \cdot \text{K}$ in IES. Glazing U-values are $6 \text{ W/m}^2 \cdot \text{K}$ in ECOTECT and $5.5617 \text{ W/m}^2 \cdot \text{K}$ in IES. The values of Thermal Transmittance, U-value for walls, roof and floor were assumed to achieved the minimum requirements of the maximum U-values as recommended by the Palestinian code for energy efficient building. See Appendix 3 for details of default settings for the two programs. For solar radiation calculations, ECOTECT uses hourly recorded direct and diffuse radiation data from the weather file (*epw).

4.4 Effect of Geometric Form on the Energy Consumption

Basically, this study examines the relation between the energy consumption and the surface to volume ratio (S/V) which is considered as the three dimensional extrapolation of the perimeter to area ratio. For this reason, 14 geometric shapes which are circular, square, rectangular, trapezoid, pentagon, hexagon, heptagon, octagon, L shape, T shape, cross shape, H shape, U shape and court shape were examined. The area (A) for these shapes is assumed to be 150 m^2 as it represents the average of residential units areas in Gaza. The height is assumed to be 6 m (2 storey) and thus the volume equals to 900 m^3 . The rectangular shape is assumed to have a width ratio of 0.618 as it represents the golden section (golden ratio). The golden ratio is applied also in the rectangular parts of the convex shapes such as L, T, cross, H, U and court shape. The ratio of the width of the shading façade to that of shaded façade is termed the depth ratio – a/b is taken to be 1 as illustrated in figure (4.3) and table (4.1). All forms were considered as stand-alone building without overshadow from any adjacent buildings. The description of the base case reference for generic residential building is clarified in table (4.2).

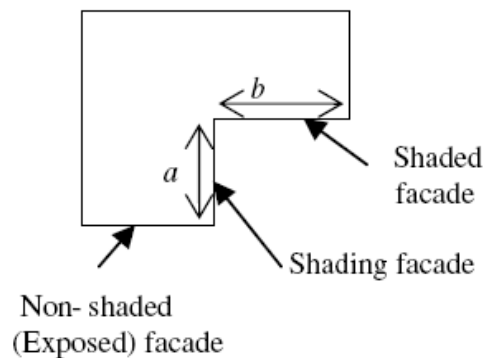


Figure (4.3): The depth ratio – a/b in the self shading geometries (convex shapes)

Source: Hachem *et al.* (2011)

Table (4.1): The relative dimensions of shading and shaded façades in the self shading geometries (convex shapes)

L Shape	U Shape	Court Shape

Table (4.2): Description of Base Case Reference for Generic residential Building

Location	Floor area (m ²)	Height (m)	Volume (m ³)	Floor to floor height (m)
Gaza city 31° N, 34° E	150	6	900	3

4.4.1 Parametric Investigation

The study investigates the effects of a number of geometric shapes in the heating, cooling and total loads. Combinations of the shape design parameters analyzed in this study are summarized in Table (4.3).

Table (4.3): Shape design parameters

Shape	circular	Square	Rectangul ar	Trapezoid	Pentagon	hexagon	Heptagon
Perspective							
Plan							
Perimeter	43.41618	48.9898	50.4145	50.8806	46.685	45.588	44.9736
Surface	410.49708	443.9388	452.487	455.2836	430.11	423.528	419.8416
S/V	0.456107866	0.493265333	0.503	0.506	0.478	0.47	0.466
Shape	Octagon	L Shape	T Shape	Cross Shape	H Shape	U Shape	Court Shape
Perspective							
Plan							
Perimeter	44.5816	62.3148	62.3148	62.3148	73.482	73.482	79.2664
Surface	417.4896	523.8888	523.89	523.89	590.892	590.892	625.598
S/V	0.464	0.582098666	0.582	0.582	0.656	0.656546666	0.695

4.4.2. Simulation Results

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

The results indicate that the total loads for the simulated shapes are increased by 69% with changing the geometric shape from the circle to the court shape at the East-

West orientation (0E) in the ECOTECT software. The circle shape achieves the lowest energy requirements so it was taken as a reference shape. The percentage of increasing in the total loads from the reference shape was evaluated for the other 13 geometric shapes. In IES software, the court shape increases in the total loads from the refer shape (circle) by about 52% Figure (4.4) shows the effect of changing geometric shape on the total loads throughout the year using the ECOTECT and IES.

The discrepancy in results between ECOTECT and IES can be explained as a result of different load calculation techniques, calculation engines and discrepancy in materials and their associated values found in the programs. ECOTECT uses the worst case annual design load while the ASHRAE load calculator uses a worst month scenario (January) for heating loads and 5 months (May-September) for cooling loads. The simulation engine and load calculation methods are different in the two programs. While ECOTECT uses the CIBSE ‘admittance method’ for calculating thermal loads, the ‘Apache Loads’ application in IES uses the ASHRAE ‘heat balance’ method (Kumar, 2008).

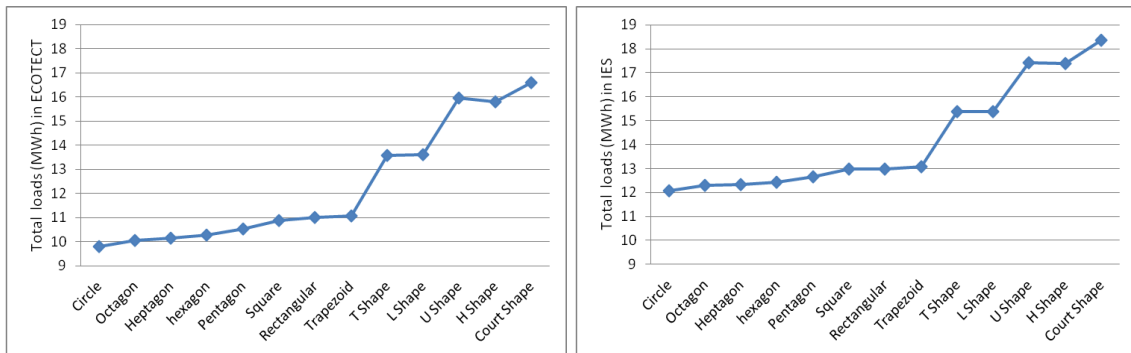


Figure (4.4): a: Annual Total loads of heating and cooling (MWh) by ECOTECT, b: Annual Total loads of heating and cooling (MWh) by IES

The same trend of increasing in the total loads can be noticed in the heating and cooling loads in figure (4.5). About 80% and 50% of increasing in the heating loads and the cooling loads respectively as a result of changing the geometric shape from the circle to the court shape in ECOTECT. It is evident that there is a slight difference between the refer shape and the square one which reaches to about 11%, 12.3% and 7.3% in the total, heating and cooling loads respectively. As the largest portion of buildings especially the residential have orthogonal polyhedral shapes, the square shape can be considered as the optimum thermal option. Also, the rectangular shape can be adopted as it has a small difference from the refer shape which reaches to about 12.2%, 15.6% and 7.1% in the total, heating and cooling loads respectively.

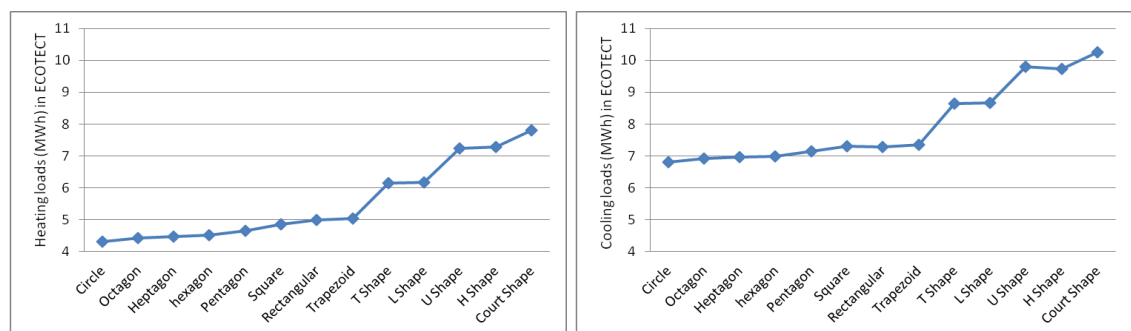


Figure (4.5): a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

In IES software, about 53.5% and 50.8% of increasing in the heating loads and the cooling loads respectively as a result of changing the geometric shape from the circle to the court shape. The square shape increases from the refer one by about 7.5%, 7.6% and 7.4% in the total, heating and cooling loads respectively.

It can be seen that there is a leap in the graphs between the compact shapes (circular, octagon, heptagon, hexagon, pentagon, square, rectangular, trapezoid) and the convex shapes (T, L, U, H and court shape). Changing the geometric shape from the square to the L, U and the court shapes for example increases the total loads by about 25.2%, 46.6% and 52.3% respectively. In order to investigate this behavior, the (s/v) ratio for the simulated shapes have to be obtained as shown in figure (4.6). It is evident that the increasing in the (s/v) ratio and the increasing in the total loads from the refer shape (circle) for the simulated shapes have the same trend. Changing the geometric shape from the circle to the court shapes increases the (s/v) ratio by about 52.4% which is more compatible with the percentage of increasing in the total loads in IES and smaller than it in ECOTECT. The rectangular, L, U and the court shapes for example increase from the reference shape by about (10.3%, 27.6%, 43.9% and 52.4% respectively) in the (s/v) ratio. The percentage of increasing in the total loads for these four shapes in ECOTECT are (12.2%, 38.9%, 62.7% and 69% respectively). However, The percentage of increasing in the total loads for these four shapes in IES are (7.5%, 27.4%, 44.2% and 52% respectively).

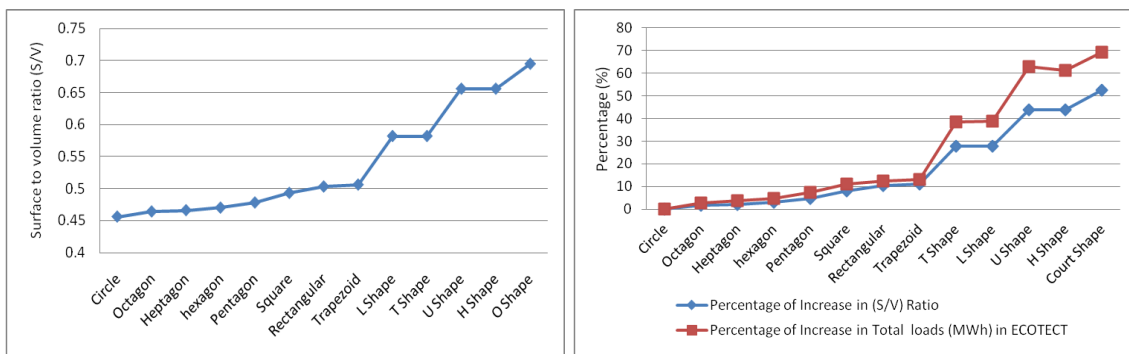


Figure (4.6): a: The (s/v) ratio for the simulated shapes, b: Percentage of Increase in (S/V) Ratio and the in Total loads by ECOTECT

Figure (4.7) illustrates a correlation between the percentage of increasing in the (s/v) ratio and the percentage of increasing in the total loads in the two programs. The coefficient of determination, R^2 (the square of the correlation coefficient, r) between the two variables is 0.9997. This means that 99.97% of increasing in the total loads is related to the increasing in the (s/v) ratio.

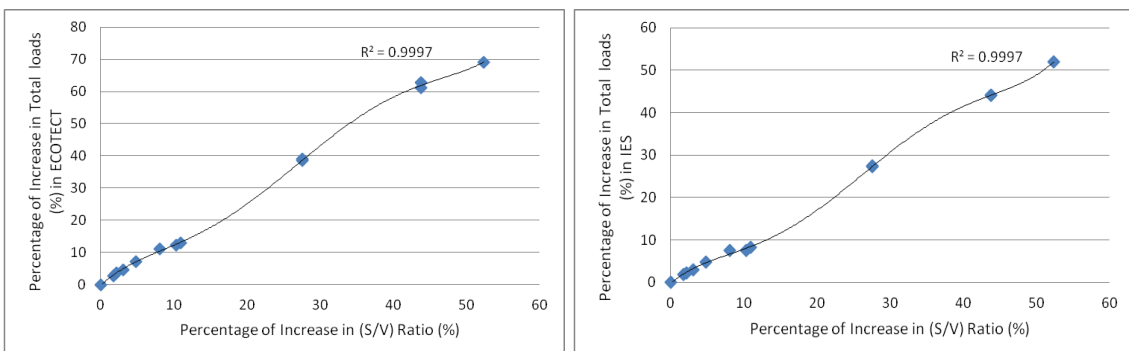


Figure (4.7): a: A correlation between the percentage of increasing in the (s/v) ratio and the total loads by ECOTECT, b: by IES

Also a higher relations emerge between the percentage of increasing in the (s/v) ratio and the percentage of increasing in the heating and the cooling loads as shown in figure (4.8). This means that the (s/v) ratio is the more responsible factor in affecting the heating and the cooling requirements. Knowing the (s/v) ratio for the shape can help to predict the percentage this shape increases in the heating and cooling energy from the most compact shape with the same volume. So, the more compact form which contain the same volume with the smallest (s/v) ratio is recommended in the climate of the Gaza Strip. Also, it can be concluded that increasing the (s/v) ratio can increase the energy consumption in the same percentage nearly.

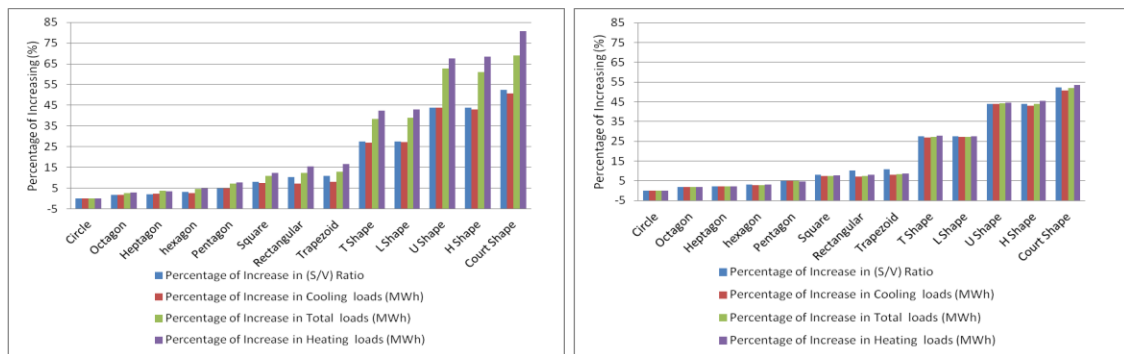


Figure (4.8): a: The percentage of increasing in the (s/v) ratio, the cooling, heating and total loads in ECOTECT, b: in IES

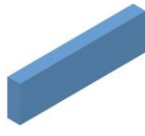
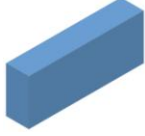



4.5 Effect of Rectangular Shape Proportions on the Energy Consumption






This section will display three parametric studies concerning the rectangular proportions and the resultant heating and cooling requirements.

4.5.1 Studying the Effect of (W/L) Ratio with Constant Volume

This study will correlate the percentage of increasing in the width to length ratio (W/L) with the percentage of decreasing in the surface to volume ratio (S/V) and the percentage of decreasing in the total solar insolation. Ten width ratios are adopted for the rectangular shape ranging between 0.1 to 1 in one degree steps. The area, height and volume for all the ten cases are kept constant. The area is taken to be 500 m² which represents one of the common options in multi story residential buildings in Gaza. Also, the building height is taken to be 20m (6 storey) and the volume is taken to be 10000 m³. Table (4.4) illustrates the ten cases. Appendix 3 presents floor plans for some of these cases.

Table (4.4): Shape design parameters

	W\L= 0.1	W\L= 0.2	W\L= 0.3	W\L= 0.4	W\L= 0.5
Perspective					
S/V Ratio	0.3611253	0.29	0.2622884	0.2479893	0.2397352
Roof/ Walls Ratio	0.160706956	0.20833333	0.235528648	0.252538899	0.263525165

	W\L= 0.6	W\L= 0.7	W\L= 0.8	W\L= 0.9	W\L= 1
Perspective					
S/V Ratio	0.2347519	0.2317367	0.23	0.2291334	0.2288841
Roof/ Walls Ratio	0.270633211	0.275123296	0.277777777	0.279121593	0.279510588

a. Parametric Investigation

The study investigates the effects of a number of parameters in the two major response variables the energy consumption and the incident solar radiation. Combinations of parameter values analyzed in this study are summarized in Table (4.5).

Table (4.5): Parameter combinations investigated in the study

Shape	Width ratio	Orientation	Glazing Ratio
Rectangular	0.1- 0.2- 0.3- 0.4- 0.5- 0.6- 0.7- 0.8- 0.9- 1	0E- 10E- 20E- 30E- 40E- 50E- 60E- 70E- 80E- 90E	0% - 10% - 20%

- **Width Ratio:** Ten values of width to length ratio (W/L) were considered, namely 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.

- **Orientation:** Ten values of orientation were considered, namely 0E, 10E, 20E, 30E, 40E, 50E, 60E, 70E, 80E and 90E as shown in figure (4.9).

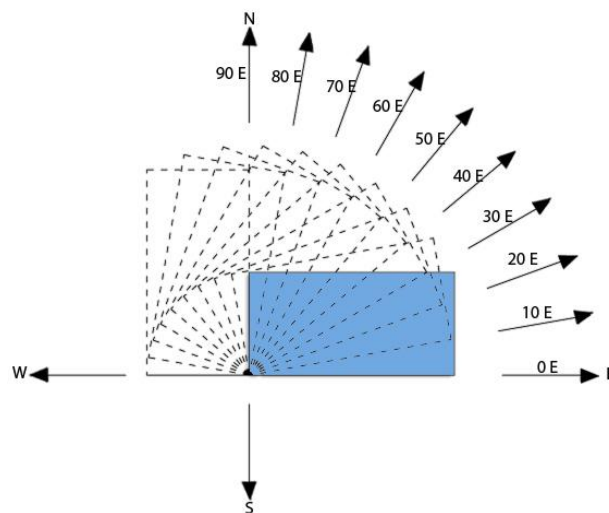
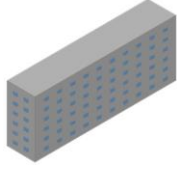
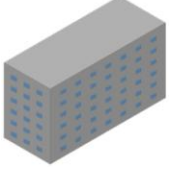
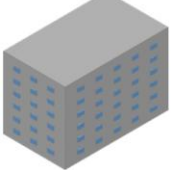
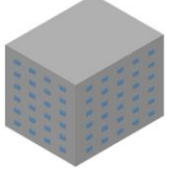
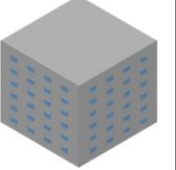


Figure (4.9): the Ten values of building's orientation considered in the study

- **Glazing Ratio:** Concerning glazing area, three values of glazing ratio were considered, namely 0%, 10% and 20% glazing, expressed as fraction of the gross floor area. The recommended glazing ratio for the temperate climate ranges between 10-20% (Walker, 2012). These values were adopted for the rectangular with five (W/L) ratio (0.2- 0.4-0.6-0.8-1). The glazing area was distributed across the enclosure in uniform way. This means that each façade has 25% of the glazing area. The fifteen cases were simulated in the East-West orientation (0E) as shown in table (4.6).

Table (4.6): distribution of the glazing (WWR= 10%) in the simulated cases

	W\L= 0.2	W\L= 0.4	W\L= 0.6	W\L= 0.8	W\L= 1
Perspective					

b. Simulation Results

The simulation results were expressed in terms of annual heating, cooling and total loads (in MWh) and the incident solar radiation (in MWh).

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

The results indicate that the total loads for the simulated shapes are reduced by 39.6% with increasing the width to length ratio (W/L) from 0.1 to 1 at the East- West orientation (0E) in ECOTECT. It is noticed that the reduction in the total loads is more remarkable with increasing the (W/L) ratio from 0.1 to 0.5. About 37.4% of reduction in the total loads occurs with increasing the (W/L) ratio from 0.1 to 0.5 while only 3.5% of the reduction occurs with increasing the (W/L) ratio from 0.5 to 1. It is notices that the optimum width ratio is 0.9 with a slight effect of changing the width ratio from 0.5 to 1. So it's advisable to select the building's width ratio in the range of 0.5 to 1 in order to reduce the energy consumption. The same trend can be observed in IES with about 31.8% of reduction in the total loads with increasing the width to length ratio (W/L) from 0.1 to 1 at the same orientation. Figure (4.10) shows the effect of changing the (W/L) ratio at different orientation on the total loads throughout the year using the ECOTECT and IES.

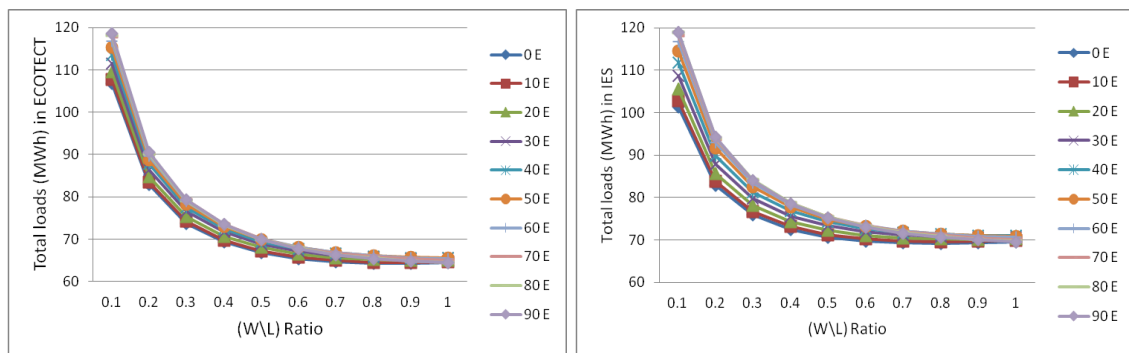


Figure (4.10): a: Annual Total loads of heating and cooling (MWh) by ECOTECT, b: Annual Total loads of heating and cooling (MWh) by IES

Changing the building orientation from the East- West orientation (0E) to the North- South orientation (90E) can increase the effect of the width ratio. The total loads are reduced by 45.7% with increasing the width to length ratio (W/L) from 0.1 to 1 at the North- South orientation (90E) in ECOTECT. However, about 41.5% of reduction occurs with increasing the width to length ratio (W/L) from 0.1 to 1 at the same orientation in IES. Also, increasing the width to length ratio (W/L) from 0.5 to 1 reduced the total loads by about 7.9% and 7.5% in ECOTECT and IES respectively in the North- South orientation comparing with only 3.5% and 1.5% of reduction in the case of the East- West orientation in ECOTECT and IES respectively. So that, more attention must be paid to the width ratio in the North- South orientation even between the shapes of width ratio ranging between 0.5 and 1.

The same trend can be observed in the heating and cooling loads as shown in figure (4.11). The heating loads are reduced by 42.9% with increasing the width to length ratio (W/L) from 0.1 to 1 in ECOTECT in the East- West orientation (0E). About 39.2% of this reduction occurs with increasing the (W/L) ratio from 0.1 to 0.5 while only 6.1% of the reduction occurs with increasing the (W/L) ratio from 0.5 to 1. The cooling loads are reduced by 36.7% with increasing the width ratio (W/L) from 0.1 to 1 in ECOTECT in the East- West orientation (0E). About 35.9% of this reduction occurs with increasing the (W/L) ratio from 0.1 to 0.5 while only 1.2% of the reduction occurs with increasing the (W/L) ratio from 0.5 to 1.

The effect of orientation in affecting the role of width ratio in reducing the energy consumption is more noticeable in the cooling requirements. Increasing the width to length ratio (W/L) from 0.1 to 1 in ECOTECT in the North- South orientation (90E) reduces the cooling loads by about 48.2% comparing with 36.7% in the East- West orientation (0E). also, increasing the width to length ratio (W/L) from 0.5 to 1, reduced the cooling loads by about 9.8% in the North- South orientation (90E) comparing with only 1.2% in the East- West orientation (0E). In IES, increasing the width to length ratio (W/L) from 0.1 to 1, reduced the heating loads by about 32.2% while it reduced the cooling loads by about 30.7% in the East- West orientation (0E). In the North- South orientation (90E), increasing the width to length ratio (W/L) from 0.1 to 1, reduced the heating loads by about 40.3% while it reduced the cooling loads by about 42.4%.

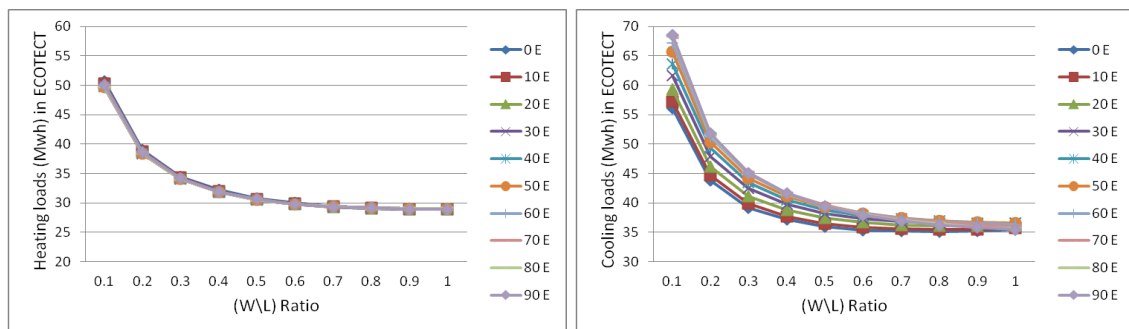


Figure (4.11): a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

It is noticed that changing the (W/L) ratio affects the total exposed surface and the relation between its two main components, the roof and the walls. As the (W/L) ratio increases and the building reach to the square shape (W/L= 1), the exposed surface decreases at the same trend of decreasing the heating, cooling and total loads as shown in figure (4.12). Taking the fixed roof area in all cases, it is reasonable that the (roof/walls) ratio increases with increasing the (W/L) ratio as shown in figure (4.12).

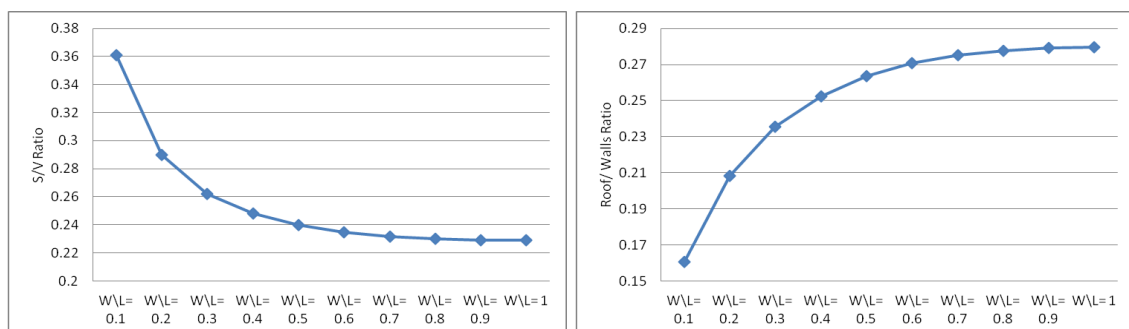


Figure (4.12): a: The (s/v) ratio for the simulated shapes, b: The (roof/walls) ratio for them

In order to understand the main factor that causes the increase in the required energy, it is necessary to find a correlation equation between the three variables; (W/L) ratio, (s/v) ratio, (roof/walls) ratio and the total loads. For this purpose, the square shape (W/L= 1) was taken as a reference shape. The percentage of difference between the other nine shapes and the reference shape in the previous four variables was evaluated. As illustrated in figure (4.13), the coefficient of determination, R^2 between the percentage of increasing in (s/v) ratio and the total loads is 0.9999. This means that 99.99% of increasing in the total loads is caused as a consequence of increasing in the (s/v) ratio. A large relation can be observed between the percentage of decreasing in (roof/walls) ratio and the percentage of increasing in the total loads.

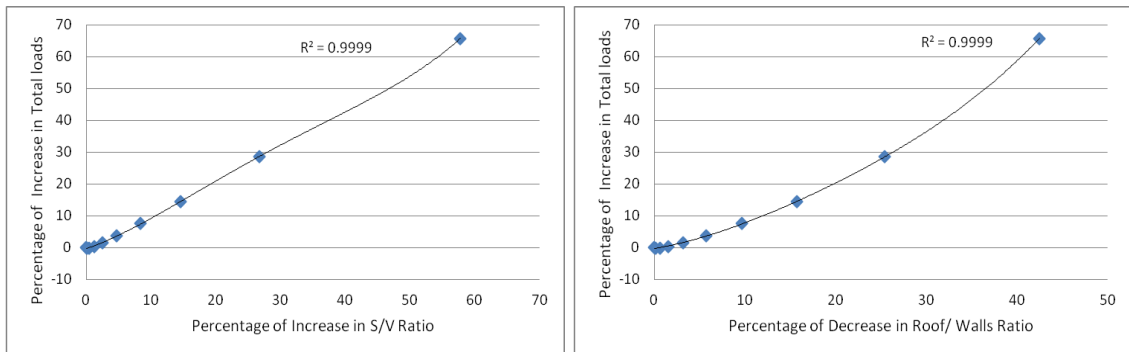


Figure (4.13): a: The percentage of increasing in the (s/v) ratio, b: The percentage of decreasing in the (roof/walls) ratio

This means that the effect of (W/L) ratio in varying the total loads can be expressed as its ability to change the (s/v) ratio and the (roof/walls) ratio which are the main responsible for changing the total loads. Figure (4.14) summarizes the relation between the percentage of changing in the (W/L) ratio and the (s/v) ratio, (roof/walls) and the total loads as a consequence. It can be mentioned that decreasing the (W/L) ratio by 90% from the refer shape (W/L= 1) to the worst ratio (W/L= 0.1) can increase the (s/v) ratio by about 57.7% and decreasing the (roof/walls) ratio by 42.5% and increasing the total loads by 65.7%. So it is recommended to decrease the (s/v) ratio and increase the (roof/ walls) ratio and increase the width ratio.

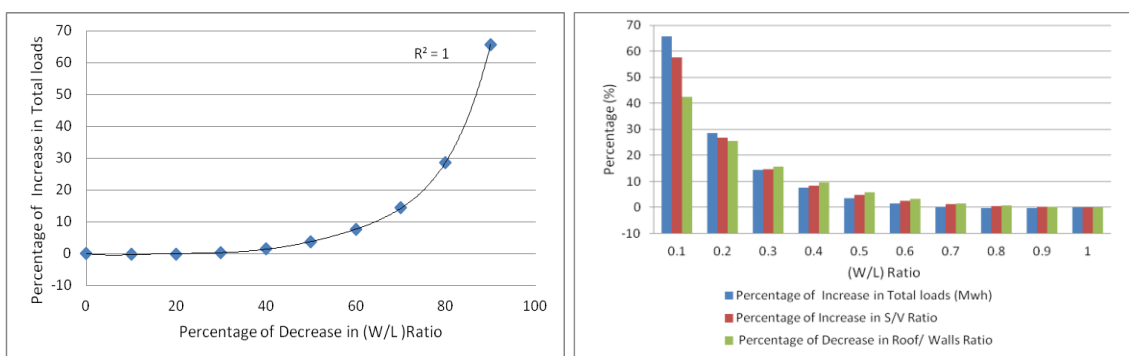


Figure (4.14): a: A correlation between the percentage of decreasing in the width ratio (W/L) and the total loads by ECOTECT, b: the percentage of decreasing in the width ratio (W/L) and other variables

The effect of changing orientation in increasing the difference in the total loads between various width ratio in spite of having the same difference of (s/v) ratio and (roof/walls) ratio can be explained as while increasing the width ratio in the East- West orientation (OE) decreases the surface area of the south and north façades, increasing the

width ratio in the North- South orientation (90E) decreases the surface area of the east and west façades which considered the most critical façades as the incident radiation on the east façades in the morning and the west façades in the evening is much greater than that on the south façades during the middle of the day. Figure (4.15) illustrates the low latitude position of the sun in the morning and the evening of summer periods which increase the incident solar radiation on the east and west façades comparing with the high latitude position of the sun on the south façade.

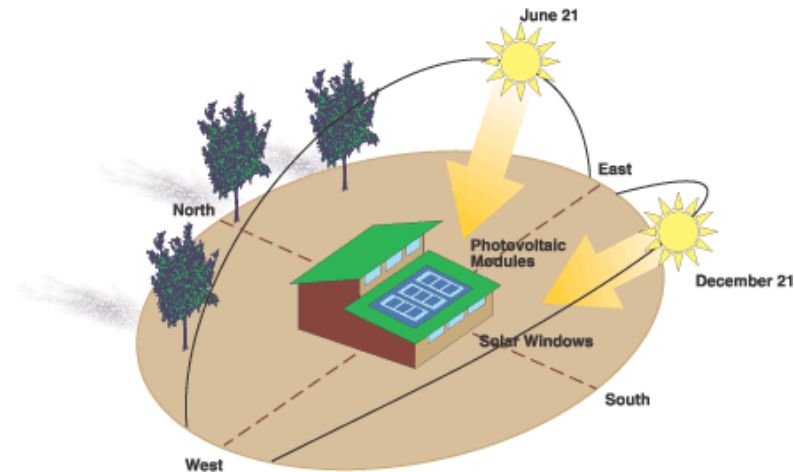


Figure (4.15): The sun path in summer and winter periods and its relation with the building façades

- Effect of Orientation

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

As the shape approaching to the square shape, the effect of orientation in changing the total loads is decreased. This is due to the four equal sides of the square shape which make the East-West orientation (0E) and the North-South orientation (90E) have the same performance. Instead, the worst orientation in this case is (45E) with unnoticeable difference in the total loads which reach to 1.8%. In IES, changing the orientation from the East-West orientation (0E) to the North-South orientation (90E) increased the total loads by about 17.3%, 13.6% and 10.7% in the case of the shapes with width to length ratios (W/L) equal to 0.1, 0.2 and 0.3 respectively. The ratio decreased to reach about 1.9% between the East-West orientation (0E) and (45E) orientation in the case of the square shape. Figure (4.16) illustrate the effect of changing orientation on the total loads for various width ratio in both ECOTECH and IES.

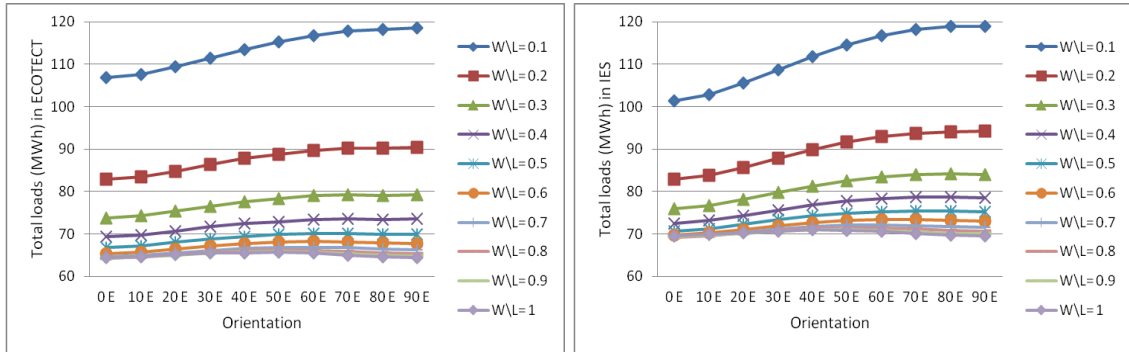


Figure (4.16): a: Total loads (MWh) by ECOTECT, b: Total loads (MWh) by IES

To clearly investigate the effect of the (W/L) ratio in affecting the orientation effects, the East-West orientation (0E) was taken as a reference case, as it achieves the lowest required energy. The percentage of difference between the other nine orientation for three main (W/L) ratio (0.1- 0.5- 1) and the refer shape was evaluated as illustrated in figure (4.17). So it is recommended to pay more attention in selection orientation especially in the shapes with smallest width ratio the East-West orientation (0E) is considered the optimum orientation in all cases. The orientation from (70E) to (90E) is considered as the worst orientation in all cases except the square shape which have the worst orientation equals to (45E) with unnoticeable differ in energy consumption.

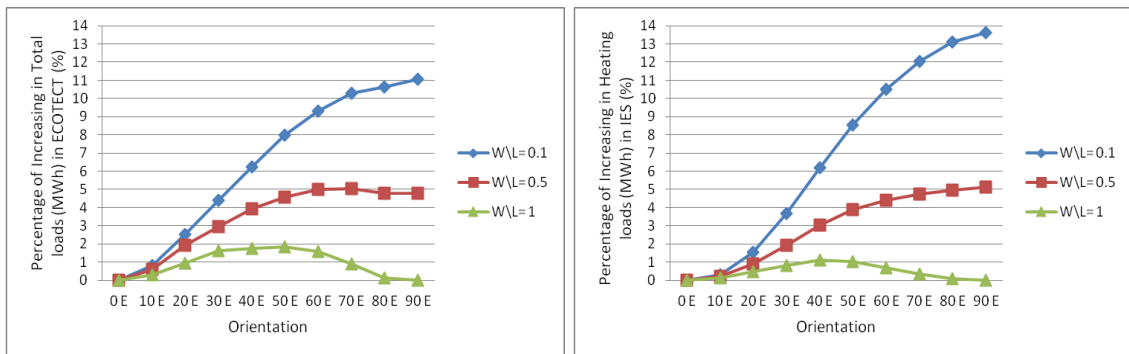


Figure (4.17): a: The percentage of increasing in the total loads for various orientations by ECOTECT, b: by IES

The effect of changing orientation is not remarkable in the heating loads. While changing orientation from (0E) to (90E) increases the total loads, it reduced the heating loads by 1.6% in the shape with width to length ratio (W/L) equal to 0.1 in ECOTECT as shown in figure (4.18). The effect of changing orientation is more noticeable in the cooling loads. About 20.5% of the cooling loads can be increased with changing orientation from (0E) to (90E) in the shape with width to length ratio (W/L) equal to 0.1. This percentage decreases gradually with increasing the (W/L) ratio to reach 2.8% in the case of the square shape (W/L= 1) with changing orientation from (0E) to (45E). Figure (4.19) illustrates the percentage of increasing in the cooling loads for various orientations in ECOTECT and IES.

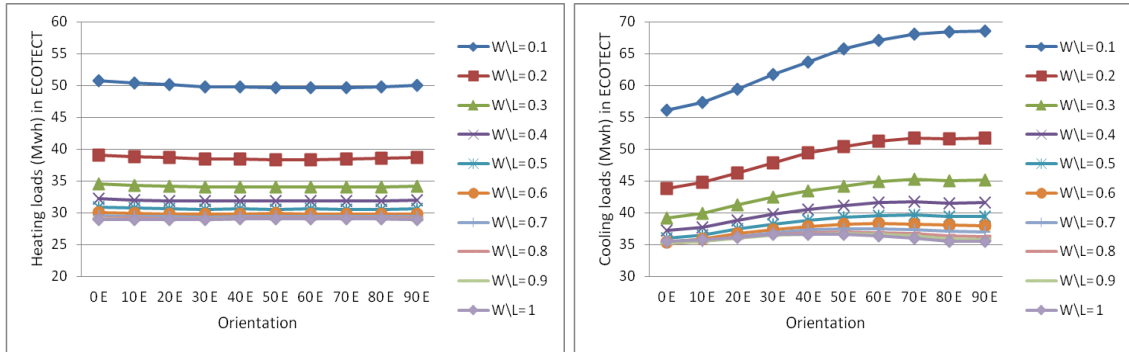


Figure (4.18): a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

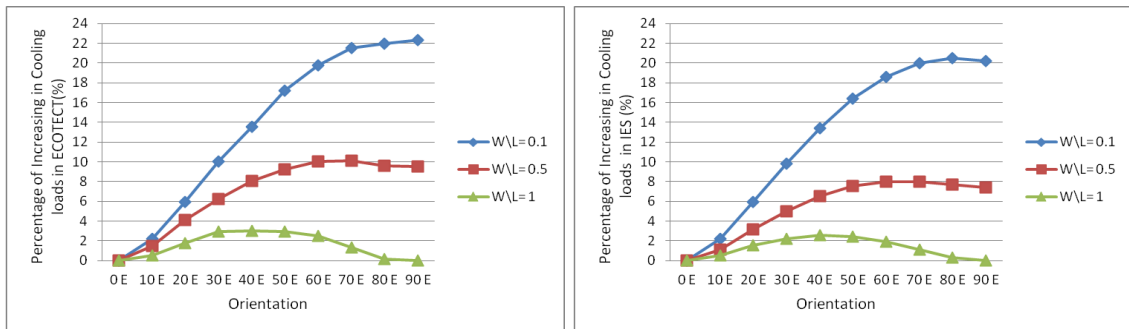


Figure (4.19): a: The percentage of increasing in the cooling loads for various orientations by ECOTECT, b: by IES

- Effect of Glazing Ratio

Glazing is considered the weakest thermal component in the building envelop due to its high U- Value. As shown in figure (4.20), adding a percentage of glazing equal to 10% of the floor area (WFR= 10%) increases the total loads by about 49.7% in the case of (W/L= 0.2). The difference reaches to 91% with increasing the glazing ratio to 20% of the floor area. It is noticed that increasing the (W/L) ratio can increase the difference. In the case of square (W/L= 1), the total loads can increase by 62.5%, 110% as a result of adding 10%, 20% of glazing respectively. See figure (4.20).

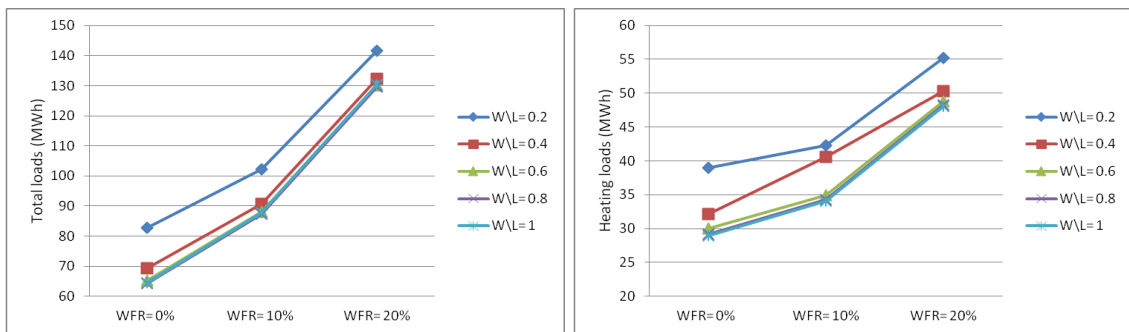


Figure (4.20): a: Total loads (MWh) by ECOTECT, b: Heating loads (MWh) by ECOTECT

The same trend can be observed in the heating and cooling loads. As shown in figure (4.20), adding a percentage of glazing equal to 10% of the floor area increases the heating loads by about 36% and 45.8% in the case of (W/L= 0.2), (W/L= 1) respectively. The difference reaches to 58% and 71% with increasing the glazing ratio to 20% of the floor area for (W/L= 0.2), (W/L= 1) respectively. The most effect can be noticed in the cooling loads. Adding a percentage of glazing equal to 10% of the floor area can increase the cooling loads by about 68.5% and 85.6% in the case of (W/L=

0.2), ($W/L = 1$) respectively. The difference reaches to 137% and 166% with increasing the glazing ratio to 20% of the floor area for ($W/L = 0.2$), ($W/L = 1$) respectively.

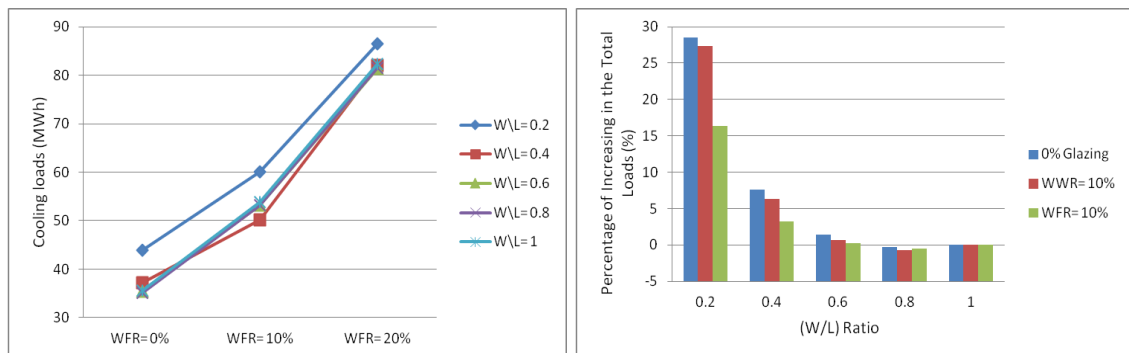


Figure (4.21): a: Cooling loads (MWh) by ECOTECT, b: The percentage of increasing in the total loads for glazing ratios by ECOTECT

Figure (4.21) summarizes the effect of the glazing on the effect of the (W/L) ratio. It can be noticed that decreasing the (W/L) ratio from 1 to 0.2 increases the required energy by 28.6% in the case of opaque envelop (0% glazing). This percentage can be decreased to reach 27.3% and 16.4% in the case of window to walls ratio (WWR) equals 10% and window floor ratio (WFR) equals 10% respectively. That means that increasing the glazing ratio has the ability to decrease the effect of the (W/L) ratio in changing the required energy although the simulated cases have the same (s/v) ratio and orientation.

- Incident Solar Radiation

The results indicate that the shapes with (W/L) ratio equal to 0.1 receive the highest amounts of incident solar radiation (MWh) for the south façade as shown in figure (4.22). Taking into consideration that this shape has the highest area of the south façade which exceeds by about 216% from the shape with (W/L) ratio equal to 1, this explains the worst thermal performance of this shape from the energy consumption point of view. It is observed that the shape with (W/L) equal to 0.1 receives about 56.7% of its total solar radiation (MWh) on its south façade comparing with 27.3% and 19.8% for the shapes with (W/L) equal to 0.5 and 1 respectively. The south façade forms about 39.2% from the total exposed surface for the shapes with (W/L) equal to 0.1.

From the figure (4.22), it's evident that the percentage of incident solar radiation on the south façade is the main responsible factor affecting the energy consumption of the three simulated shapes. For more illustration, figure (4.22) shows the same trend for the percentage of incident solar radiation on the south façade and the total required energy for the three simulated shapes ($W/L = 0.1, 0.5$ and 1). It can be noticed a small difference between the shapes with (W/L) equal to 0.5 and 1 in the total loads while there is a noticeable difference between them in the term of percentage of incident solar radiation on the south façade. This can be explained as the square shape ($W/L = 1$) receives an amount of incident solar radiation on the east and west façades more than the shape with (W/L) equal to 0.5. This makes the difference between the two shapes in the terms of the total loads (MWh) is too small.

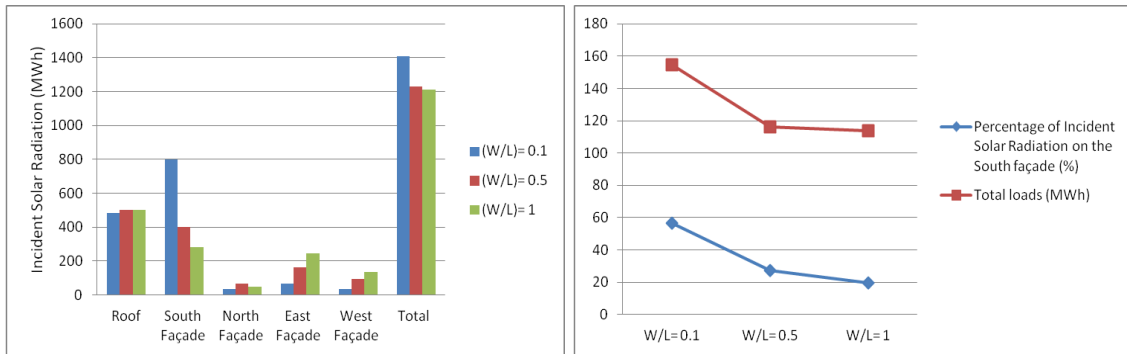


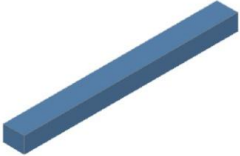


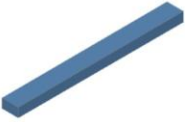
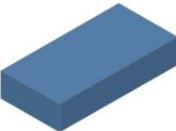

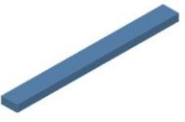
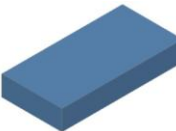

Figure (4.22): a: Incident solar radiation for various width ratios, b: comparative between the percentage of solar radiation on the south façades and the total loads

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

It is evident that the form morphology can be determined throughout the relation between its components. The main relation in this case is that between the roof area and the walls area which affects the building height. The second relation is between the walls which expressed as the (W/L) ratio that affects the building elongation. For investigating the effect of these ratios, 10 (W/L) ratio ranging between (0.1-1) with 5 (Roof/walls) ratio ranging between (0.2-1) were examined. The volume for the base case was evaluated from the assumption that the minimum width of the rectangular is 4 m as it represents the average of room width. The maximum length can be obtained from the smallest (W/L) ratio equal to 0.1 which means that the rectangular length is 40 m and the area (A) is 160 m² which represents the average of residential units areas. The maximum height can be obtained from the (Roof/walls) ratio equal to 0.1 which mean that the walls area is 1600 m² and the total exposed surface is 1760 m². The perimeter for the assumed base case equals to 88 m and the height equals to 18.18 m (6 storey) and thus the volume equals to 2909 m³. All the forms investigated in this study have the same volume, table (4.7) illustrates this set of forms.

Table (4.7): The simulated cases in the study

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

Roof\wall= 0.6			
Roof\wall= 0.8			
Roof\wall= 1			

a. Parametric Investigation

The study investigates the effects of a number of parameters in the heating, cooling and the total loads. The two main parameters in this study are:

- **Width Ratio:** Ten values of width to length ratio (W/L) were considered, namely 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.
- **Roof/Walls Ratio:** Five values of (Roof/Walls) ratio were considered, namely 0.2, 0.4, 0.6, 0.8 and 1.

b. Simulation Results

The simulation results were expressed in terms of annual heating, cooling and total loads (in MWh).

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

Apparently, it can be noticed that with increasing the width to length ratio (W/L) the required loads gradually reduced at all values of (Roof/Walls) ratio. With increasing the width to length ratio (W/L) from 0.1 to 1 at the East- West orientation (0E), the total loads for the simulated shapes are reduced by 31.6%, 27%, 27%, 27.2%, 27.5% for the shapes with roof/walls ratio equals to 0.2, 0.4, 0.6, 0.8 and 1 respectively. This means that the effect of the (W/L) ratio in changing the total loads reduced with increasing the (Roof/Walls) ratio. Also, the graph indicates that the rate of decrease becomes markedly smaller as the (W/L) ratio becomes greater than 0.5. It can be noticed for example that about 30.4% of decrease in the total loads occurs with increasing the (W/L) ratio from 0.1 to 0.5 while only 1.7% of this decrease occurs with increasing the (W/L) ratio from 0.5 to 1. The same trend can be noticed in IES. With increasing the width to length ratio (W/L) from 0.1 to 1 at the East- West orientation (0E), the total loads for the simulated shapes are reduced by 24.4%, 25%, 25.6%, 26% and 26.4% for the shapes with roof/walls ratio equals to 0.2, 0.4, 0.6, 0.8 and 1 respectively as shown in figure (4.23).

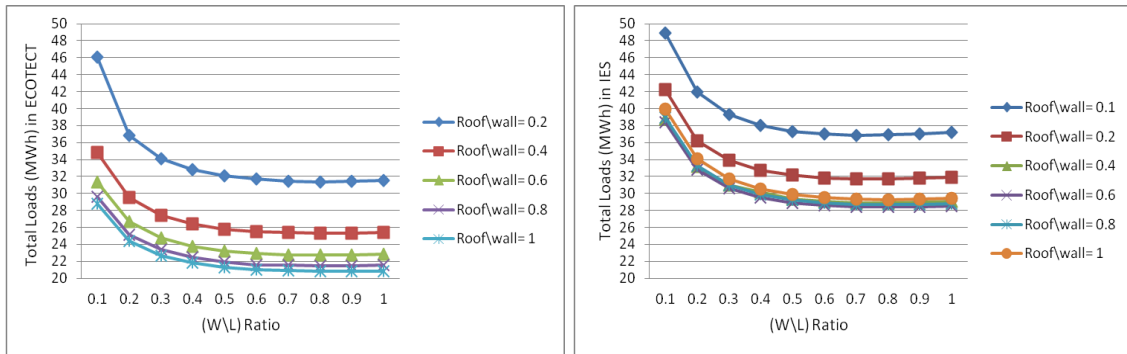


Figure (4.23): a: Total loads (MWh) by ECOTECT, b: Total loads (MWh) by IES

It can also be observed that the heating load reduced remarkably with increasing the (W/L) ratio from 0.1 to 0.5 at any values of the (Roof/Walls) ratio. Any increase in the (W/L) ratio from 0.5 to 1 affects slightly the heating loads as shown in figure (4.24). The heating loads decreased by about 35.6% and 31.6% with increasing the (W/L) ratio from 0.1 to 1 for the shapes with (Roof/Walls) ratio equals to 0.2 and 1 respectively. Given the cooling loads, it can be noticed that the effect of the (W/L) ratio in changing the cooling loads increased with increasing the (Roof/Walls) ratio. The cooling loads for the simulated shapes are reduced by 27.8%, 24.1% for the shapes with roof/walls ratio equals to 0.2 and 1 respectively. In IES, the heating loads decreased by about 25.8% and 27.3% with increasing the (W/L) ratio from 0.1 to 1 for the shapes with (Roof/Walls) ratio equals to 0.2 and 1 respectively. Also, the cooling loads decreased by about 23.3% and 25.7% with increasing the (W/L) ratio from 0.1 to 1 for the shapes with roof/walls ratio equals to 0.2 and 1 respectively.

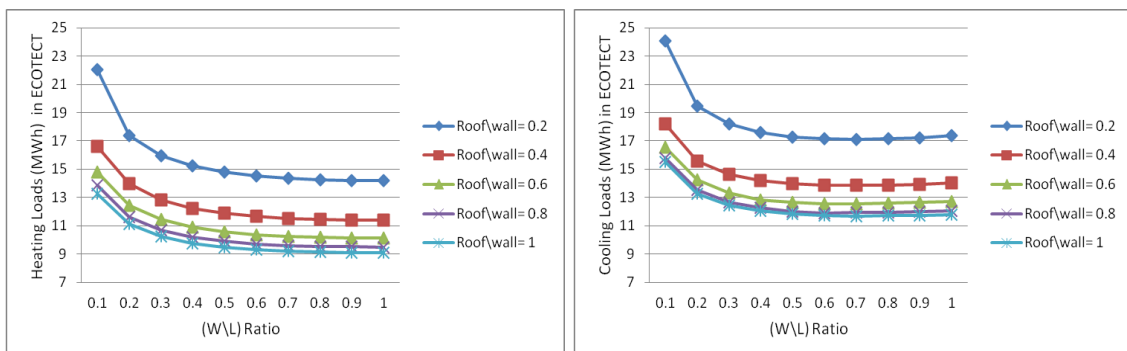


Figure (4.24): a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

- Effect of (Roof/Walls) Ratio

Increasing the (Roof/ Walls) ratio which means decreasing the building height with the same volume have a great effects on the required energy as shown in figure (4.25). Increasing the (Roof/ Walls) ratio from 0.2 to 1 in ECOTECT at the East- West orientation (OE) reduced the total energy by 30.9%, 29% and 28.8% for the shapes with the width to length ratio (W/L) equals to 0.1, 0.5 and 1 respectively. This means that varying the width ratio has a small effects (about 2%) in affecting the impact of the (Roof/ Walls) ratio on changing the total loads (MWh). The same trend can be observed in IES. Increasing the (Roof/ Walls) ratio from 0.1 to 1 reduced the total energy by 22.4%, 24.9% and 26.4% for the shapes with the width to length ratio (W/L) equals to 0.1, 0.5 and 1 respectively as shown in figure (4.25).

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

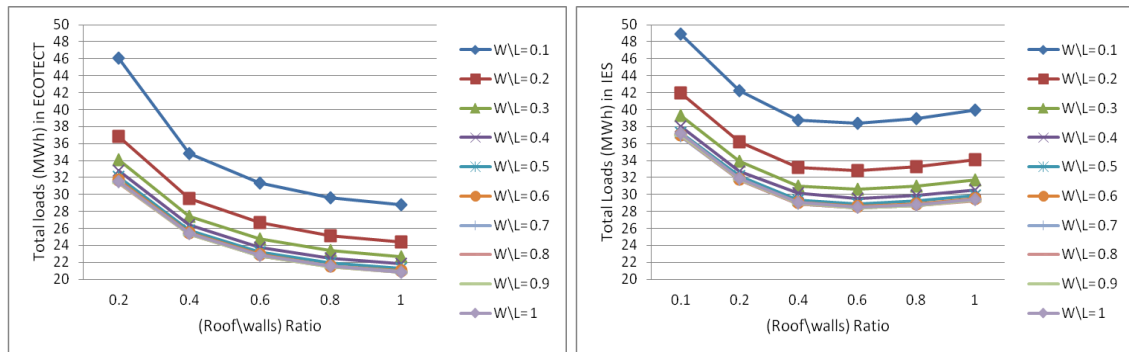


Figure (4.25): a: Total loads (MWh) by ECOTECT, b: Total loads (MWh) by IES

In order to explain this behavior, the surface to volume ratio (S/V) for the shape with width to length ratio (W/L) equals 0.5 and within six values of (Roof/ Walls) ratio equal to 0.1, 0.2, 0.4, 0.6, 0.8 and 1 was determined as shown in figure (4.27). It can be shown that the (S/V) ratio for the simulated cases has the same trend of the total loads. Increasing the (Roof/ Walls) ratio from 0.1 to 0.6 reduced the (S/V) ratio by about 24.9% which is compatible with the percentage of reduction in the total loads (29.1%). Increasing the (Roof/ Walls) ratio from 0.6 to 1 increased the (S/V) ratio by about 5.4%.

Hence, the thermal behavior of the simulated cases can be explained as a consequence of changing the (S/V) ratio. Determining the fabric heat gain for the same cases can also explain their behavior. As shown in figure (4.26), the heat loss during the winter period (December- February) decreases by about 31% with increasing the (Roof/ Walls) ratio from 0.2 to 1 which decreases the heating loads in the shapes with higher (Roof/ Walls) ratio. However, the heat gain during the summer period decreases by about 11% with increasing the (Roof/ Walls) ratio from 0.2 to 0.6 which decreases the cooling loads. Increasing the (Roof/ Walls) ratio from 0.6 to 1 increased the heat gain by about 3%.

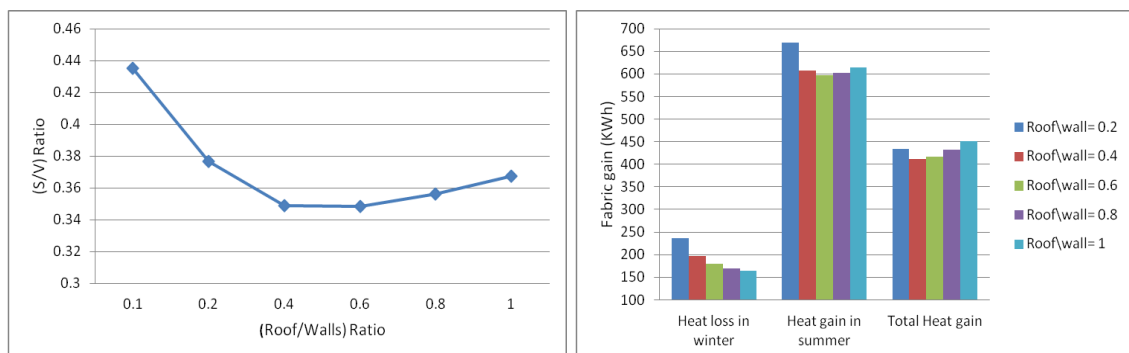


Figure (4.26): a: (S/V) ratio for the simulated cases, b: Fabric gain for the simulated cases

The previous result can be confirmed by showing the trend of the heating and cooling loads. It can be shown from figure (4.27) that the heating loads decreased by

about 53%, 47.2% and 46.6% with decreasing the (Roof/ Walls) ratio from 0.2 to 1 for the shapes with the width to length ratio (W/L) equals to 0.1, 0.5 and 1 respectively as a result of decreasing the heat loss. About 14% of reduction in the cooling loads occurs with increasing the (Roof/ Walls) ratio from 0.2 to 0.6 followed by 4.9% of increasing with increasing the (Roof/ Walls) ratio from 0.6 to 1 as shown in figure (4.27).

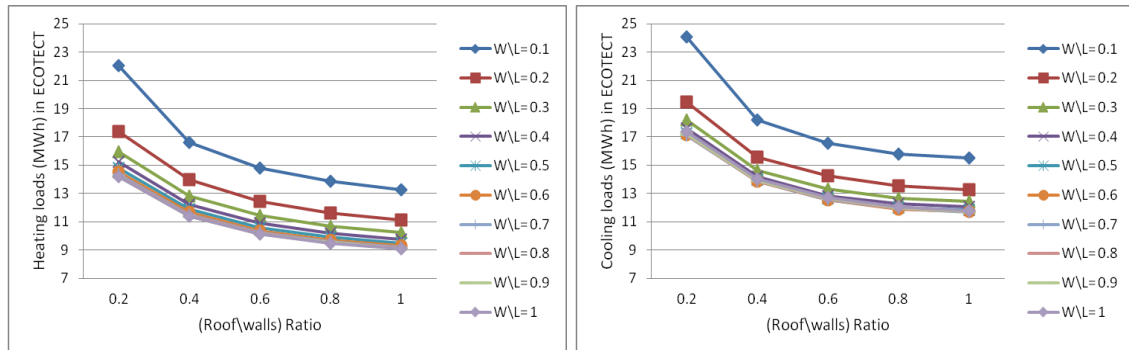

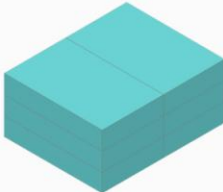
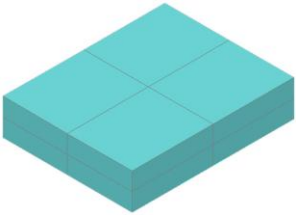


Figure (4.27): a: Heating loads (MWh) by ECOTECH ,b: Cooling loads (MWh) by ECOTECH

It can be concluded that the (Roof/ Walls) ratio equals to 0.6 is more preferable for both cooling and heating requirements. Taking into consideration the unnoticeable difference in the total loads between the two values of the (Roof/ Walls) ratio equals to 0.4 and 0.6, there is a flexibility in selecting the (Roof/ Walls) ratio to range between 0.4 and 0.6. Also, the width to length ratio (W/L) equals 0.8 is advisable in the energy saving point of view. Table (4.8) displays three options of the apartment block displayed in this study with three values of the (Roof/ Walls) ratio and the same (W/L) equals 0.8. Taking the shape with the (Roof/ Walls) ratio equals 0.5 as an optimum case, the percentage of increasing in the total loads for the other two shapes was determined in the table.

Table (4.8): The options of the apartment block based on various (roof/ walls) ratio

	Roof\wall= 0.1	Roof\wall= 0.5	Roof\wall= 1
Perspectives			
Building's Dimension (L*W*H)	11.8*9.4* 26.2	20.2*16.1*9	25.3*20.3*5.7
Percentage of increasing in the total loads (%)	29.8%	0	3%

4.5.3 Effect of Height with Constant Surface to Volume Ratio

This study investigated one of the main dimensions in the building form which is height. In order to compare different heights, the building volume was kept constant. It

is evident that increasing the height would decrease the area and thus the (Roof/ Walls) Ratio would change in each case. Nine heights are adopted to the rectangular shape, namely 6, 9, 12, 15, 18, 21, 24, 27 and 30 m. The storey height is taken to be 3 m and this means that each one of the simulated cases increases by one storey from the other shape. The smallest area was assumed to be 200 m² and the largest height was assumed to be 30 m (10 storey) and thus the assumed volume was taken to be 6000 m³. The (W/L) ratio in the base case was assumed to be 1 (square shape) and the exposed surface was evaluated to be 1897 m² and thus the (s/v) ratio was taken to be 0.316. As the purpose of this study is to investigate the height effect, the (s/v) ratio is assumed to be fixed in all the simulated cases. In order to achieve this purpose, the area increased as the height reduced and the (W/L) ratio also increased.

a. Parametric Investigation

The study investigates the effects of a number of parameters in the two major response variables energy requirements and the incident solar radiation. Combinations of parameter values analyzed in this study are summarized in Table (4.9) and (4.10).

Table (4.9): Parameter combinations investigated in the study

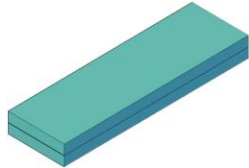
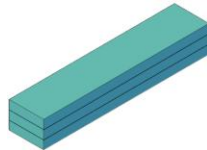
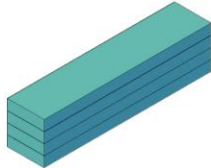
Shape	Height (m)	orientation	Glazing Ratio
Rectangular	6- 9- 12- 15- 18- 21- 24- 27- 30	0E- 10E- 20E- 30E- 40E- 50E- 60E- 70E- 80E- 90E	0% - 10% - 20%

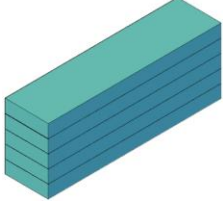
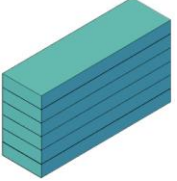
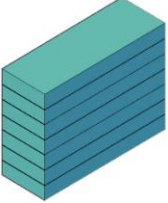
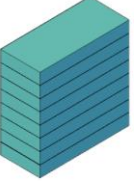
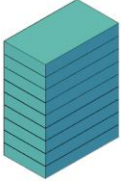
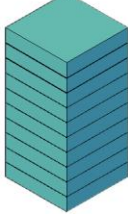
- **Height:** Nine values of height were considered, namely 6, 9, 12, 15, 18, 21, 24, 27 and 30 m.

- **Orientation:** Ten values of orientation were considered, namely 0E, 10E, 20E, 30E, 40E, 50E, 60E, 70E, 80E and 90E.

- **Glazing Ratio:** Concerning glazing area, three values of glazing ratio were considered, namely 0%, 10% and 20% glazing, expressed as fraction of the gross floor area. These values were adopted for the rectangular with five (W/L) ratio (0.2- 0.4-0.6- 0.8-1). The glazing area was distributed across the enclosure in uniform way. This means that each façade has 25% of the glazing area. The fifteen cases were simulated in the East-West orientation (0E).

Table (4.10): Parameter combinations investigated in the study

Height	H= 6m	H= 9m	H= 12m
Perspective			
Area	1000	666.666	500
(Roof/ Walls) Ratio	1.11475	0.54183	0.35789
(W/L) Ratio	0.3045	0.2083	0.2194
Height	H= 15m	H= 18m	H= 21m

Perspective			
Area	400	333.333	285.714
(Roof/ Walls) Ratio	0.26719	0.21316	0.177314
(W\L) Ratio	0.2516	0.2973	0.3579
Height	H= 24m	H= 27m	H= 30m
Perspective			
Area	250	222.222	200
(Roof/ Walls) Ratio	0.15178	0.13268	0.11785
(W\L) Ratio	0.4407	0.5678	1

b. Simulation Results

The simulation results were expressed in terms of annual heating, cooling and total loads (in MWh) and the incident solar radiation (in MWh).

- Effect of Height

The results indicate that the total loads for the simulated shapes are increased by 62.5% with increasing the building height from 6 m to 30 m at the East- West orientation (0E). Figure (4.28) shows the effect of changing the building height at different orientation on the total loads throughout the year. The increasing percentages in ECOTECT are 20.6%, 33.1%, 41.7%, 47.7%, 55.5%, 58.7% and 62.5% with increasing the building height from 6 m, 9 m, 12 m, 15 m, 18 m, 21 m, 24 m, 27 m and 30 m. It can be noticed that there is a nonlinear relationship between the building height and the total loads. This means that increasing the building height by one story doesn't cause the same percentage of loads increasing. As the building height increased, the percentage of increasing in the total loads decreased. Increasing the building height from 6 m to 30 m with constant (s/v) ratio in IES increases the total loads by about 11.3%.

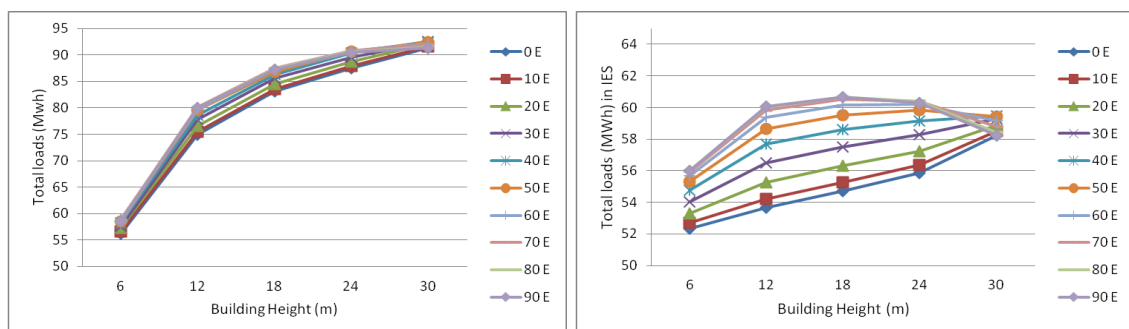


Figure (4.28): a: Total loads (MWh) by ECOTECT, b: Total loads (MWh) by IES

The same trend can be observed in the heating and cooling loads as shown in figure (4.29). The heating loads are increased by 37.6% with increasing the building height from 6 m to 30 m. The more important effect of increasing the building height can be observed in the cooling loads. About 107.6% of increasing in the cooling loads occurs with increasing the building height from 6 m to 30 m with the same (s/v) ratio.

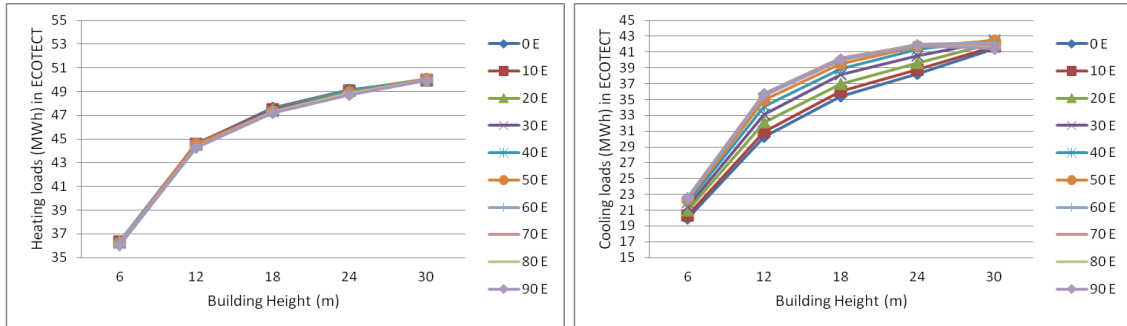


Figure (4.29): a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

As the (s/v) ratio is constant for all the simulated cases, increasing the building height affects each the width to length ratio (W/L) and the (roof/walls) ratio. In order to determine the main factor affecting the total loads when increasing the building height, the shape with 6 m height was taken as a reference shape as it achieves the lowest energy requirements. The percentage of increasing in the total loads and decreasing in the (roof/walls) ratio and increasing in the (W/L) ratio between the other eight shapes and the reference shape was evaluated as shown in figure (4.30). It is observed from the figure that the trend of the curve of the percentage of increasing in the total loads is more similar to the trend of the curve of the percentage of decreasing in the (roof/walls) ratio. It can be concluded that increasing the total loads required by the building geometries with the same (s/v) ratio as a result of increasing the height is more related to the decreasing in the (roof/walls) ratio which increases the vertical walls surfaces.

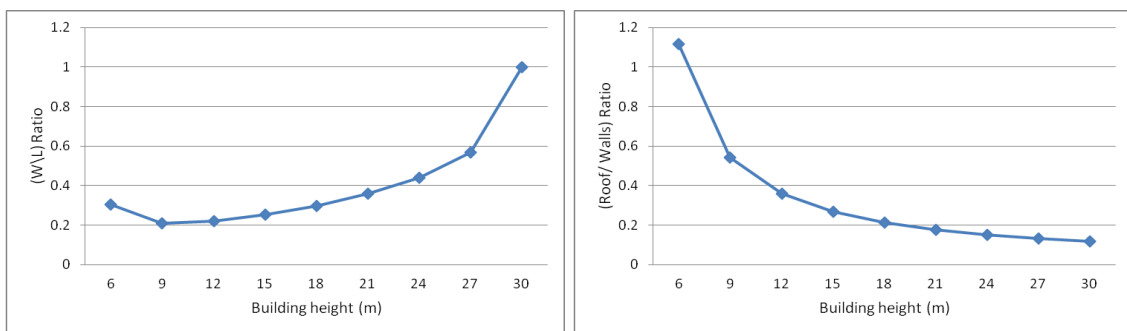


Figure (4.30): a: Width to length ratio (W/L), b: (Roof/ walls) ratio for the simulated cases

It is evident from the figure (4.31) that the percentage of increasing in the total loads is lower than the percentage of decreasing in the (roof/walls) ratio. For example, decreasing the (roof/walls) ratio by about 67.9%, 80.9%, 86.4% and 89.4% can increase the total loads by about 33.1%, 47.7%, 55.5% and 62.5% for the geometries with 12 m, 18 m, 24 m and 30 m respectively.

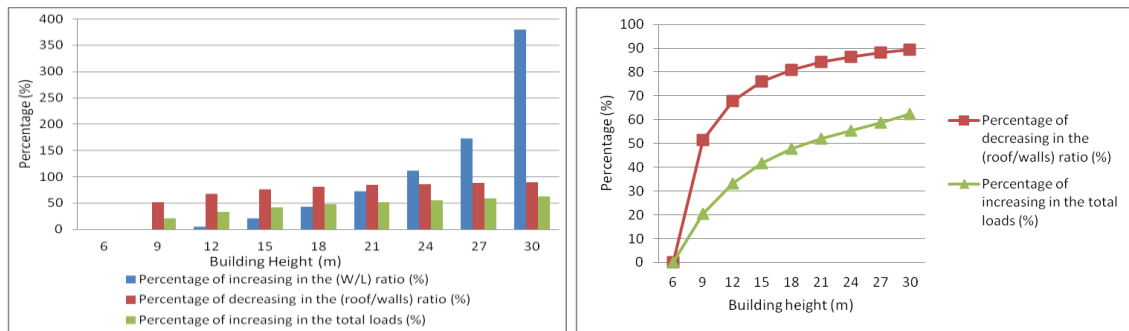
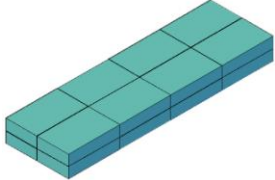
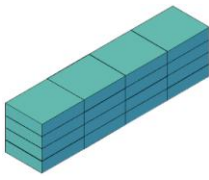
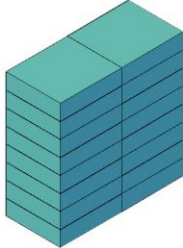


Figure (4.31): The relation between the percentage of increasing in the total loads and decreasing in the (roof/ walls) ratio for the simulated cases

Taking 3 options of buildings height (6m, 12m and 24 m) which involve the same volume and exposed surface as shown in table (4.11). By dividing each geometry to the same number of residential apartments (16 apartments). Each apartment has the same area (125 m²) as it considered one of the common options in the apartment building in the Gaza Strip. As stated above, the geometry of 12m and 24m height increase in the total loads by 33% and 55.5% respectively from the geometry of 6m height. That's means that the horizontal arrangements of residential apartments is better thermally than the vertical arrangements of the same (s/v) ratio.

Table (4.11): comparative between 3 options

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

- Effect of Orientation

Changing the orientation of the simulated shapes with difference height is seen to have the ability to change the required energy as it affects the amounts of solar radiation falling on the various components of the building surface. The results indicate that the total loads for the simulated shapes are increased by 6.8% with changing the orientation from the East-West orientation (0E) to the North-South orientation (90E) for the shape with 12 m height in ECOTECH. This ratio is decreased to reach 5% in the case of the shape with 18 m height and 3.5% in the case of the shape with 24 m height.

As the height of the building increases and thus the shape approaching to the square shape, the effect of orientation in changing the total loads is decreased. This is due to the four equal sides of the square shape which make the East-West orientation (0E) and the North-South orientation (90E) have the same performance. Instead, the worst orientation in this case is (45E) with unnoticeable difference in the total loads which

reach to 1.3%. In IES, changing the orientation from the East-West orientation (0E) to the North-South orientation (90E) for the shape with 12 m, 18 m and 24 m height increases the total loads by about 11.9%, 10.8% and 7.9% respectively. Figure (4.32) illustrate the effect of changing orientation on the total loads for various buildings height.

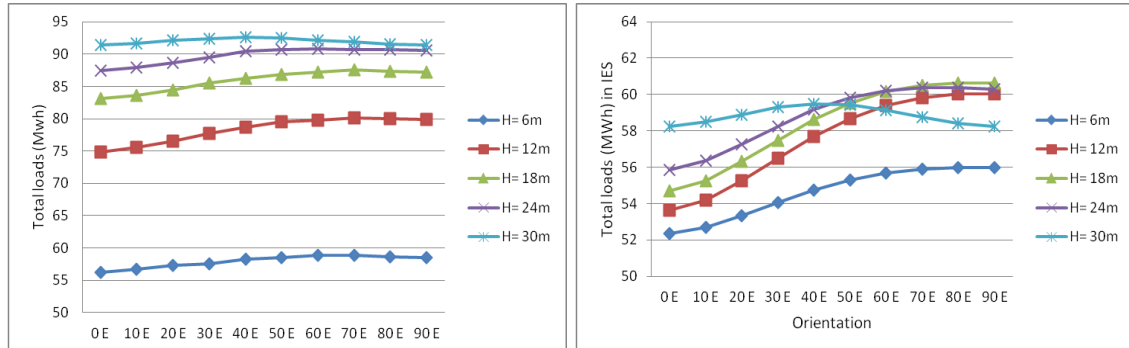


Figure (4.32): a: Total loads (MWh) by ECOTECT, b: Total loads (MWh) by IES

The effect of changing orientation is not remarkable in the heating loads. While changing orientation from (0E) to (90E) increases the total loads, it reduced the heating loads by a very small value reaches to 0.65% as shown in figure (4.33). The most effect of changing orientation can be noticed in the cooling loads. About 17.7% of the cooling loads can be increased with changing orientation from (0E) to (90E) in the shape with 12 m height. This percentage decreases gradually with increasing the height to reach 13%, 9.2 in the case of the shapes with 18 m and 24 m height respectively. An increasing of about 2.5% occurs in the shape with 30 m height (square shape, W/L= 1) with changing orientation from (0E) to (45E). Comparing these results with the results of the study of the effect of (W/L) ratio (section 4.4.1), it is can be concluded that the impact of orientation in affecting the energy consumption, especially the cooling is more associated with the width ratio. Increasing the width to length ratio (W/L) has an impact on decreasing the effect of orientation in changing the energy consumption.

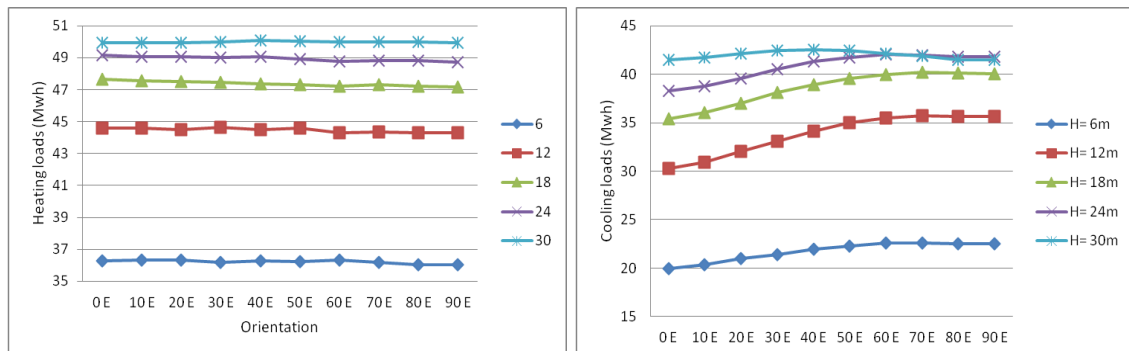


Figure (4.33): a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

To clearly investigate the effect of the building height in affecting the orientation effects, the East-West orientation (0E) was taken as a reference case as it achieve the lowest required energy. The percentage of difference between the other nine orientation for four heights (12 m- 18 m- 24 m- 30 m) and the reference shape was evaluated. As illustrated in figure (4.34), changing the orientation from (0E) to (90E) can increase the required heating and cooling loads by 6.8%, 5% and 3.5% for the cases of 12 m, 18 m and 24 m height respectively.

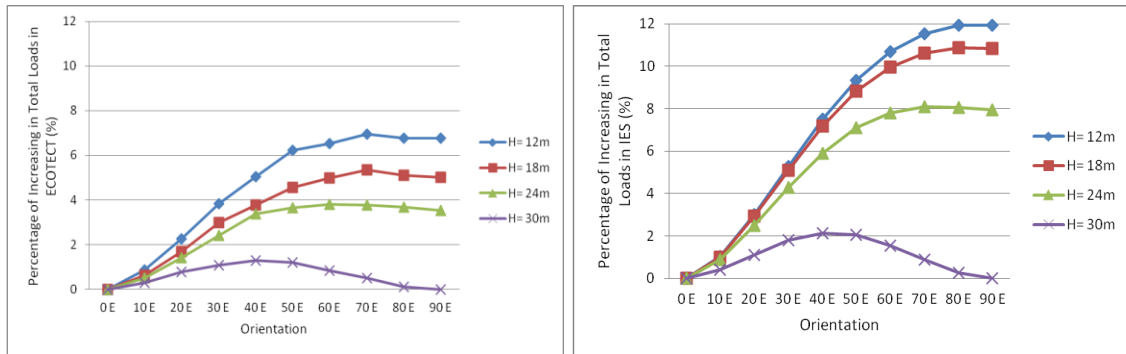


Figure (4.34): a: The percentage of increasing in the total loads by ECOTECT, b: by IES

- Effect of Glazing Ratio

The results indicates that adding a percentage of glazing equal to 10% of the floor area can increase the total loads by about 70.1% in the case of the geometry with 6m height as shown in figure (4.35). Its noticed that increasing the building height can decrease the increasing in the total loads to reach to about 55.6%, 50.3%, 48.5% and 47.1% in the case of the geometry with 12m, 18m, 24m and 30m height respectively. Figure (4.35) summarizes the effect of the glazing ratio in affecting the impact of building height in changing the total loads. It can be noticed that increasing the building height from 6m to 30m can increase the required energy by 62.5% in the case of opaque envelop (0% glazing). This percentage can decreased to reach 40.5% in the case of 10% glazing. That's means that increasing the glazing ratio has the ability to decrease the effect of the building height in increasing the required energy although the simulated cases have the same (s/v) ratio and orientation.

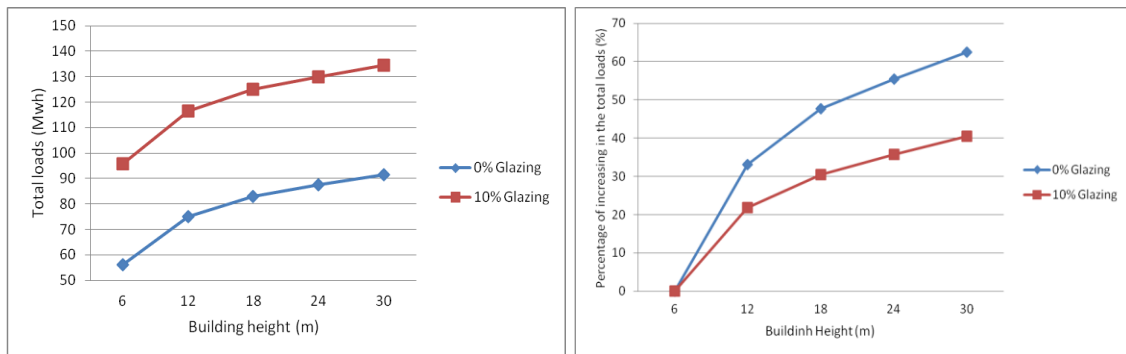


Figure (4.35): a: Total loads for various glazing ratio by ECOTECT, b: The percentage of increasing in the total loads by ECOTECT

- Incident Solar Radiation

The results indicates that the geometry with the lowest height equal to 6m receive the highest amounts of incident solar radiation. As shown in figure (4.36), the total amounts of incident solar radiation reduced with increasing the building height. It decreased by about 34.2% from the shapes with 6m height to the shape with 30 m height with the same exposed surface. As illustrates in figure (4.37), the roof area reduced by 80% with increasing the building height from 6m to 30m. The same percentage of reduction can be observed to the incident solar radiation falling on the roof surface. The same curve of changing the south façade surface and its incident solar radiation can be observed with the same percentage of change reach to about 23.4%.

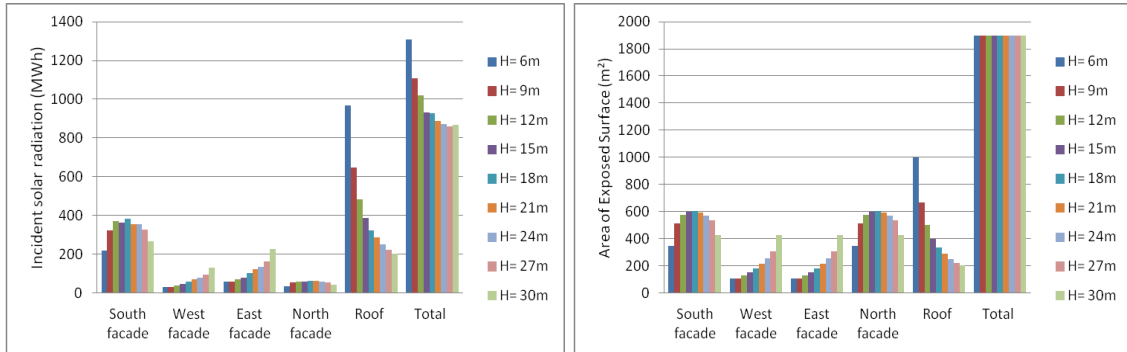


Figure (4.36): a: Incident solar radiation for various building's height, b: area of exposed surfaces

Although all the simulated cases have the same exposed surface, they received different amounts of incident solar radiation according to the difference on the solar radiation falling on different components. Increasing the building height from 6m to 30m can increase the incident solar radiation on the east and west façades by about 304.8% and 305.6% respectively. This increasing is compatible with the percentage of increasing in their exposed surface. Comparing this large percentage of increasing in the area of the east and west façades and the incident solar radiation can explain the increasing in the required energy with increasing the building height.

4.6 Effect of the Self Shading on the Energy Consumption





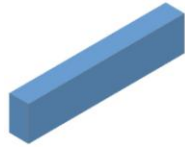



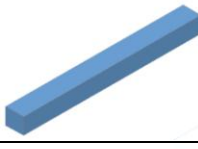
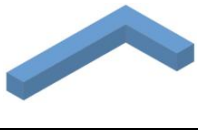
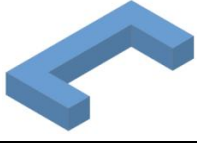

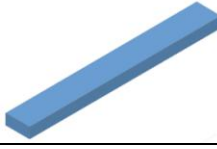
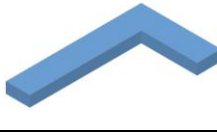
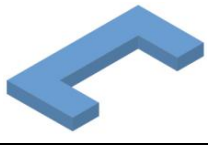

The previous studies showed that the surface to volume ratio is predominant factor affecting the thermal performance of different geometric shapes. Hachem *et al.* (2011) investigated the solar potential of different shapes. The results indicated that the number of shading facades in-self shading geometries and their relative dimensions are the major parameters affecting solar incident and transmitted radiation. The study is based on two design days which are a sunny cold winter day (in January), and a sunny hot summer day (in July). This study aims to investigate the effect of varying geometry with constant (s/v) ratio on the self shading. For this purpose, four generic forms which are rectangular, L shape, U shape and court shape were examined. The study examined 3 depth ratios which are 0.1, 0.5, 1 and 4 roof/ walls ratios which are 0.1, 0.25, 0.5 and 1.

In order to evaluate the volume, it was assumed that the minimum width of the L shape is 1 m. For achieving the minimum depth ratio which is 0.1, this means that the length of the L shape is 10 m. The building depth is assumed to be 4 m as it represents the average of room width. This means that the area (A) for the base case will be 60 m² and the perimeter equals to 38 m. The area of walls surfaces is taken to be 600 m² in order to achieve the minimum (roof/ walls) ratio which is 0.1. This means that the total exposed surface is 660 m². The building height can be evaluated from the walls surfaces equation which equals to the multiple of the perimeter and the height (walls area= perimeter* height). This means that the building height is 15.7 m (nearly 5 storey). Hence, the base case volume is equal to 942 m³ and the (s/v) ratio is 0.7. Table (4.12) illustrates the simulated cases in this study.

The external surfaces of the examined forms (walls and roof) are assumed opaque, i.e. no openings were taken into consideration to avoid the influence of windows and glazed surfaces on the building's thermal performance. This means that the exposed surface will receive solar radiation strike on it without any reflection. Also, no casual heat gain or ventilation was considered and all the other thermal factors involved were

kept unchanged. So, the heat gain is expected to result only from the incident solar radiation (solar heat gain). The long axes of the simulated cases are assumed to have the east-west orientation.

Table (4.12): Parameter combinations investigated in the study

	Rectangular	L Shape	U Shape	Court Shape
Roof\ walls= 0.1				
Roof\ walls= 0.25				
Roof\ walls= 0.5				
Roof\ walls= 1				

4.6.1 Parametric Investigation

The study investigates the effects of a number of parameters in the two major response variables the energy requirements and the incident solar radiation. Combinations of parameter values analyzed in this study are summarized in table (4.13) and (4.14).

Table (4.13): Parameter combinations investigated in the study

Shape	Depth ratio	(Roof/Walls) Ratio	(S/V) Ratio
Rectangular	Basic design	0.1-0.25-0.5-1	0.7-0.8-0.9
L Shape	0.1-0.5-1	0.1-0.25-0.5-1	0.7-0.8-0.9
U Shape	0.1-0.5-1	0.1-0.25-0.5-1	0.7-0.8-0.9
Court Shape	0.1-0.5-1	0.1-0.25-0.5-1	0.7-0.8-0.9

a. Depth Ratio

The depth of the shadow-receiving façade and the number of shadow projecting façades play an important role in determining the amount of solar radiation incident on the shaded façade (Hachem *et al.* 2011). Three values of the depth ratio are adopted for L, U and Court shapes. These depth ratios are 0.1- 0.5 and 1. In the design of units with varying depth ratios, the floor area is kept constant.

b. (Roof/Walls) Ratio













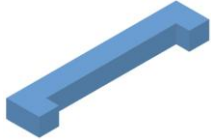


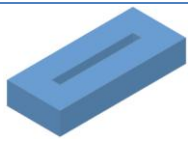





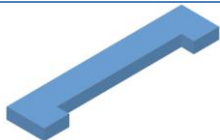





Four values of (Roof/Walls) Ratio are adopted for rectangular, L, U and Court shapes. These values are 0.1, 0.25, 0.5 and 1. The important of this ratio is to investigate

the effect of building height and the relation between the roof area and the walls area. In the design of units with varying (Roof/Walls) ratios, the depth ratio and the (s/v) ratio are kept constant while the floor area and height varies for each case.

c. Surface to Volume Ratio (S/V)

Three values of the (s/v) ratio are adopted for rectangular, L, U and Court shapes. These values are 0.7, 0.8 and 0.9.

Table (4.14): Parameter combinations investigated in the study

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

4.6.2 Simulation Results

The simulation results were expressed in terms of annual heating, cooling and total loads (in MWh) and the incident solar radiation (in MWh).

a. Effect of Depth Ratio

The results indicate a slight effect of the depth ratio on the total loads. The most important point is that the effect of the depth ratio in affecting the total loads varies according to the various geometric shape and (roof/ walls) ratio. Apparently, it can be observed as shown in figure (4.37) that with decreasing the (roof/ walls) ratio the difference can be remarkable. For example, increasing the depth ratio from 0.1 to 0.5 for the U Shape with a (roof/ walls) ratio equal to 0.1 reduced the required loads by about 8%. This ratio decreased to reach 0.8 in the case of (roof/ walls) ratio equal to 1 for the same geometric shape. This means that with increasing the building height which decrease the (roof/walls) ratio, the depth ratio becomes more important. This can be explained as which decreasing the (roof/ walls) ratio, the percentage of vertical walls from the exposed surface increased and thus the percentage of self shaded facades in the convex shapes increased. As a consequence, increasing the depth ratio has the ability to increase the percentage of the shaded facades which help to reduce the required energy. This explains why the increase in the depth ratio affects the cooling loads in a greater manner than its effect on the heating loads.

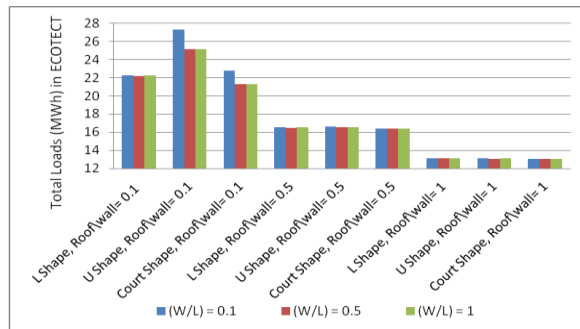


Figure (4.37): Total loads (MWh) for various geometric shapes

Figure (4.38) illustrates the effect of the depth ratio on the heating and cooling loads for three geometric shapes (L, U and Court Shapes) and with three (roof/walls) ratio (0.1, 0.5 and 1). Increasing the depth ratio from 0.1 to 0.5 for the U Shape with a (roof/ walls) ratio equal to 0.1 reduced the cooling loads by about 16.6%. as the (roof/walls) ratio increases, the difference can't be noticed. On the other hand, the heating loads increased slightly by about 1.5% with increasing the depth ratio from 0.1 to 0.5 for the U Shape with a (roof/ walls) ratio equal to 0.1.

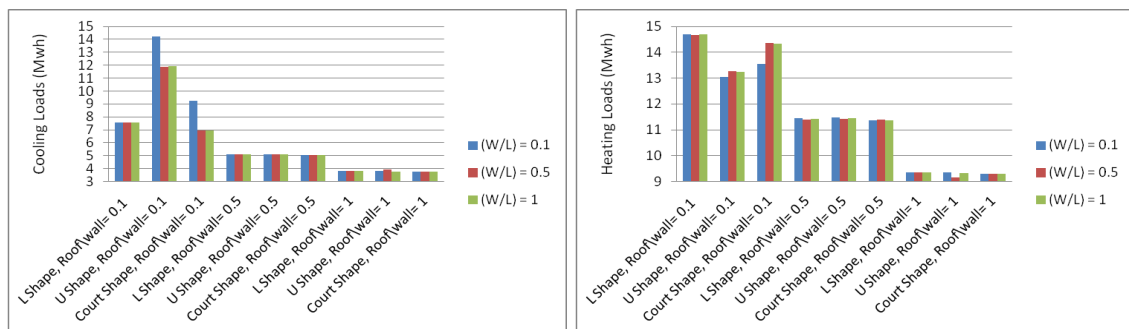


Figure (4.38): a: Heating loads (MWh), b: Cooling loads(MWh)

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

b. Effect of (Roof/Walls) Ratio

It is evident that increasing the (roof/walls) ratio has a great effect in reduction the required energy in any geometric shape and with any (s/v) ratio and depth ratio as shown in figure (4.39). The effort here is to investigate the role of these factors in affecting the impact of the (roof/walls) ratio. Increasing the (roof/walls) ratio from 0.1 to 1 reduced the total loads by 45.7%, 40.9%, 48.1%, 38.6% for the rectangular, L shape, U shape and court shape respectively. Increasing the (roof/walls) ratio from 0.1 to 1 reduced the cooling loads by 57%, 49.9%, 67.1%, 45.7% for the rectangular, L shape, U shape and court shape respectively. While increasing it from 0.1 to 1 reduced the heating loads by 35.4%, 36.2%, 23%, 35.2% for the rectangular, L shape, U shape and court shape respectively.

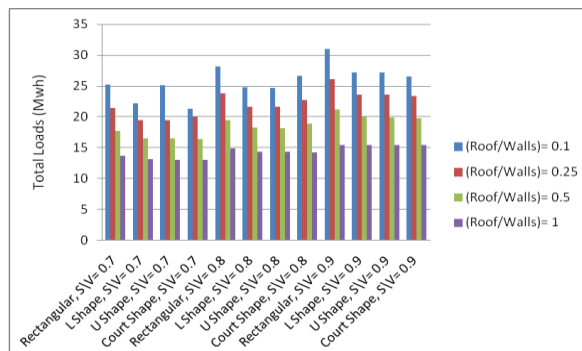


Figure (4.39): Total loads (MWh) for various geometric shapes, (s/v) ratio and (roof/walls) ratio

c. Effect of Geometric Shape

The results indicate a large effect of the geometric shapes on the total loads with a small (roof/walls) ratio. It is evident that the U shape has the worst thermal performance in with all the simulated depth ratio (W/L) and (roof/walls) ratio as it require the largest amount of energy. As shown in figure (4.40), the difference in total loads is more noticeable as the (roof/walls) ratio decreased. The total loads reduced by 15.4% with changing the geometric shape from the U shape to the court shape with the same (roof/walls) ratio equal to 0.1 and the same depth ratio equal to 0.5. This percentage of reduction decreased to reach only 0.7% with a (roof/walls) ratio equal to 0.5. The court shape seems to have the lowest energy requirements with a small difference between it and the L shape. The reduction in the total loads reaches to 4.3% between the court and the L shape and about 11.6 between the L shape and the U shape with a (roof/walls) ratio equal to 0.1 and a depth ratio equal to 0.5.

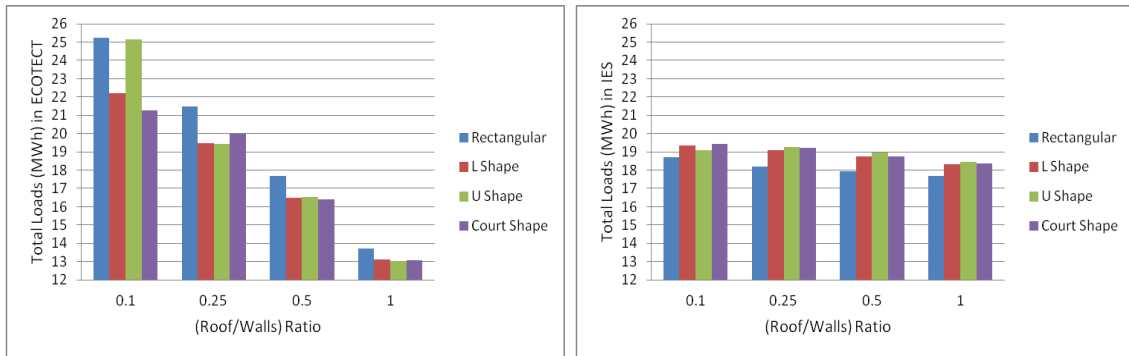


Figure (4.40): a: Total loads (MWh) by ECOTECT, b: Total loads (MWh) by IES

In order to explain this thermal behavior, the heating and cooling loads have to be studied. It is evident from figure (4.41) that the U shape is more preferable in winter as it achieves the lowest heating loads. However, it is the worst shape in summer as there are a large difference between it and the other two shapes in the cooling loads. There are a reduction in the cooling loads by about 41.7% between the U shape and the court shape with (roof/walls) ratio equal to 0.1 and a depth ratio equal to 0.5. this reduction reaches to about 36.4 between the U shape and the L shape and about 8.3% between the L shape and the court shape. This means that for achieving a better cooling situations, the court shape followed by the L shape and the U shape is preferable. On the other hand, the U shape achieves the lowest heating requirements by a difference reaches to 8.2% and 10.5% between it and the court shape and the L shape respectively. This means that for achieving a better heating situations, the U shape followed by the court shape and the L shape is preferable.

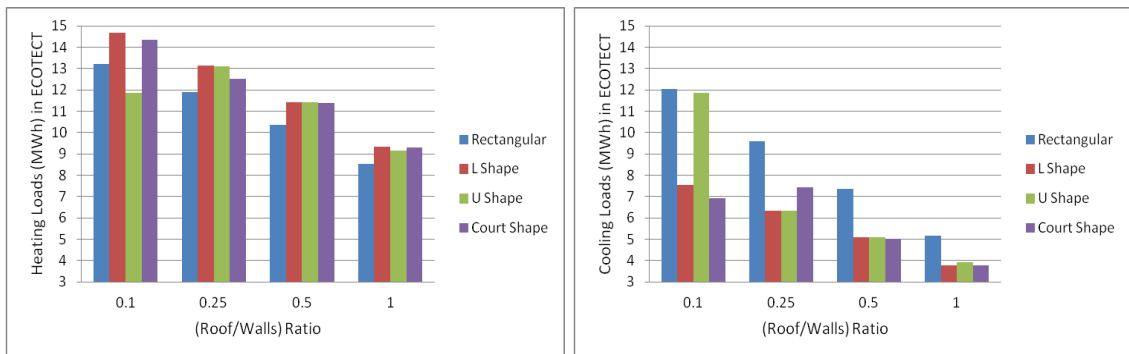


Figure (4.41): a: Heating loads (MWh) by ECOTECT, b: Cooling loads (MWh) by ECOTECT

d. Incident Solar Radiation

The incident solar radiation was evaluated for the four shapes (rectangular, L, U and court) with (S/V) ratio equals 0.7 and (Roof/walls) ratio equals 0.1 and depth ratio equals 0.5. The results indicate that the rectangular shape receives the highest amount of the solar radiation on the south façades, followed by the U, L and court shape as shown in figure (4.42). Both the rectangular and the U shape receive an amount of fabric heat gain during summer more than the L and court shape by about 74%. However, they losses an amount of heat through the fabric during winter less than the L and court shape by about 55% as shown in figure (4.42). This is compatible with the heating and cooling response of these shapes as illustrated previously in figure (4.41).

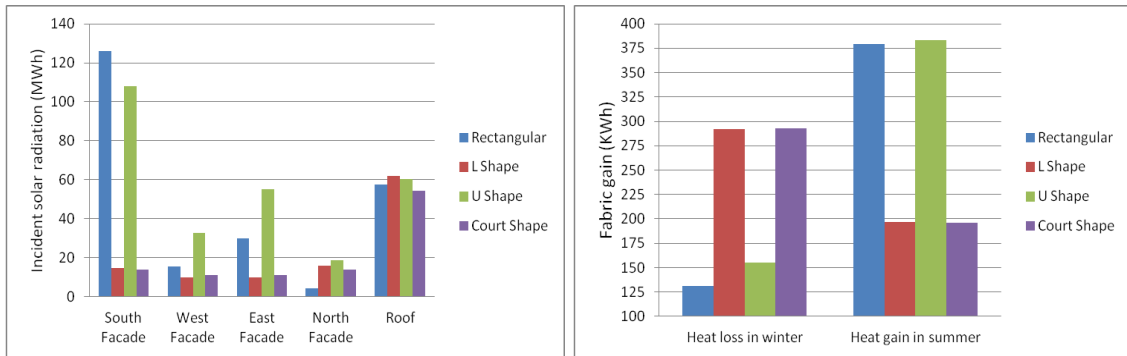


Figure (4.42): a: Incident solar radiation for various geometric shapes, b: fabric gain

4.7 Conclusion

This chapter dealt with the effect of building proportions and ratios which determines the relations between the building components. Many ratios have been studied such as surface to volume ratio, width ratio, roof to walls ratio and depth ratio for the convex shapes. It is concluded that the surface to volume ratio is the more important aspect affecting the thermal performance of geometric shapes. However, having the same surface to volume ratio to the same shape with various proportions creates a variety in the thermal response and energy consumption. The geometric shape of a building is integrated with other design parameters such as orientation and glazing to determine the thermal response of the building. Variation in the form ratios and proportion can affect the impact of these parameters in the term of energy consumption. The self shading of different geometric shapes with the same surface to volume ratio have a great impact in affecting the heating and cooling energy requirements. The self shading is more valuable in a forms with a small roof to walls ratio as its impact appears significantly in a large area of vertical walls. The incident solar radiation falling on the building is the more responsible factor on its thermal response.

Chapter 5: Investigation of the Thermal Performance of Buildings in the Urban Fabric

5.1 Introduction

The previous chapter dealt with building geometry, proportions and ratios and their relations to each other as individual buildings. Actually, buildings clustered with each others in an urban configurations consisting with the spaces between them the urban morphology. Building and its plot are an entity in the urban context and cannot be treated in isolation (Goulding *et al.* 1992). Hence, the buildings proportions have a great relations with the urban canopy which affects the solar potential and thus the thermal response for the outdoor and indoor environment of the residential blocks. The geometry of the adjacent buildings plays an important role in the microclimatic conditions in the urban canopy (Shashua-Bar *et al.* 2004). Building height and its relation to the street width which is known as the aspect ratio (H/W) is one of the most factors affecting the urban form and its thermal response. Buildings height and the number of stories affects the plot ratio which indicated to have a large influence on the solar potential on roofs. Also, the solar potential on building façade is more dependent to site coverage (Cheng *et al.* 2006).

Also, the way in which the buildings height arranges in the urban fabric, either uniformly or randomly can affect the solar potential and the adjacent shading between buildings. In the same context the horizontal layout of the built form either regular or mutual has an interaction with the solar radiation. There have been some studies to investigate the relation between the urban geometry and the energy performance of the individual buildings. Ratti *et al.* (2005) document an effect of almost 10% in the relationship between urban morphology and the annual per-meter energy consumption of non-domestic buildings. In order to provide a full understanding to the previous integrated parameters, this chapter was divided into 3 sections. The first section introduced a study of the urban geometry and spacing in order to examine the relation between the building geometry and the urban canopy and the thermal performance. It dealt basically with four parameters which are the spacing ratio, the aspect ratio, the width ratio and the street orientation.

The second section studied the urban density in two ways, the plot ratio and the site coverage. The study focused on the building height as it considered the main determinant of the urban density. It also examined the vertical layout of the building configuration and its effect on the thermal response. The study taken into consideration three scales in the urban fabric which are the urban block as a whole, the individual building and the apartments in different floors and within various orientation. The third section will be dedicated to study the effect of the horizontal layout of the built form. It takes into consideration five parameters which are the width ratio, the building's orientation within the plot, the building location within the block, the street orientation and the urban configuration, either regular or mutual.

5.2 The Effect of the Urban Geometry and Spacing on the Solar Potential and Energy Consumption

Urban geometry is considered one of the most factors affecting the outdoor microclimate. Many parameters were used to describe the urban geometry. This study focused on the effect of the urban geometry on the indoor thermal performance of

building. Hence, the spacing ratio, the aspect ratio and the street orientation were taken as the most important parameters linking the building's dimensions with the urban geometry. The spacing ratio (L_1 / L_2) can be described as the ratio between the distance between adjacent buildings L_1 and the frontal length of building L_2 . The aspect ratio (H/W) is relating the building height H to the width of the street W . The simulated cases are chosen to represent the common options in the housing complexes in the Gaza Strip. The floor area (A) is taken to be 500 m^2 and the building height is taken to be 20 m (nearly 6 storey) and thus the volume is taken to be 10000m^3 . The study examines 210 urban block with each block consists of 6 buildings and only the central building was considered as shown in figure (5.1).

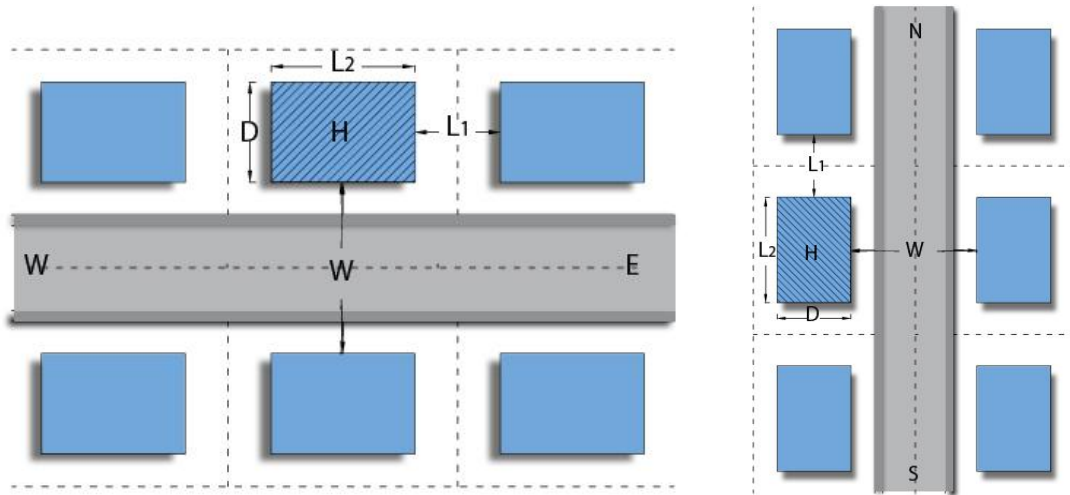


Figure (5.1): The generic form of the urban block

5.2.1 Parametric Investigation

The study investigates the effects of a number of urban forms on the heating, cooling, total loads and the incident solar radiation. Tables (5.1), (5.2) and (5.3) display the Parameter combinations investigated in the study.

a. Spacing Ratio (L_1 / L_2): Seven values of spacing ratio were considered, namely 0.1, 0.2, 0.4, 0.6, 0.8, 1 and 1.2.

b. Aspect Ratio (H / W): Five values of aspect ratio were considered, namely 0.25, 0.5, 1, 2, and 4. Taking into consideration the fixed height of the simulated cases (20 m), these values of (H / W) represents five values of street's width, namely 80, 40, 20, 10, and 5 m.

c. Width to Length Ratio: Three values of width to length ratio (W/L) were considered, namely 0.4, 0.7 and 1.

d. Street Orientation: Two values of street orientation were considered which are the east west and north- south orientation.

Table (5.1): Parameter combinations investigated in the study

Shape	Spacing Ratio (L_1/L_2)	Aspect Ratio (H/W)	Width to Length Ratio	Street Orientation
Rectangular	0.1- 0.2- 0.4- 0.6- 0.8- 1- 1.2	0.25- 0.5- 1- 2- 4	0.4- 0.7- 1	E-W and N-S

Table (5.2): Parameter combinations investigated in the study

	(L1 / L2)= 0.1	(L1 / L2)= 0.4	(L1 / L2)= 0.8	(L1 / L2)= 1.2
(H/W)= 0.25				
(H/W)= 0.5				
(H/W)= 1				
(H/W)= 2				
(H/W)= 4				

Table (5.3): Parameter combinations investigated in the study

Aspect Ratio	Elevation
0.25	
0.5	
1	
2	
4	

5.2.2 Simulation Results

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

a. Effect of Spacing Ratio (L_1/L_2)

The results indicate that the cooling loads for the simulated shapes are increased by about 20.7% with increasing the spacing ratio (L_1/L_2) from 0.1 to 1.2 for the square shape with width to length ratio equals to 1 and aspect ratio equals to 0.25 at the East-West orientation (E-W) in ECOTECT (which means increasing the distance between buildings from 2.2 m to 26.8 m in this case). Increasing the aspect ratio (H/W) has a slight impact in affecting the percentage of increasing of the cooling loads. Increasing the spacing ratio from 0.1 to 1.2 increased the cooling loads by about 20.7% and 21.7% in the case of aspect ratio equals to 0.25 and 4 respectively. The same trend can be observed in IES. Increasing the spacing ratio from 0.1 to 1.2 increased the cooling loads by about 14.9% and 15.7% in the case of aspect ratio equals to 0.25 and 4 respectively. Figure (5.2) shows the effect of increasing the spacing ratio on the cooling loads throughout the summer period.

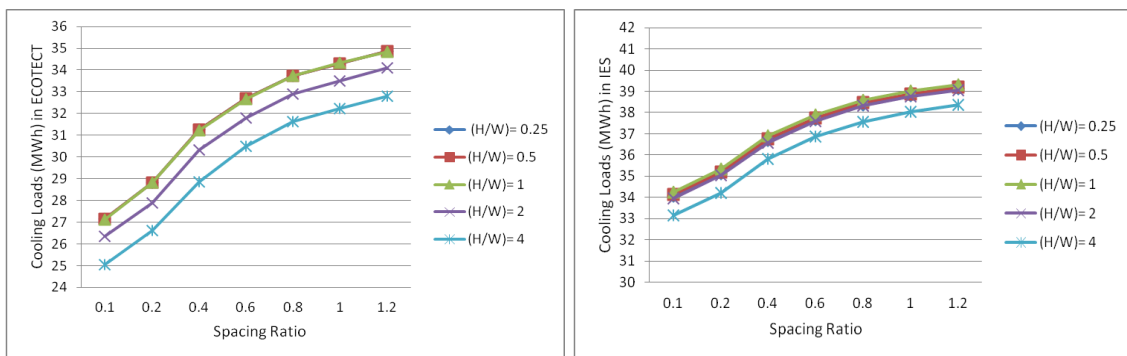


Figure (5.2): a: Cooling loads in the (E-W) street by ECOTECT, b: by IES

This percentage of increasing is decreased to reach 7.2% and 9% with changing the street orientation from the (E-W) to the (N-S) in ECOTECT. It also decreased to reach 3.8% and 4.8% with changing the street orientation from the (E-W) to the (N-S) in IES as shown in figure (5.3). Increasing the spacing ratio decreased the potential of adjacent shading and increased the solar radiation on building's façades. This explains the bad effect of increasing the spacing ratio in the summer periods.

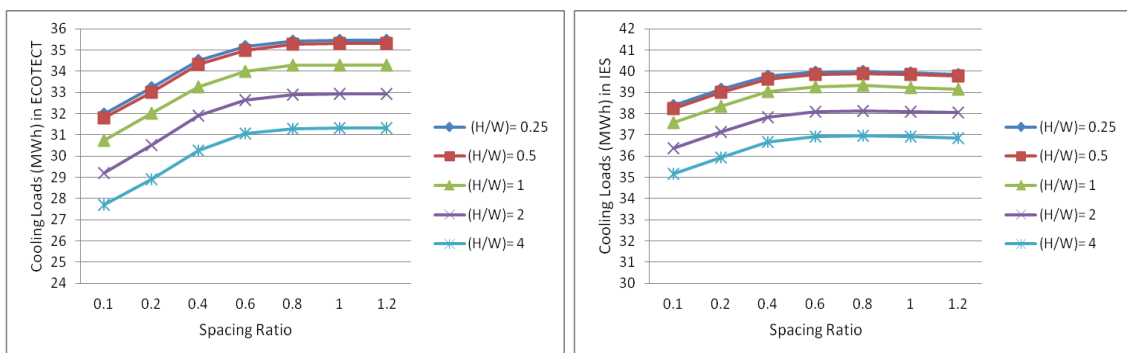


Figure (5.3): a: Cooling loads in the (N-S) street by ECOTECT, b: by IES

Increasing the spacing ratio in the case of the East- West street increases the solar radiation on the east and west façades. However, in the case of the North- South street the spacing ratio affects the north and south façades. Taking into consideration the low latitude position of the sun in the morning and evening of the summer periods which increases the solar potential on the east and west façades comparing with the south one, this explains the large increasing in the cooling loads with increasing the spacing ratio in the case of the East- West street comparing with the North- South one. It is noticed

that the percentage of increasing in the cooling loads is decreased by decreasing the width ratio. As shown in figure (5.4), the percentage of increasing in the cooling loads is decreased from 20.8% to 16.3% and 10.5% with decreasing the width to length ratio (D/L_2) from 1 to 0.7 and 0.4 respectively. With increasing the width ratio, the surface area of the east and west façades increased. This explains the increasing in the cooling loads with increasing the width ratio. So it is recommended to pay more attention to the spacing ratio as the building be closer to the square shape and on the East- West street orientation.

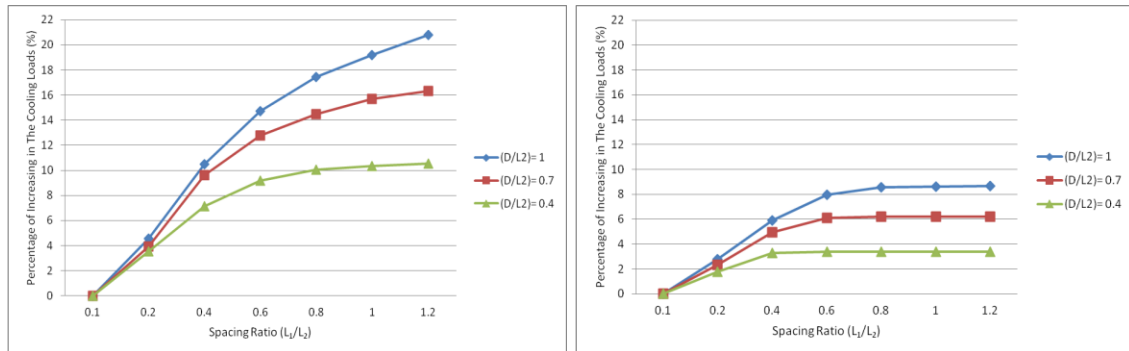


Figure (5.4): a: The percentage of increasing in the cooling loads by ECOTECT in the (E-W) street, b: in the (N-S) street

However the spacing ratio has a large effect on the cooling loads, it has a slight effect on the heating loads. As shown in figure (5.5), increasing the spacing ratio (L_1/L_2) from 0.1 to 1.2 for the square shape at the East- West orientation (E-W) in ECOTECT reduced the heating loads by about 3.6% in the case of aspect ratio equals to 4. This percentage decreased to reach 2.7% in the case of aspect ratio equals to 0.25. The same trend can be shown in IES with the percentage of decreasing reaches to about 2.2% and 3.5% in the case of aspect ratio equals to 0.25 and 4 respectively as shown in figure (5.5). Increasing the spacing ratio increases the solar potential on building's façades which decreases the heating loads.

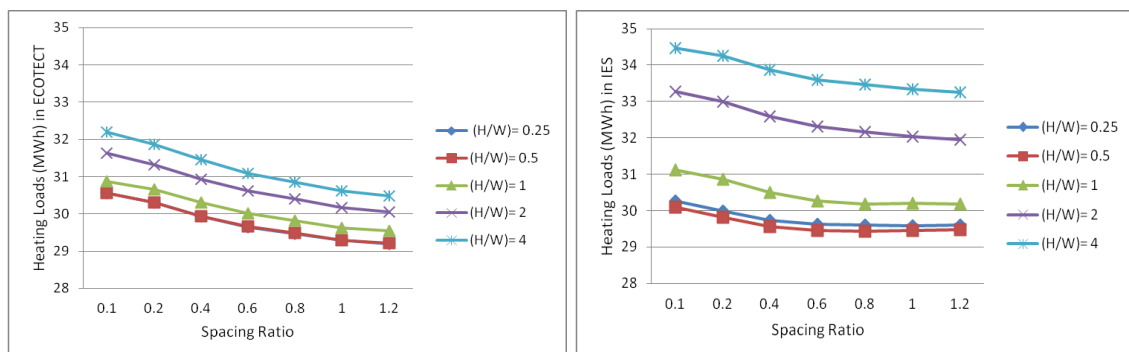


Figure (5.5): a: Heating loads in the (E-W) street by ECOTECT, b: by IES

It is noticed that changing the street orientation from the (E-W) to the (N-S) have a slight impact in affecting the percentage of decreasing in the heating loads. Increasing the spacing ratio (L_1/L_2) from 0.1 to 1.2 for the square shape at the North- South orientation (N-S) reduced the heating loads by about 3.4% and 2.4% in the case of aspect ratio equals to 4 and 0.25 respectively. The IES shows a large percentage of reduction reaches to about 9.7% and 10.8% in the case of aspect ratio equals to 4 and 0.25 respectively as shown in figure (5.6). Increasing the spacing ratio increases the solar potential on the south façades which reduces the heating loads.

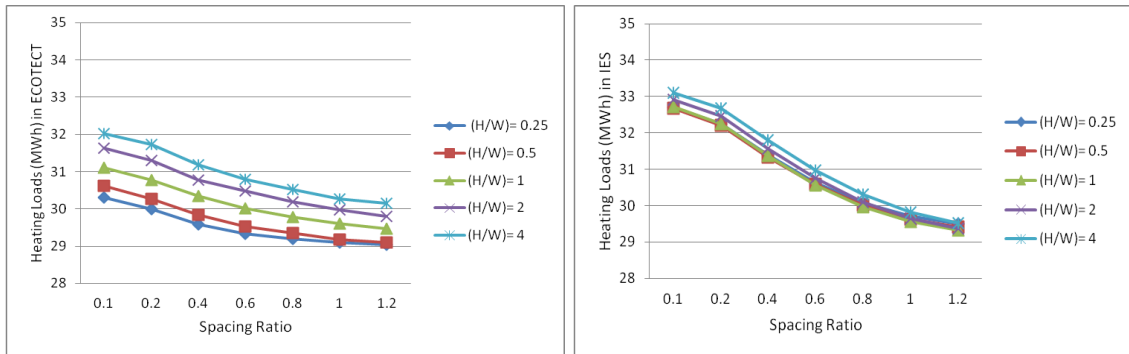


Figure (5.6): a: Heating loads in the (N-S) street by ECOTECT, b: by IES

The total loads takes the same trend of the cooling loads. Increasing the spacing ratio (L_1/L_2) from 0.1 to 1.2 for the square shape at the East- West orientation (E-W) in ECOTECT increased the total loads by about 11% and 10.5% in the case of aspect ratio equals to 0.25 and 4 respectively. A similar percentage of increasing can be observed on IES which reach to about 6.8% and 5.9% in the case of aspect ratio equals to 0.25 and 4 respectively as shown in figure (5.7). So it is recommended to use a smaller spacing ratio in the East- West streets in order to reduce the energy consumption. A spacing ratio equals to 0.1 is considered the optimum case for the cooling and total requirements.

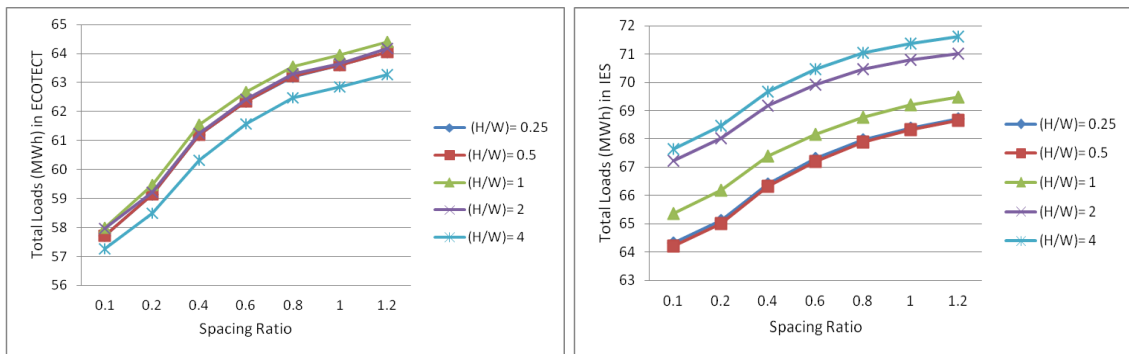


Figure (5.7): a: Total loads in the (E-W) street by ECOTECT, b: by IES

It can be noticed that changing the street orientation from the (E-W) to the (N-S) in ECOTECT decreased the percentage of increasing in the total loads to reach 3.5% and 2.9% in the case of aspect ratio equals to 0.25 and 4 respectively. However, increasing the spacing ratio in IES reduces the total loads by about 2.4% and 2.7% in the case of aspect ratio equals to 0.25 and 4 respectively as shown in figure (5.8). There is a flexibility to use any spacing ratio in the North- South streets as the difference in the energy consumption doesn't exceed 4%. However, taking the heating requirements into consideration, it is recommended to use a large spacing ratio in the North- South streets in order to increase the solar radiation on the south façades which reduces the heating loads and slightly increases the cooling loads. This is due to the high angle of the sun in the midday when it is opposite the south façades.

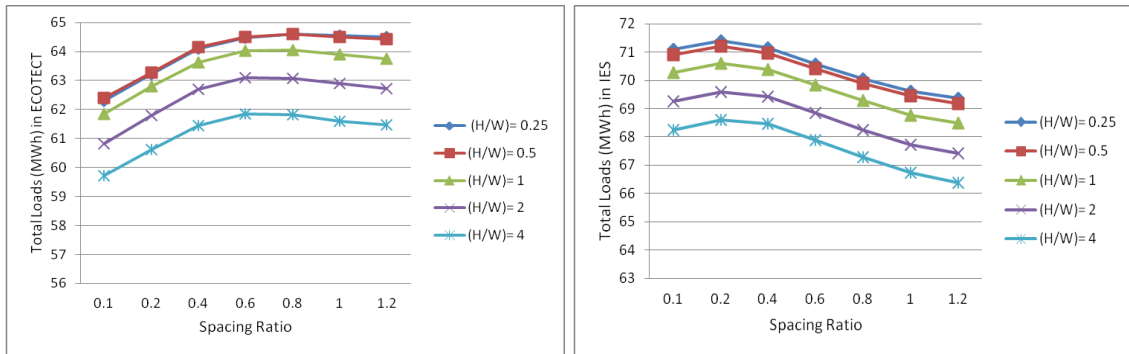


Figure (5.8): a: Total loads in the (N-S) street by ECOTECT, b: by IES

b. Effect of Aspect Ratio (H/W)

The results indicate that the cooling loads for the simulated shapes are decreased by about 4.8% with increasing the aspect ratio (H/W) from 0.25 to 4 for the square shape with width ratio equals to 1 and spacing ratio equals to 0.1 at the East- West orientation (E-W) in ECOTECT (which means reducing the street's width from 80 m to 5 m). The percentage of reduction reaches to about 2.7% for the same case in IES as shown in figure (5.9). Increasing the aspect ratio increases the shading potential and thus decreasing the solar radiation which reduces the cooling requirements. It is noticed that the values of aspect ratio smaller than 1 have the same cooling loads.

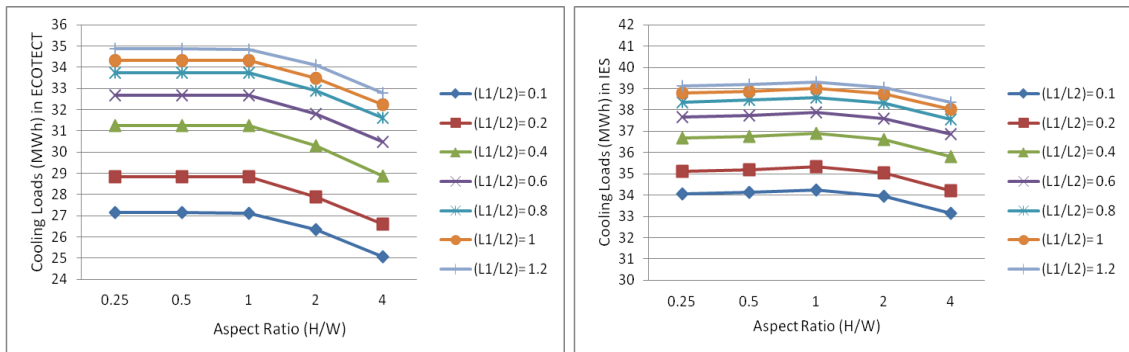


Figure (5.9): a: Cooling loads in the (E-W) street by ECOTECT, b: by IES

The percentage of reduction increased to reach 11.6% in the case of the North-South street in ECOTECT and 8.4% in IES as shown in figure (5.10). This can be explained as the increasing of aspect ratio in the simulated models reduced the solar radiation on the south façade in the case of the East- West street orientation, it reduced the solar radiation on the east façade in the case of the North- South street orientation. As mentioned previously, the east façade is more critical in determining the cooling loads in the summer periods than the south one due to the low angle of the sun in the morning comparing with the high angle of it in the midday which increases the solar radiation on the east façades comparing with the south one.

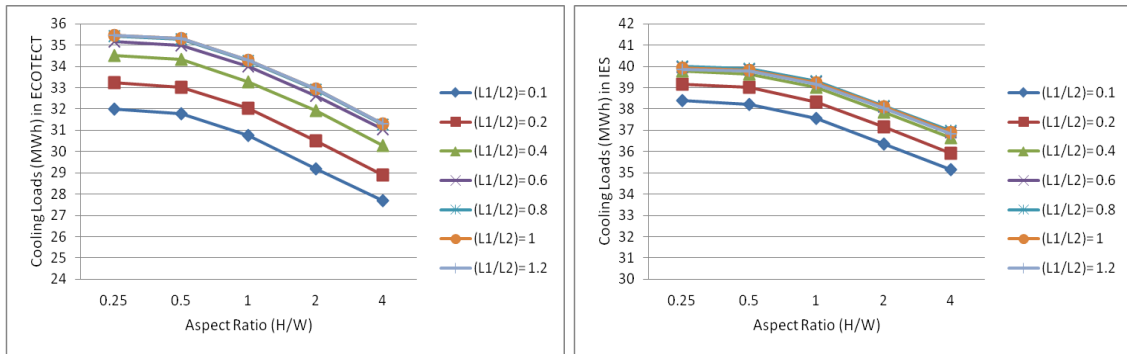


Figure (5.10): a: Cooling loads in the (N-S) street by ECOTECT, b: by IES

As a result, increasing the surface of the facade overlooking the street and increasing its percentage to the total exposed surface can increase the role of the aspect ratio in affecting the cooling loads. This means that increasing the building elongation by decreasing the width to length ratio (D/L_2) increases the impact of the aspect ratio. As shown in figure (5.11), decreasing the aspect ratio from 4 to 0.25 in the case of the East-West street orientation and with spacing ratio equals to 0.1 increases the cooling loads by about 5%, 5.3% and 8.6% in the case of building geometry with width ratio equals to 1, 0.7 and 0.4 respectively. Changing the street orientation 90° to the North-South increases this percentages to reach 13.1%, 14.4% and 18.2% in the case of building geometry with width ratio equals to 1, 0.7 and 0.4 respectively.

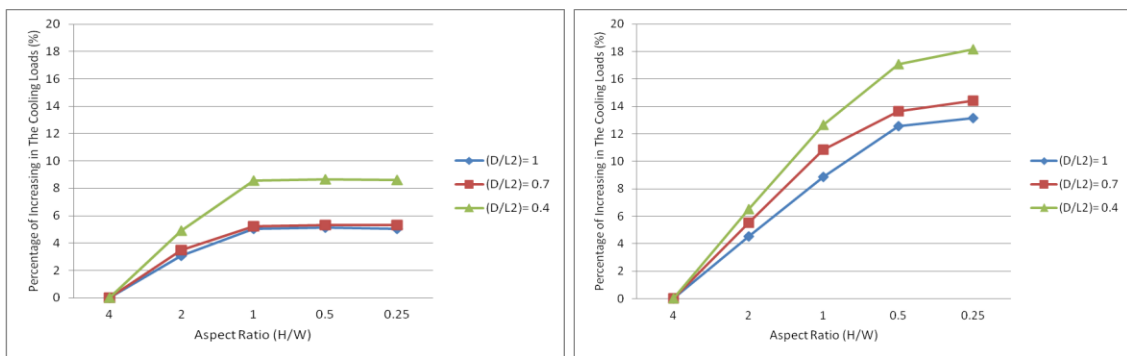


Figure (5.11): a: The percentage of increasing in the cooling loads by ECOTECT in the (E-W) street, b: by the (N-S) street

Increasing the aspect ratio from 0.25 to 4 for the square shape at the East-West orientation (E-W) in ECOTECT increases the heating loads by about 3.6% and 2.6% for the case of spacing ratio equals to 0.1 and 1.2 respectively. The percentage of reduction reaches to about 13.9% and 12.4% in IES for the case of spacing ratio equals to 0.1 and 1.2 respectively as shown in figure (5.12). So a larger aspect ratio is advisable for reducing the heating loads in the East-West due to the increasing in the solar potential on the south façades.

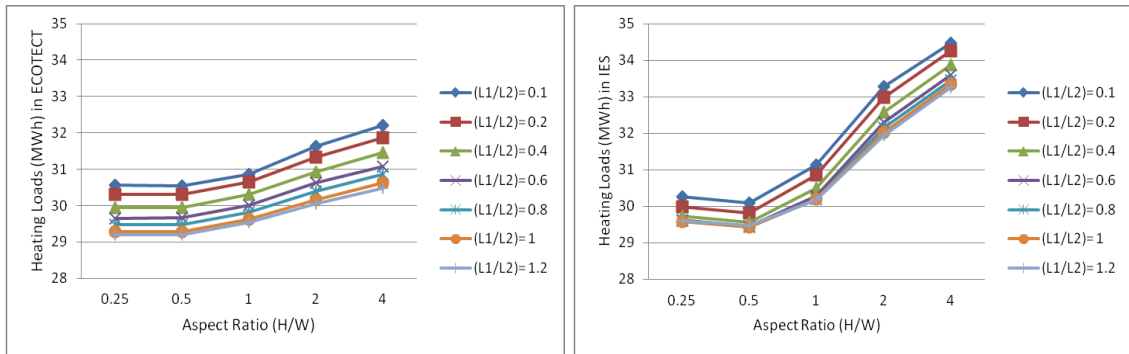


Figure (5.12): a: Heating loads in the (E-W) street by ECOTECT, b: by IES

Changing the street orientation to the (N-S) decreases the percentages of increasing to reach 2.5% and 1.4% respectively as shown in figure (5.13). Decreasing the width ratio has an effect in increasing this percentages to reach 4.7% and 3% in the case of width ratio equals to 0.4. So it is concluded that increasing the aspect ratio slightly decreased the cooling loads and greatly increases the heating loads in the East- West streets. In contrast, it largely decreases the cooling loads and slightly increases the heating loads in the North- South streets.

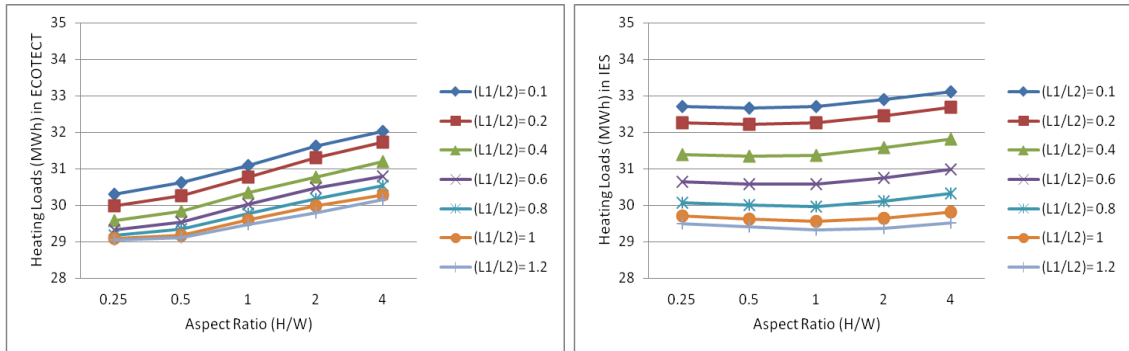


Figure (5.13): a: Heating loads in the (N-S) street by ECOTECT, b: by IES

From the total loads point of view, Increasing the aspect ratio at the East- West street orientation has less than 1% of reduction in the total loads in ECOTECT, however it increases the total loads by about 5.1% in IES as shown in figure (5.14).

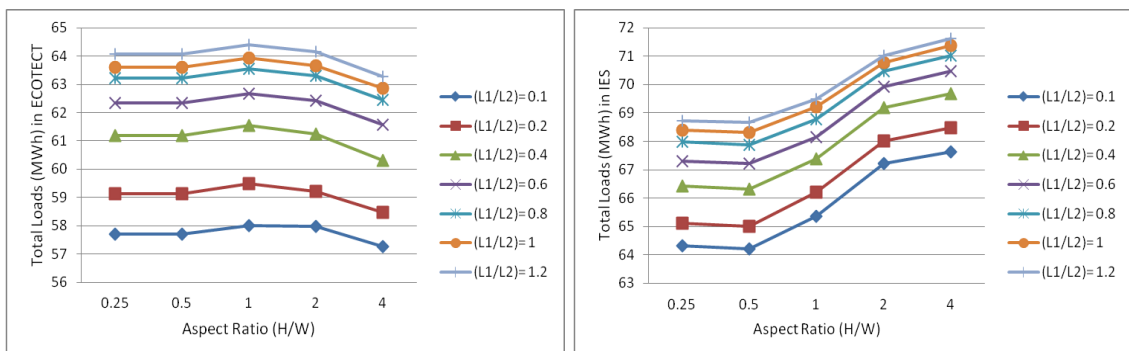


Figure (5.14): a: Total loads in the (E-W) street by ECOTECT, b: by IES

Showing figure (5.15), it is evident that the effect of aspect ratio in affecting the total loads differs according to the street orientation. Increasing the aspect ratio at the North- South street orientation decreases the total loads by about 4.2% and 4% in ECOTECT and IES respectively.

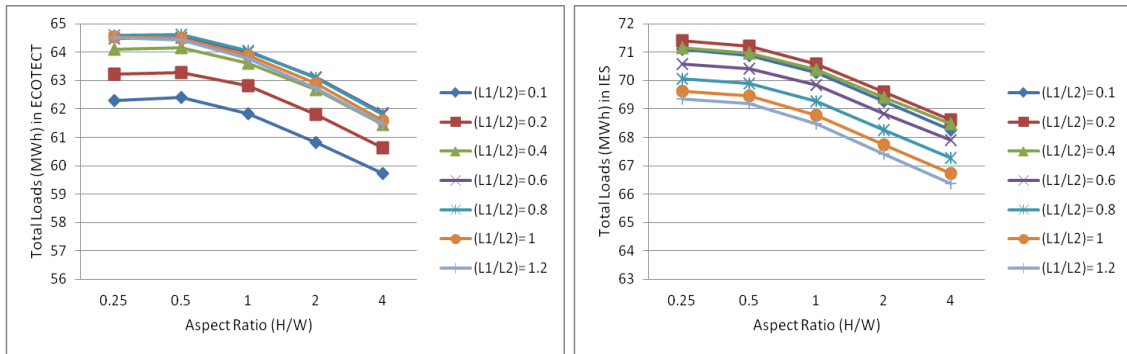


Figure (5.15): a: Total loads in the (N-S) street by ECOTECT, b: by IES

Figure (5.16) presents the more preferable option in the (E-W) street in order to be applied in the Gaza Strip. The model has a spacing ratio(L1/L2) equals 0.1 and aspect ratio (H/W) equals 0.5. The more preferable option in the (N-S) street has a spacing ratio (L1/L2) equals 1.2, and aspect ratio (H/W) equals 4.

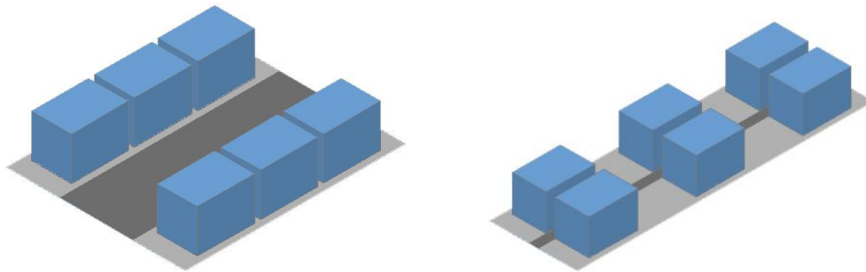


Figure (5.16): a: The more preferable option in the (E-W) street, b: in the (N-S) street

c. Effect of Street Orientation

The study compares the thermal performance of the two main street orientation which are the east- west and the north- south orientation. The study takes into consideration the three width ratio of buildings which are 0.4, 0.7 and 1 and two spacing ratio (L1/L2) which are 0.1 and 1.2 and two aspect ratio (H/W) which are 0.25 and 4 in order to investigate the impact of these variables in affecting the role of street orientation, see figure (5.17).

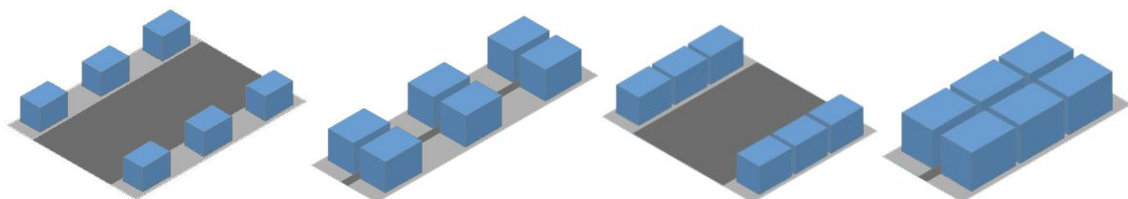


Figure (5.17): a: The simulated cases in the study

As shown in figure (5.18), the street orientation has a great effect on the cooling loads especially in a small values of aspect ratio. For more details, changing the street orientation from the east- west to the north- south orientation with (H/W) equals to 0.25 can increase the cooling loads by about 21.1%, 19.9% and 17.8% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively and with small spacing ratio (0.1) by ECOTECT. Increasing the aspect ratio can reduced the difference to reach 12.9%, 11.5% and 10.5% respectively. Hence, it can be possible to minimize the bad impact of the north- south streets by increasing the aspect ratio which means increasing the buildings height so that a large shaded area of the east and west façades can be

achieved. The same trend can be observed in IES. Changing the street orientation from the east- west to the north- south orientation with (H/W) equals to 0.25 and spacing ratio equals 0.1 increases the cooling loads by about 17.2%, 14.6% and 12.7% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively as shown in figure (5.18).

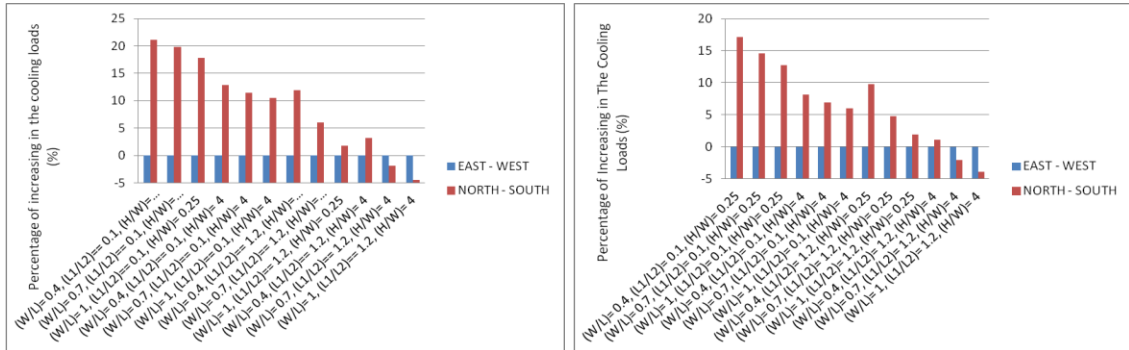


Figure (5.18): a: The percentage of increasing in the cooling loads by ECOTECT, b: by IES

The street orientation has a slight effect on the heating loads. The north- south orientation has a better thermal response in the winter periods of about 2.2%, 1.5% and 1.6% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively and with large aspect ratio in ECOTECT. It can be noticed in IES that increasing the aspect ratio (H/W) from 0.25 to 4 changes the better of street's orientation from the east- west to the north- south orientation in the heating loads point of view. For more explanation, changing the street orientation from the east- west to the north- south orientation with (H/W) equals to 0.25 in IES increases the heating loads by about 11.7%, 9.5% and 8.1% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively and with small spacing ratio equals 0.1. On the other hand changing the street orientation from the east- west to the north- south orientation with a large (H/W) equals to 4 decreases the heating loads by about 11.2%, 10.3% and 8.5% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively as shown in figure (5.19).

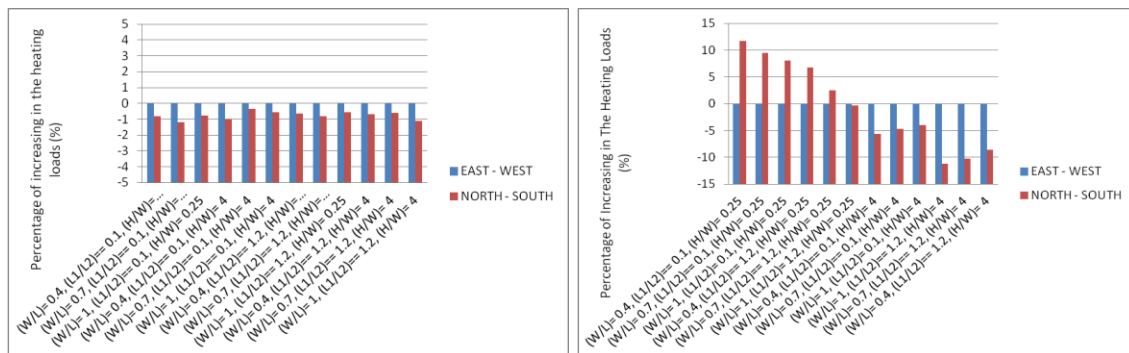


Figure (5.19): a: The percentage of increasing in the heating loads by ECOTECT, b: by IES

From the total loads point of view, it can be observed from figure (5.20) that the east- west street is the more preferable one in both ECOTECT and IES for all the simulated cases especially in the case of large aspect ratio (H/W) equals to 4 and large spacing ratio (L1/L2) equals to 1.2. For more details, changing the street orientation from the east- west to the north- south orientation with a small (H/W) equals to 0.25 and a small spacing ratio (0.1) increases the total loads in ECOTECT by about 10.2%, 9% and 8% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively. It increases the total loads in IES by about 14.7%, 12.2% and 10.5% in the case of

buildings with width ratio equals to 0.4, 0.7 and 1 respectively. However, changing the street orientation from the east- west to the north- south orientation with a large (H/W) equals to 4 and a large spacing ratio (1.2) decreases the total loads in ECOTECT by about 1.2% and 2.8% in the case of buildings with width ratio equals to 0.7 and 1 respectively. It decreases the total loads in IES by about 3.5%, 5.9% and 7.3% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively. Table (5.4) illustrates the 12 cases simulated in the study and the preferable street's orientation in each case.

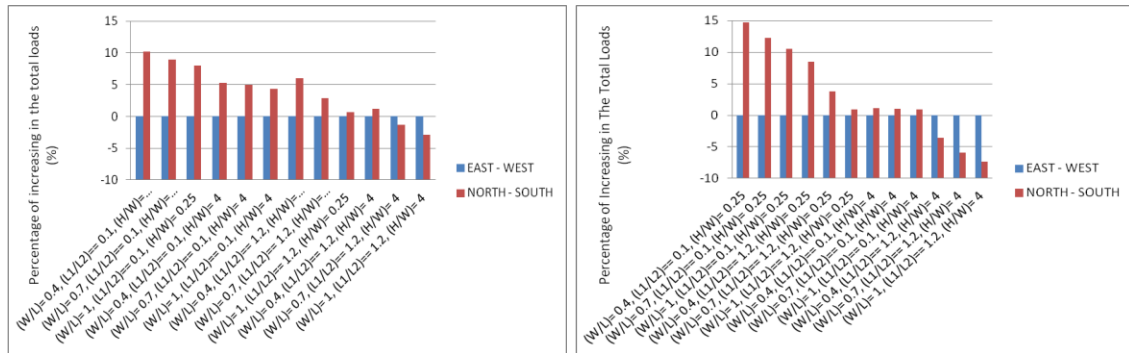
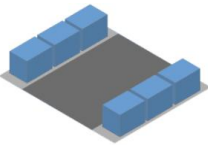
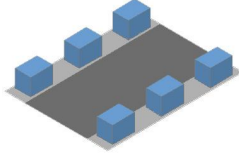
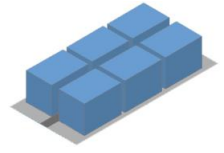
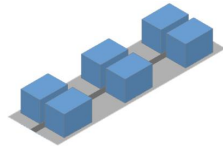


Figure (5.20): a: The percentage of increasing in the total loads by ECOTECT, b: by IES

Table (5.4): The 12 options investigated in the study

	(L1/L2)= 0.1, (H/W)= 0.25	(L1/L2)= 1.2, (H/W)= 0.25	(L1/L2)= 0.1, (H/W)= 4	(L1/L2)= 1.2, (H/W)= 4
Perspective				
Width ratio= 0.4	(E-W) street is better than (N-S) street by about 14.7% in the total loads	(E-W) street is better than (N-S) street by about 8.5% in the total loads	(E-W) street is better than (N-S) street by about 1.1% in the total loads	(N-S) street is better than (E-W) street by about 3.5% in the total loads
Width ratio= 0.7	(E-W) street is better than (N-S) street by about 12.2% in the total loads	(E-W) street is better than (N-S) street by about 3.8% in the total loads	(E-W) street is better than (N-S) street by about 1% in the total loads	(N-S) street is better than (E-W) street by about 5.9% in the total loads
Width ratio= 1	(E-W) street is better than (N-S) street by about 10.5% in the total loads	(E-W) street is better than (N-S) street by about 0.95% in the total loads	(E-W) street is better than (N-S) street by about 0.9% in the total loads	(N-S) street is better than (E-W) street by about 7.3% in the total loads

d. Incident Solar Radiation

It's evident that the incident solar radiation is the main responsible factor in the thermal response of the simulated cases. As the simulated cases is taken to be the middle building in the urban configuration, which surrounded from each the south, west and east facade, the incident solar radiation on these façades have to be analyzed. About 24 cases was handled which included three width ratios (1, 0.7, 0.4), two street orientations (E-W, N-S), two aspect ratios (H/W) (0.25, 4) and two spacing ratio (SR) (0.1, 1.2). as indicated in figure (5.21), the building in an urban configuration of aspect

ratio equals to 4 and spacing ratio equals to 0.1 with an E-W street orientation receives the least amounts of incident solar radiation. This explains why this model achieves the best thermal behavior in summer period and the worst behavior in winter.

It's evident that decreasing the spacing ratio (SR) from 1.2 to 0.1 for the same (H/W) ratio equals to 4 reduces the incident solar radiation on the south, west and east façades by about 15%, 59% and 71.6% respectively. This demonstrates the significant role of mutual shading from the adjacent building in affecting the incident solar radiation on building façades and thus its thermal performance. To indicate the effect of aspect ratio in affecting the role of spacing ratio, the incident solar radiation in the case of (H/W) ratio equals to 0.25 was analyzed. Decreasing the spacing ratio (SR) from 1.2 to 0.1 for (H/W) ratio equals to 0.25 reduces the incident solar radiation on the west and east façades by about 56% and 68.7% respectively. It's obviously that increasing the (H/W) ratio has a slightly effect in decreasing the impact of the spacing ratio in reducing the solar radiation on the west and east façades. On the other hand, increasing the (H/W) ratio greatly affects the solar radiation on the south façade. As shown in the figure, the solar radiation on the south façade is the same in the case of (SR) equals to 0.1 and 1.2 for (H/W) ratio equals to 0.25 and that's mean that there is no adjacent shading on the south façade.

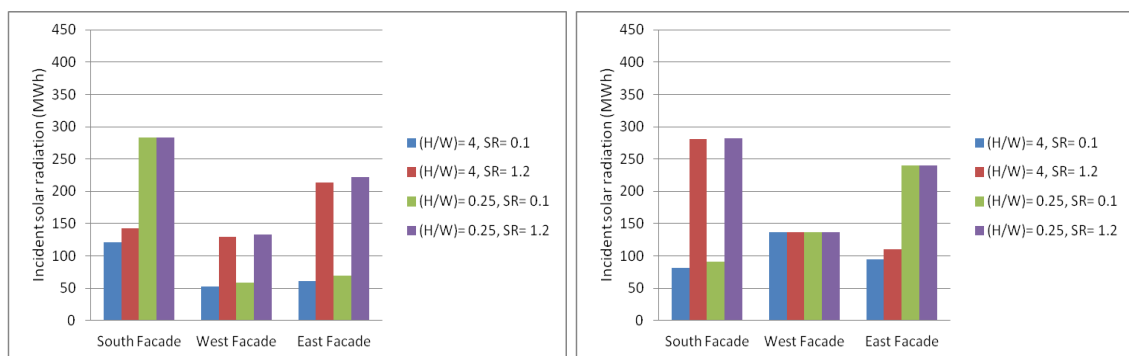


Figure (5.21): a: Solar radiation in the (E-W) Street, b: in the (N-S) Street

In the term of aspect ratio, it is evident from figure (5.21) that its effect is more noticeable on the south façade. Increasing the aspect ratio (H/W) from 0.25 to 4 in the case of spacing ratio equals to 0.1 has an effect in decreasing the incident solar radiation on the south, west and east façades by about 57.2%, 9% and 12.6% respectively. By increasing the spacing ratio to reach 1.2, the percentage of reduction in the solar radiation reduced to reach 49.7%, 2.5% and 3.6% on the south, west and east façades respectively.

Figure (5.22) summarize the effect of decreasing the spacing ratio in decreasing the incident solar radiation on the main south, west and east façades and in the two main street orientation. It is evident that the spacing ratio is more important in the case of east- west streets as it affects significantly the solar radiation falling on the east and south façades.

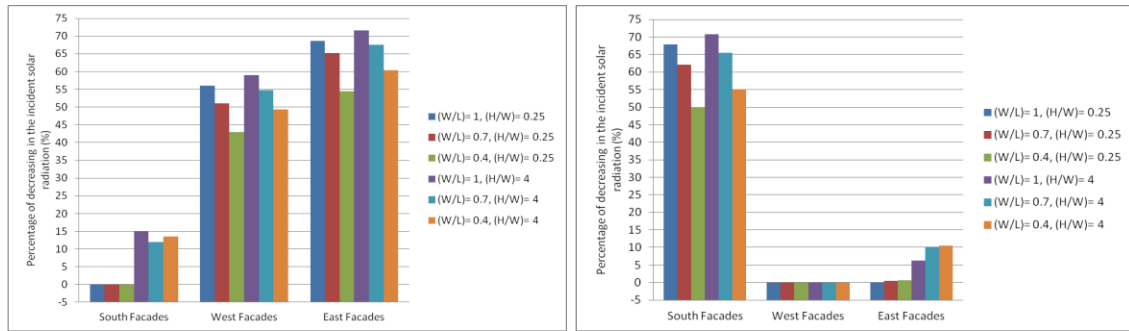


Figure (5.22): a: Percentage of decreasing in the incident solar radiation in the E-W Street, b: in the N-S Street

5.3 The effect of the Urban Density on the Solar Potential and Energy Consumption

One of the main important determination of the urban morphology is the building form. Changing the building morphology in the previous studies which include changing the (roof/ walls) ratio have a major role on changing the urban density. Building height greatly affects the urban density and spacing between buildings and thus the solar potential. According to Cheng *et al.* (2006), Densities are examined in two ways, i.e. plot ratio and site coverage: plot ratio is defined as the ratio of total floor area to site area, and site coverage is the ratio of building footprints to site area. Varying the building height with constant volume, plot area and thus a constant plot ratio has an effect in changing the site coverage.

This study investigated the effect of building height in the urban context. Hence, three generic models of the more common residential blocks were presented. Each block consisted of 16 plots with an area equals to 1200 m² for each plot and with the same street width equals to 12m. Each model will represent a particular case of urban morphology according to the building height. The first model was taken to represent the high coverage developments with a 900 m² building area and 12m height (4 floors) which means a site coverage equals 0.75 and plot ratio equals 3. On the other hand the second model was taken to represent the low coverage developments with a 400 m² building area and 27m height (9 floors) which means a site coverage equals 0.33 and plot ratio equals 3, see table (5.5). The third model was taken to represent the mixed case with a mutual arrangement of building height. Figure (5.23) shows perspectives for the three generic models represented in this study.

Table (5.5): Parameter combinations investigated in the study

	Model 1 (4 floor configuration)	Model 2 (9 floors configuration)	Model 3 (Mix configuration)
Plot area (m²)	1200	1200	1200
Building area (m²)	900	400	650
Building height m (number of floors)	12m (4 floors)	27m (9 floors)	19.5
Site coverage (%)	% 75	% 33.3	54.15
Plot ratio	3	3	3

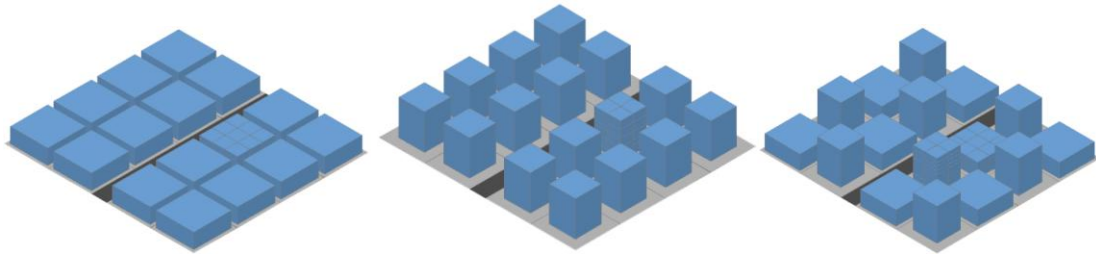


Figure (5.23): The generic models; 4 floor configuration, 9 floors configuration and Mix configuration

Basically, this study concerned both the urban and architectural scale. For more detail, the study analyzed the energy consumption for each block as a set of buildings. After that the study compared the thermal performance for the individual building in each block. Finally, the study investigated the thermal performance of building apartments in each block and with different orientations in order to illustrate the impact of various urban configuration on the smallest unit in the urban block which is the residential apartment.

On the urban scale, the results indicate that the high coverage configuration which consists of 4 floor buildings have a better thermal response more than the 9 floor and the mix configuration. As shown in figure (5.24), the mix configuration increases from the 4 floor configuration in ECOTECT by about 25.2%, 9% and 15% in the cooling, heating and total loads respectively. The 9 floor configuration increases from the 4 floor configuration by about 47%, 18.6% and 28.9% in the cooling, heating and total loads respectively. The same trend can be noticed in IES. The 9 floor configuration increases from the 4 floor configuration by about 17.4%, 9.6% and 13.8% in the cooling, heating and total loads respectively as shown in figure (5.24). So a high site coverage is recommended in order to reduce the cooling and heating requirements.

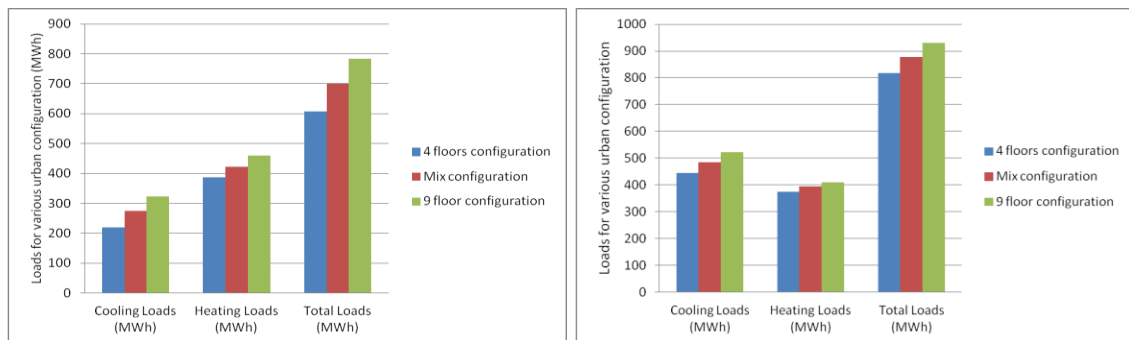


Figure (5.24): a: Cooling, heating and total loads for various configuration in ECOTECT, b: in IES

Many variables affected the thermal response of the previous urban configuration. Varying in the total exposed surface of buildings, spacing between building and the mutual shading from the adjacent buildings have an impact in determining the thermal response in the urban context. To be more clearly, the thermal performance of an individual building have to be studied. The study compared the 4 floor and 9 floor buildings in two urban configuration based on the vertical arrangements which are the uniform vertical and the mix vertical configuration. Hence four buildings were assumed in this study as shown in table (5.6).

Table (5.6): The simulated cases in the study

	4 floor buildings in vertical uniform configuration	4 floor buildings in vertical mix configuration	9 floor buildings in vertical uniform configuration	9 floor buildings in vertical mix configuration
plan				
elevation				

As shown in figure (5.25), it's evident that varying the site coverage have a great effect in the thermal performance of buildings more than varying the vertical arrangements of buildings. Decreasing the site coverage from 0.75 to 0.333 with the same plot ratio which means the same volume for each building found buildings with a surface to volume ratio (S/V) larger than these of the high site coverage by about 9%. Also decreasing the site coverage found a large spacing ratio between buildings which has an effect in increasing the cooling, heating and total loads by about 48.6%, 18% and 28.7% respectively in ECOTECT and by about 18.6%, 8.3% and 13.7% in IES. Keeping the same building form and changing the vertical arrangements of buildings in the urban configuration to achieve the mix configuration have a slight effect in the heating and total loads which didn't exceed 2%. However, the 4 floor building achieve a better thermal response in the mix configuration in the summer periods by about 3%. In contrast, the 9 floor building has a worse performance in the mix configuration by about 6% in the cooling loads as shown in figure (5.25).

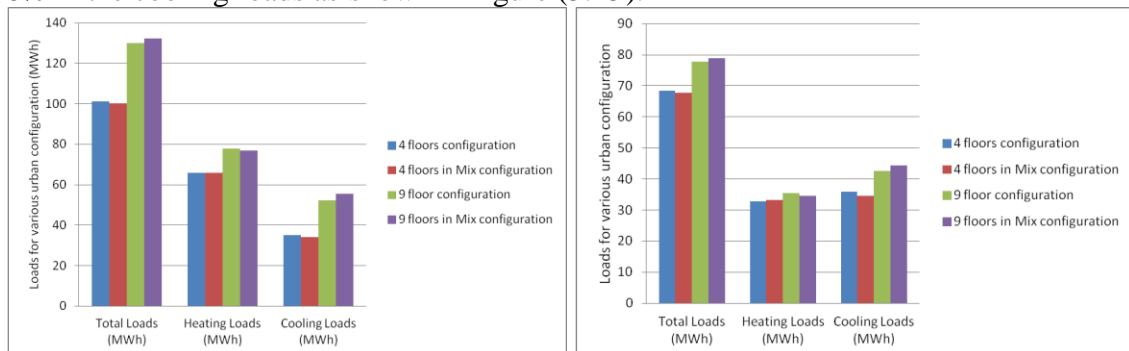


Figure (5.25): a: Cooling, heating and total loads for various configuration by ECOTECT, b: by IES

In order to explain this behavior, the incident solar radiation on buildings components in each of the four configuration were analyzed. As shown in figure (5.26), the 4 floor building in the uniform configuration receives more incident solar radiation than the 4 floor building in the mix configuration by about 11.4%, 3%, 7.4% and 11.9% on the south, west, east façades and the roof respectively. This can explain the better thermal response of the 4 floor building in the mix configuration in the summer periods. However the spacing ratio increases in the mix configuration which has an effect in increasing the cooling loads, the mutual shading from the adjacent high buildings has a great effect on decreasing the amounts of solar radiation which decreases the cooling loads. This means that the impact of spacing ratio is associated with the vertical

arrangements of building in the urban configuration. The mix vertical configuration has a worse effect in increasing the incident solar radiation in the 9 floor building by about 15%, 14.4% and 25.3% on the south, west and east façades respectively. This increasing in the solar radiation can be explained as a result of the low height of the adjacent buildings which decreases the shaded area of the total exposed surface.

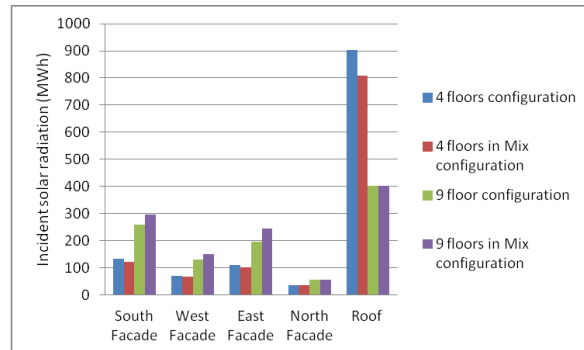


Figure (5.26): Incident solar radiation for various urban configuration

It can be concluded that the high site coverage block is advisable especially for the cooling requirements with a possibility to enhance its heating performance by increasing the spacing in front of the south façades. It is also recommended to utilize the advantages of the mutual vertical arrangements of building in achieving shading on the roof and building's façades by using different height of buildings.

5.3.1 Comparison between Apartments in Various Urban Configuration

As mentioned above, the impact of the urban form in affecting the thermal performance of the individual buildings is associated with the mutual shading of the adjacent buildings. It is obvious that the effect of mutual shading varies according to the apartments arrangements and orientations. This part of study investigated the effect of adjacent shading on the cooling, heating, total loads and the incident solar radiation of the building apartments in various orientation and urban vertical configuration. The thermal performance was analyzed for four apartments orientation which are south- east apartment, south- west apartment, north- east apartment and the north- west apartment. The four apartments orientation were analyzed for three floors types which are the ground, middle and upper floor.

These 12 models were analyzed in four urban configuration according to the two variables; site coverage and vertical arrangements which are the 4 floor building in a vertical uniform configuration, the 4 floor building in a vertical mix configuration, the 9 floor building in a vertical uniform configuration and the 9 floor building in a vertical mix configuration. Hence 48 models were simulated in this study. All these models have the same area equals to 100 m² and constant volume equals to 300 m³. The simulated cases were classified into 3 groups according to the exposed surface which are the ground, middle and upper floor. Apartments in each group have the same exposed surface and thus (S/V) ratio in order to investigate only the impact of urban configuration which include here the site coverage and the vertical arrangements in affecting the adjacent shading in various apartment orientation. See figure (5.27).

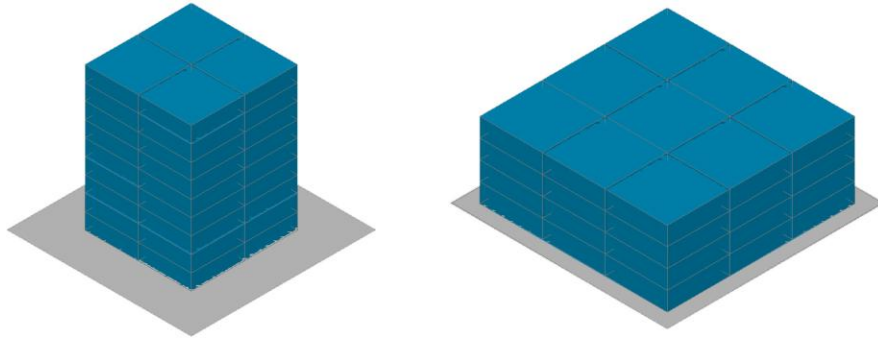


Figure (5.27): The two apartment blocks simulated in the study

a. Cooling Loads

The results indicate that the apartment block with various orientation in the high site coverage (4 floor building) in the mix vertical configuration have a bad behavior in the summer periods in the ground and middle floors. In contrast, it has a better response in the upper floor. The apartments in the 4 floor building in the mix vertical configuration increase in the cooling loads from those in the uniform vertical configuration by about 17.6% and 8.7% in the south- east apartment in the ground and middle floor respectively. However they decrease by about 8.8% in the upper floor. This means that both the ground and middle floors adversely affected by the mix vertical configuration due to the increasing in the spacing ratio while the upper floors take the advantages of adjacent shading. See figure (5.28). This means that it is preferable to apply the mix vertical urban configuration with integration with the high site coverage in order to achieve a large shaded area of the roof surfaces.

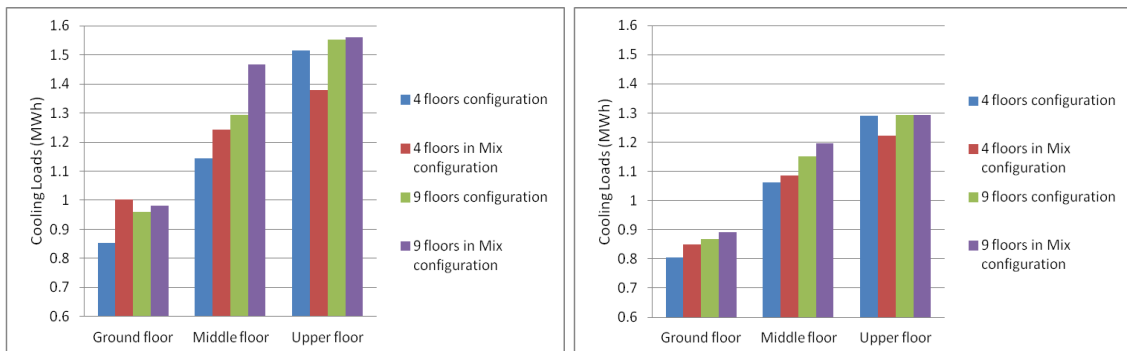


Figure (5.28): a: Cooling Loads in the South- east apartment, b: in the South- west apartment

It is evident that varying the apartments orientation has an impact in affecting the role of urban configuration in changing the cooling loads. To illustrate the role of apartments orientation, figure (5.29) shown that changing the urban vertical configuration from the uniform to the mix configuration for the 4 floor building increases the cooling loads by about 17.6%, 5.5%, 10.3% and 3.6% for the South- east apartment, South- west apartment, North - east apartment and the North- west apartment in the ground floor respectively. In the case of the middle floor, the percentage of increasing reaches to about 8.7%, 2.2%, 4.9% and 3% for the South- east apartment, South- west apartment, North- east apartment and the North- west apartment respectively. In the case of the upper floor, the percentage of reduction reaches to about 8.8%, 5.2%, 10.5% and 5.2% for the South- east apartment, South- west apartment, North- east apartment and the North- west apartment respectively.

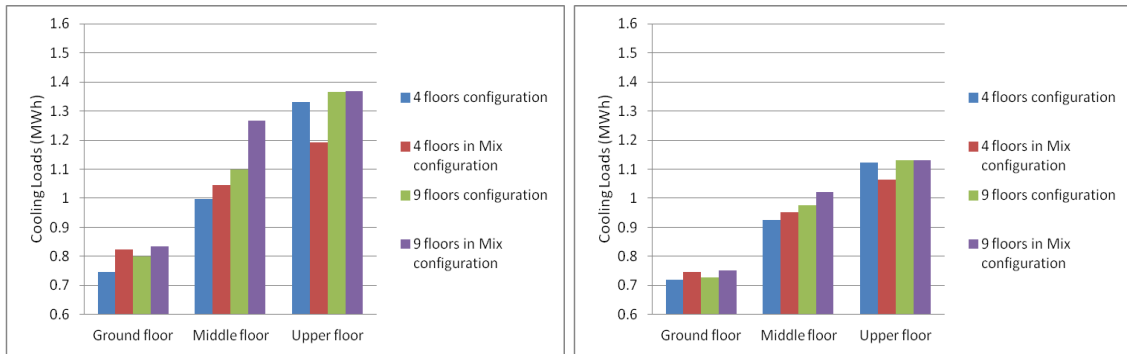


Figure (5.29): a: Cooling Loads in the North - east apartment, b: in the North – west apartment

b. Heating Loads

As shown in figure (5.30), the apartments in the 4 floor building in the uniform vertical configuration increase in the heating loads from those in the mix vertical configuration by about 3.2% and 3.8% in the south- east apartment in the ground and middle floor respectively. Also, they increase in the heating loads from those in the 9 floor building in the mix vertical configuration by about 1.2% and 10% in the south- east apartment in the ground and middle floor respectively. This is due to the small spacing in the 4 floor uniform configuration which reduced the incident solar radiation on the apartment's façades in the ground and middle floors which increase the heating loads. The same trend can be noticed in the south- west apartment. The apartments in the upper floor of the 4 floor building in the mix vertical configuration increase in the heating loads from those in the 9 floor building in the mix vertical configuration by about 4.7% in both the south- east and south- west apartments. This is due to the adjacent shading on these apartments in the 4 floor building in the mix vertical configuration which increases the heating loads.

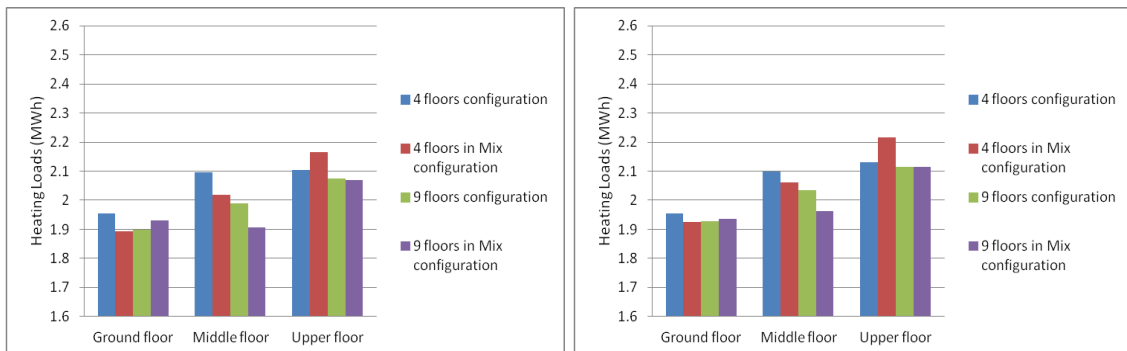


Figure (5.30): a: Heating Loads in the South- east apartment, b: in the South- west apartment

c. Total Loads

As shown in figure (5.31), the total loads of apartments take the same trend of the cooling loads. The apartments in the 4 floor building in the uniform vertical configuration decrease in the total loads from those in the 9 floor building in the mix vertical configuration by about 3.8% and 4.1% in the south- east apartment in the ground and middle floor respectively. However, the 4 floor building in the mix vertical configuration achieves a better thermal response in the upper floor by about 2.3%.

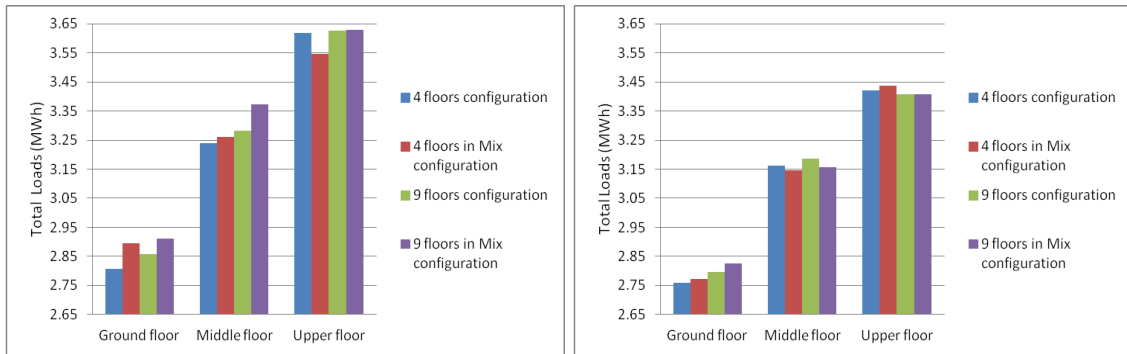


Figure (5.31): a: Total Loads in the South- east apartment, b: in the South- west apartment

d. Incident Solar Radiation

In order to explain the thermal response of the apartments in various urban configuration, the incident solar radiation on the building's components in each floor was determined.

- Ground Floor

The results indicate that the ground floor in the vertical uniform high density configuration receives the least amount of solar radiation on its façades. The ground floor in the same 4 floor building but within a vertical mix configuration receives more solar radiation by about 69% and 91.7% in the south and east façades of its south- east apartments. This means that the ground floor of the high site coverage negatively affected by the vertical mix configuration. Comparing the 9 floor building in various configuration as shown in figure (5.32), the vertical mix configuration decreases the incident solar radiation on the east and west façades by about 13.8% and 4.6% respectively, while increasing the solar radiation on the south façade by only 5.4%. the incident solar radiation on the building's façades has the same trend of the total loads for the ground floor and this means that the solar radiation is the main responsible for the thermal response of apartments in various urban configurations.

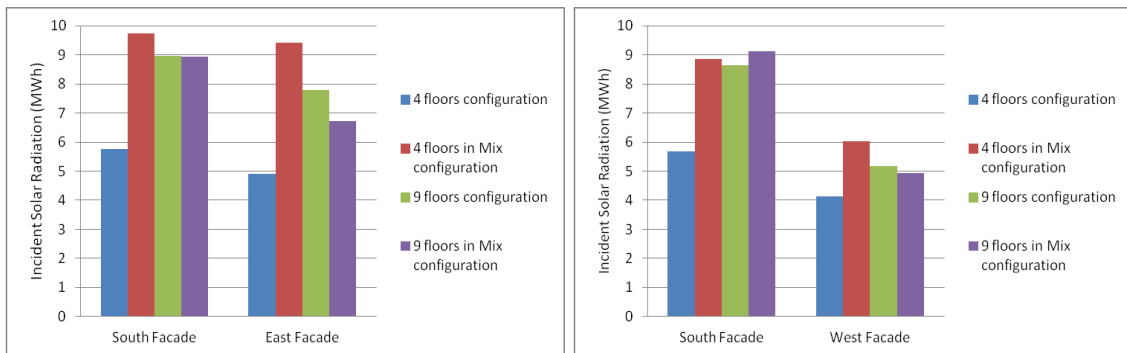


Figure (5.32): a: Solar radiation on the South- east apartment, b: in the South- west apartment

- Middle Floor

As shown in figure (5.33), the apartments in middle floor of the 4 floor building in the uniform vertical configuration receives the lowest amount of solar radiation on their façades and this explains the better thermal response of them in the total loads point of view. For more details, the solar radiation on the south façade of this floor reduces by about 57.6% and 58.9% from the solar radiation on the south façade of this floor in the 9 floor building in the mix vertical configuration for both the south- east and south-

west apartment respectively. Also, the solar radiation on the east façade of this floor reduces by about 57.9% from the solar radiation on the east façade of this floor in the 9 floor building in the mix vertical configuration for the south- east apartment. The solar radiation on the west façade of this floor reduces by about 44.3% from the solar radiation on the west façade of this floor in the 9 floor building in the mix vertical configuration for the south- west apartment. This is due to the small spacing in this configuration which reduce the solar radiation. This behavior is more compatible with the total loads of the middle floor in this various configuration.

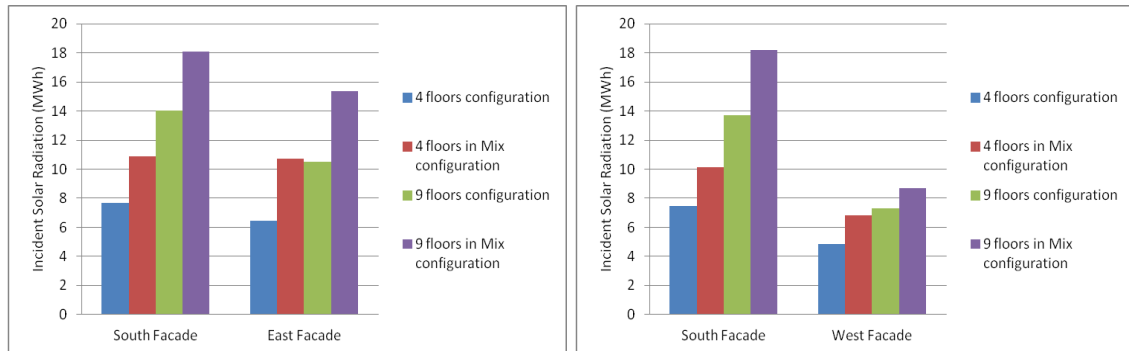


Figure (5.33): a: Solar radiation on the South- east apartment, b: in the South- west apartment

- Upper Floor

Figure (5.34) showing that the 4 floor building in the mix vertical configuration receives the least amount of solar radiation on its south, east, west façades and its roof. This can explain the better thermal response of the upper floor in this building. The south- east apartments in this floor receives an amount of solar radiation less than their counterparts in the other configuration by about 31.5%, 23.1% and 15.4% in the south, east façades and the roof respectively. In the same context, The south- west apartments in this floor receives an amount of solar radiation less than their counterparts in the other configuration by about 38.6%, 14.8% and 15.4% in the south, west façades and the roof respectively. So it can be concluded that enhancement of the thermal performance of the upper floors can be achieved throughout the mix vertical configuration. Otherwise, the upper floor in the other configuration have nearly the same response.

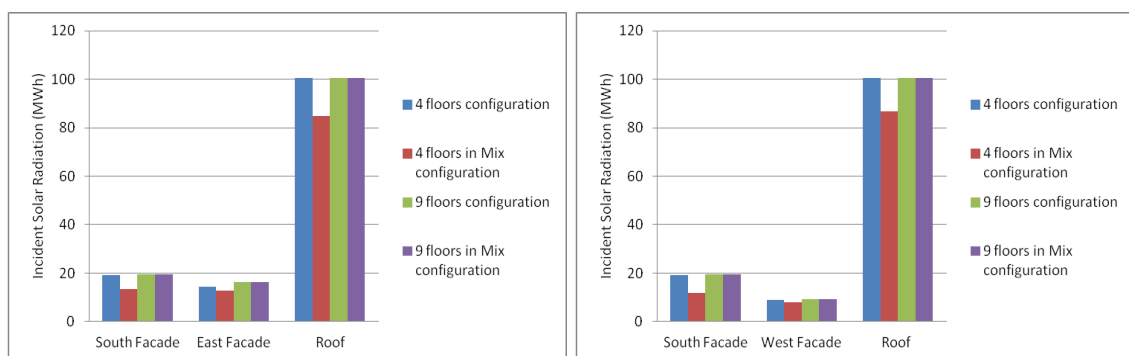


Figure (5.34): a: Solar radiation on the South- east apartment, b: in the South- west apartment

5.3.2 Effect of Plot Ratio

As mentioned previously, the other method representing the urban density is the plot ratio. This part of study will examine the effect of plot ratio on the thermal performance in the case of constant site coverage. Hence, the same urban block with the same area of

plot equals to 1000 m² and the same street width equals to 12 m in the east- west orientation was assumed. Three cases of plot ratio based on the building height (number of storey) were assumed. The first case represents the low plot ratio equals to 2 and consists of 4 storey. The second and the third cases represents the medium and high plot ratio equals to 4 and 6 and consists of 8 and 12 storey respectively as shown in figure (5.35).

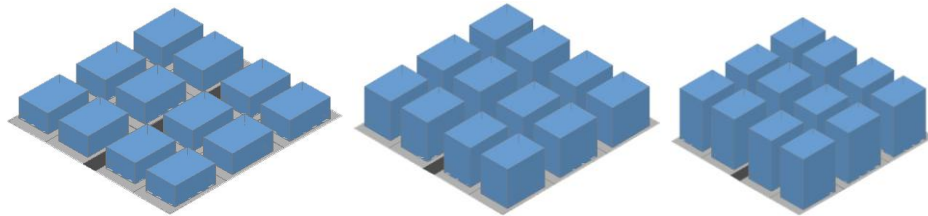


Figure (5.35): a: Plot ratio= 2, b: Plot ratio= 4, c: Plot ratio= 6

Basically, this study analyzed the energy consumption for the whole building by evaluating the average of energy consumption for the floor. This can be obtained from dividing the total energy consumption on the number of floors in each case. After that the study compared the thermal performance for the three levels of floors; ground, middle and upper in each building and within various plot ratio.

The results indicate that the buildings in the high plot ratio (12 floor) has a better thermal response. As shown in figure (5.36), increasing the number of stories from 4 to 12 storey which means increasing the plot ratio from 2 to 6 has an effect in decreasing the cooling and total loads by about 19.7% and 9% by ECOTECT respectively. However, increasing the plot ratio has a slight effect in increasing the heating loads by about 3.1% by ECOTECT. In IES increasing the plot ratio from 2 to 6 reduces the cooling, heating and total loads by about 23.6%, 11.3% and 18.8% respectively.

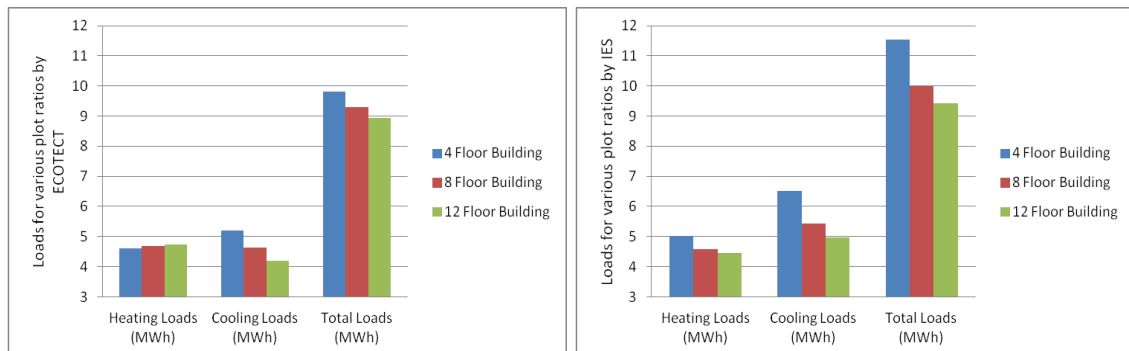


Figure (5.36): a: Heating, Cooling and Total Loads for various plot ratios by ECOTECT, b: by IES

To clearly investigate the effect of plot ratio, the energy requirements for the main floors were determined. The results indicate that the buildings in the high plot ratio has a better thermal response in the summer periods. The difference is more reasonable in the ground and middle floors. As shown in figure (5.37), decreasing the number of stories from 12 to 4 storey which means decreasing the plot ratio has an effect in increasing the cooling loads by about 27.7% and 21.6% in the ground and middle floor respectively. As the plot ratio increased, the solar potential on the buildings façades especially in the lower floors decreased and this can explain the better cooling response of the high plot ratio. As the upper floor has the more contact with the outdoor environments, it doesn't affected by the plot ratio. In contrast, the high plot ratio has a

slight effect on increasing the heating loads. The buildings in the low plot ratio has a better heating response of about 4.9% and 10.2% in the ground and middle floor respectively.

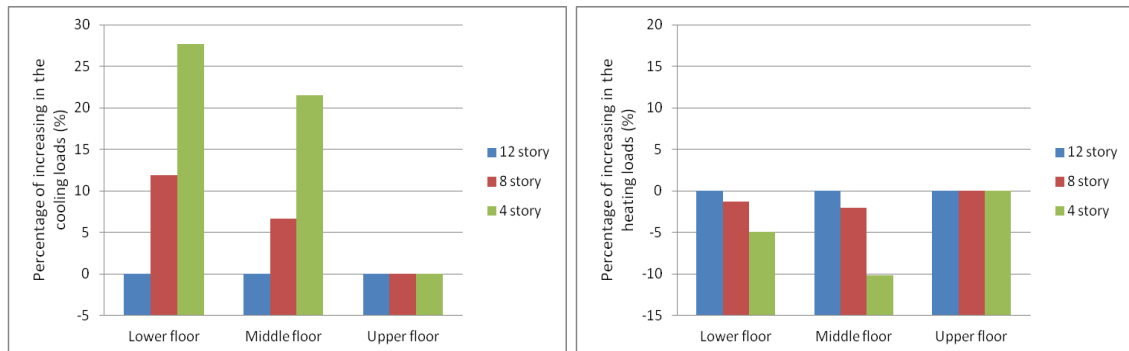


Figure (5.37): a: Percentage of increasing in the cooling loads, b: percentage of increasing in the heating loads by ECOTECT

In order to identify the optimum plot ratio in the energy consumption point of view, the total loads have to be determined. Showing figure (5.38), it is evident that the plot ratio has a little effect on the total loads which doesn't exceed 5%. For more details, decreasing the plot ratio from 6 to 2 which means decreasing the number of storey from 12 to 4 increases the total loads by about 5% and 1.9% in the ground and middle floor respectively without any change in the energy consumption of the upper floor.

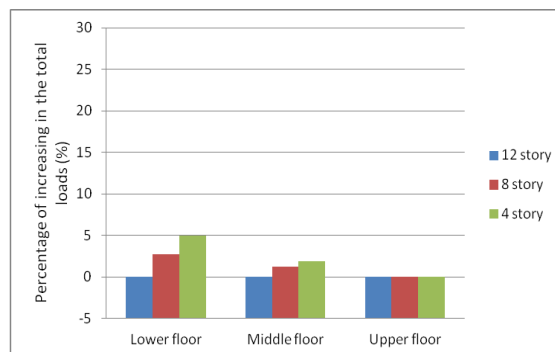


Figure (5.38): Percentage of increasing in the total loads by ECOTECT

5.4 The Effect of the Urban Configuration on the Energy Consumption

Urban configuration was considered as a complex issue as there are several parameters affecting its environmental microclimate. The building's form, orientation within the plot, its location within the block and the way they clustered along the streets can all determine the urban form. The mutual shading between building and the solar potential affects greatly with these parameters and hence affecting the comfort condition within the urban blocks. This study is an attempt to investigate the effect of these combinations parameters on the indoor thermal performance and energy consumption. The study examined 72 urban block with each block consisted of 12 buildings and only the three central building along the street were considered. Building's areas and heights and the street width were fixed so that all forms have the same plot ratio, site coverage and aspect ratio. The floor area of building (A) is taken to be 400 m² and the building height is taken to be 15 m (5 storey) and thus the volume is taken to be 6000m³. The parcel's area is taken to be 1200 m² in order to accommodate all the buildings with various width ratios and orientations. Hence the site coverage is taken to be 0.33.

5.4.1 Parametric Investigation

The study investigates the effects of a number of parameters in the heating, cooling and total loads. Combinations of parameter values analyzed in this study are summarized in Table (5.7) and table (5.8).

a. Width to Length Ratio: Three values of width to length ratio (W/L) were considered, namely 0.4, 0.7 and 1.

b. Street Orientation: Four values of street orientation were considered which are the east west, north- south, north east- south west and north west- south east orientation.

c. Urban Configuration: Two values of urban configuration were considered which are the regular and the mutual configuration.

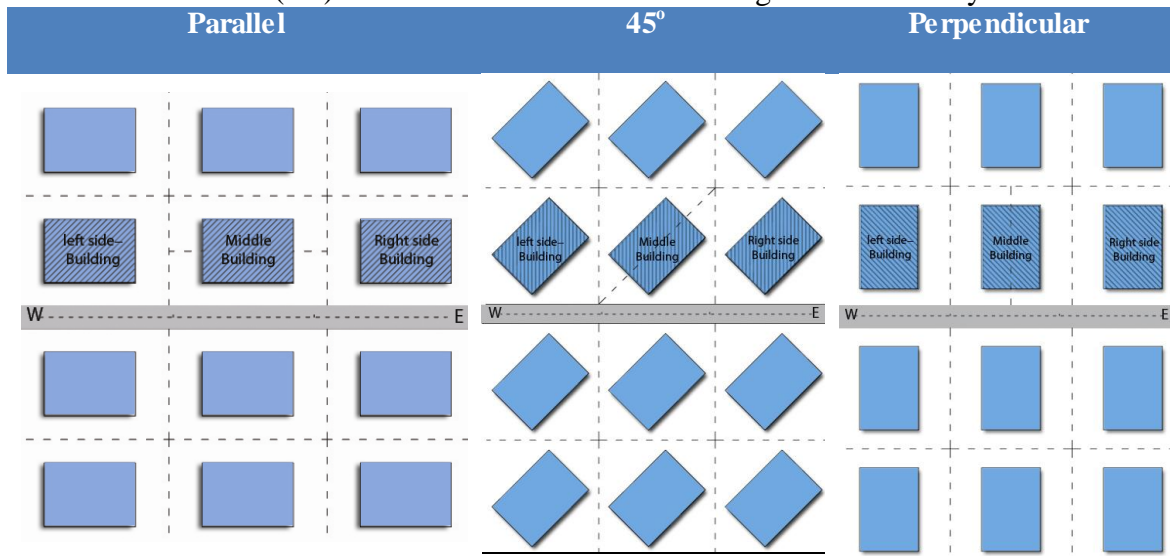
d. Building Orientation: Three values of orientation were considered, namely when the long axis of the building is parallel to the street, the long axis of the building rotates 45° from the long axis of the street and the long axis of the building is perpendicular to the street

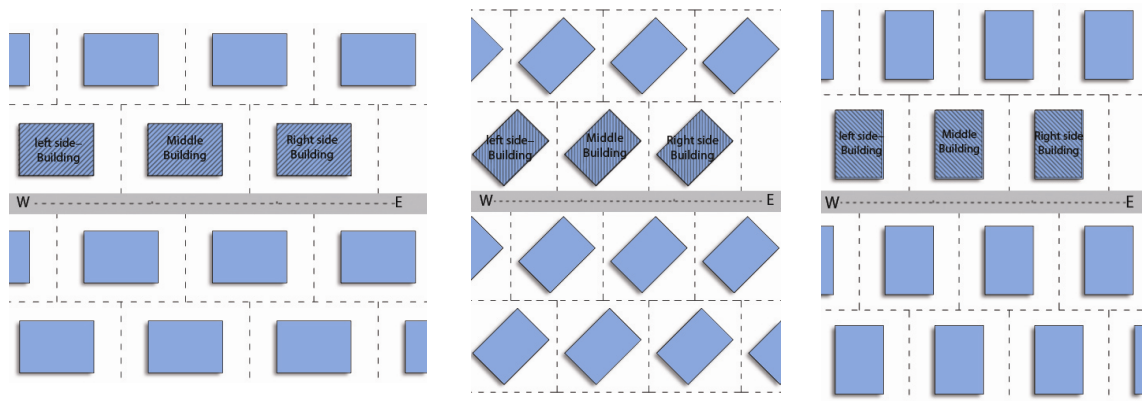
e. Building Location: Three location of building were considered which are the Right side, Middle and the left side building. Hence, 216 cases are simulated in this study.

Table (5.7): Parameter combinations investigated in the study

Shape	Width to Length Ratio	Building orientation	Street orientation	Urban configuration	Building location
Rectangular	0.4, 0.7, 1	Parallel, 45°, perpendicular	E – W, N- S, NE- SW, NW- SE	Regular, mutual	Right side, Middle, left side

Table (5.8): Parameter combinations investigated in the study





5.4.2 Simulation Results

The simulation results were expressed in terms of annual heating, cooling and total loads (in MWh).

a. Effect of Street Orientation

The results indicate that the east- west orientation for the street is more preferable in the cooling loads point of view when the long axes of the building (plot) is parallel to the street orientation. Changing the street orientation from the east- west to the north east- south west orientation can increase the cooling loads by about 9% by ECOTECT in the case of building with a width to length ratio equals 0.4 and within regular urban configuration. The percentage of increasing in the cooling loads reduced with increasing the width ratio from 0.4 to 1 to reach about 5%. The same trend can be observed in IES with about 7% of increasing in the cooling loads with changing the street orientation from the east- west to the north- south. Showing figure (5.39), it is clear that the effect of street orientation decreased with increasing the width ratio. It is also shown that the effect of urban configuration; either regular or mutual configuration appears clearly in the case of north- south street.

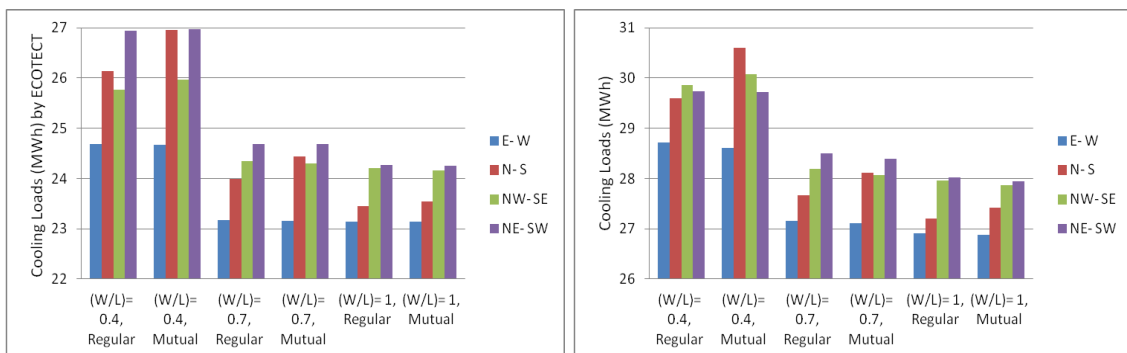


Figure (5.39): a: Cooling loads by ECOTECT with the long axis of the building parallels to the street, b: cooling loads by IES

Changing the street orientation has a slight effect on increasing the heating loads which doesn't exceed 2% by ECOTECT. However, changing the street orientation from the east- west to the north west- south east for the building with a width to length ratio equals 0.4 and within regular urban configuration increases the heating loads by about 8.3% in IES. This percentage of increasing reduced in the case of mutual urban configuration to reaches about 7% as shown in figure (5.40).

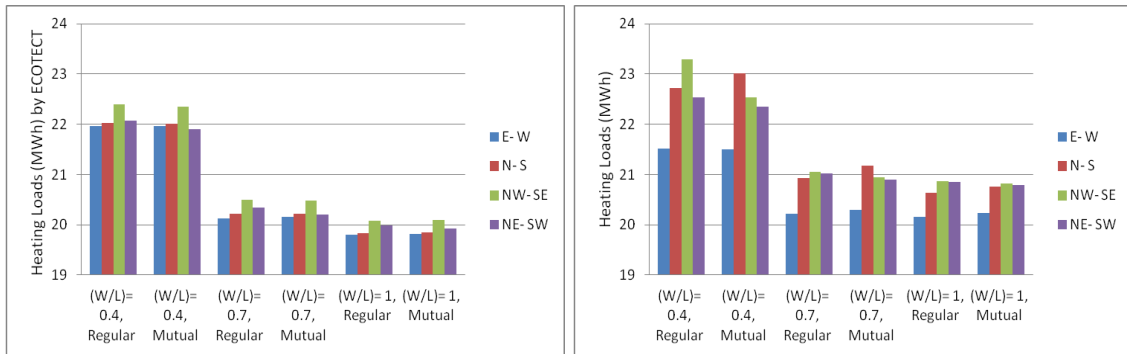


Figure (5.40): a: Heating loads by ECOTECT with the long axis of the building parallels to the street, b: Heating loads by IES

To summarize the effect of street orientation on the energy consumption, the total loads were determined. Changing the street orientation from the east- west to the north east- south west orientation can increase the total loads by about 5% by ECOTECT in the case of building with a width to length ratio equals 0.4 and within regular urban configuration. The same trend can be observed in IES with about 5.8% of increasing in the total loads with changing the street orientation from the east- west to the north west- south for the building with a width ratio equals 0.4 and within regular urban configuration. Also, the total loads increased by about 7% with changing the street orientation from the east- west to the north- south for the building with a width to length ratio equals 0.4 and within mutual urban configuration as shown in figure (5.41).

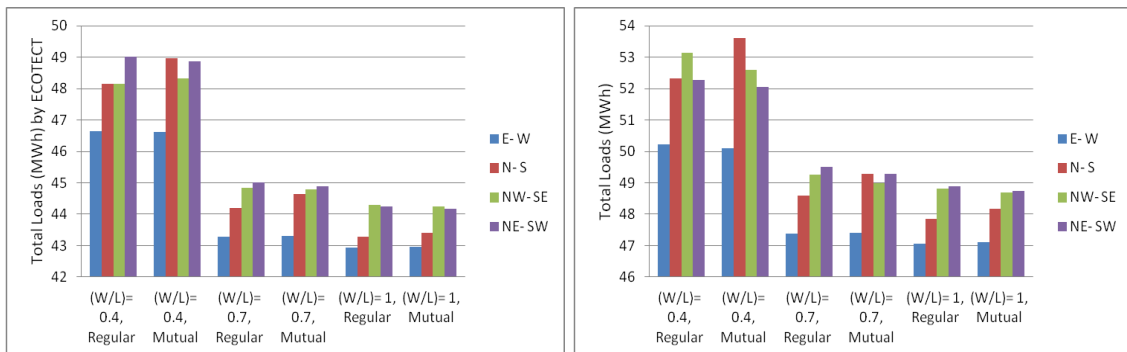


Figure (5.41): a: Total loads by ECOTECT with the long axis of the building parallels to the street, b: Total loads by IES

Changing the building orientation to have an angle of 45° with the street axis or to be perpendicular to the street can change the optimum orientation of the street. As shown in figure (5.42), when the long axis of the building (plot) have 45° angle with the street, the north west- south east orientation becomes the optimum orientation of the street with a difference in the cooling loads reaches to about 7.5% with the east- west street orientation. The north west- south east orientation of the street becomes the optimum orientation in this case as the buildings have their long axis parallel to the east- west orientation. This means that the optimum orientation of the street is associated with the building orientation. As the streets represents one of the first decisions in determining the urban blocks, the bad effect of their orientation can be eliminated by the true orientation of the building. Figure (5.43) presents the optimum configurations for different street orientations.

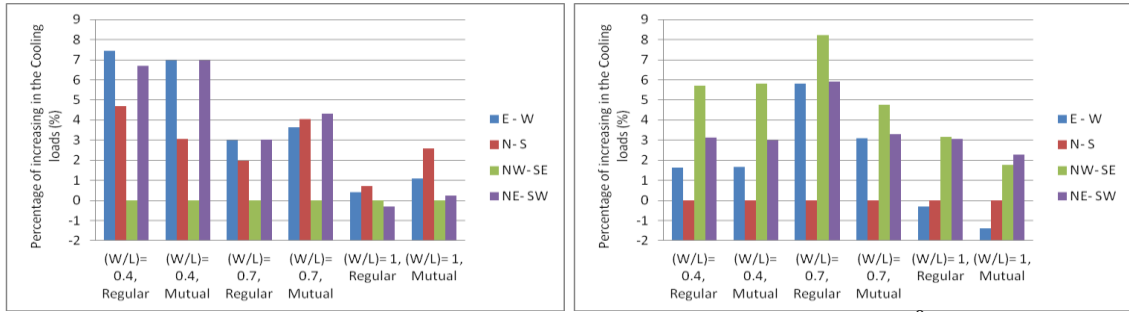


Figure (5.42): a: Cooling loads with the long axis of the building is 45° with the street, b: Cooling loads by ECOTECT with the long axis of the building is perpendicular with the street

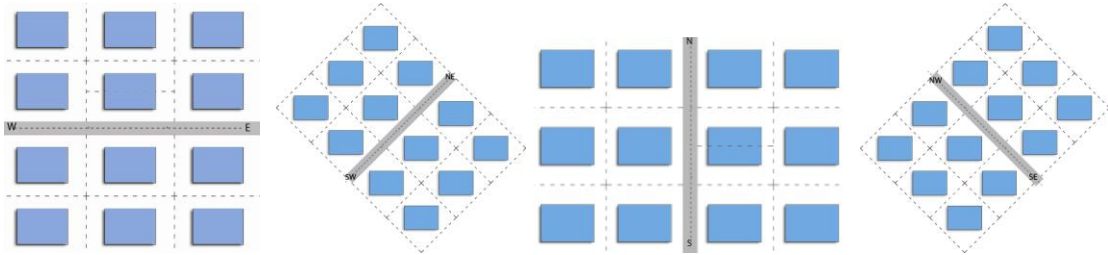


Figure (5.43): The optimum configurations for different street orientations

b. Effect of Building Orientation

In the previous chapter, the building orientation has been changed from the east-west to the north-south orientation in an interval of 10° for a separated building. The results indicated a small difference between the orientation of 45° and 90° which reaches to only 1%. This study investigate the effect of building orientation in the urban context. Hence three locations of the building in the urban block are assumed which are the right side, the middle and the left side building on the east-west street. As shown in figure (5.44), the orientation of 45° has the worst thermal response in the term of cooling loads in the three building locations. The important aspect to be mentioned here is that while the difference in the cooling loads between the 45° and the perpendicular orientation doesn't exceed 1% in the case of the right side building, the difference reaches about 7% and 2% in the case of the middle and the left side buildings respectively. That's means that it is possible to avoid the bad effect of the perpendicular orientation of the building by protecting its east and west sides by adjacent buildings in order to increase the shaded area and enhance its thermal response. Also, changing the building orientation from the east-west (parallel to the street) to 45° increases the cooling loads by about 10.6%, 8% and 8.3% for the right side, middle and left side building respectively by ECOTECT. The same trend can be observed in IES as shown in figure (5.44).

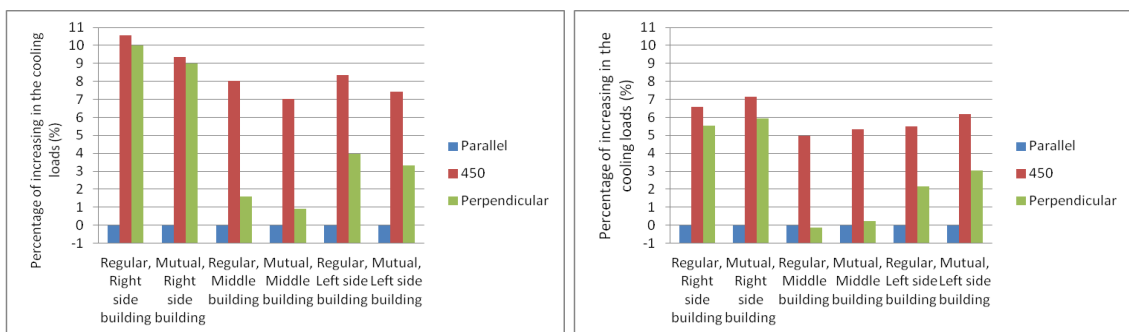


Figure (5.44): a: Percentage of increasing in the cooling loads by ECOTECT, b: by IES

c. Effect of Urban Configuration

One of the main determinant of the urban form is the way in which the buildings arrange with each other's which called the urban configuration. This study compares between two ways of urban configuration which are the regular and the mutual configuration. The long axes of the building (plot) is taken to be parallel to the street orientation. The simulation is hold for the middle building with three width ratio and in four street orientation, see figure (5.45).

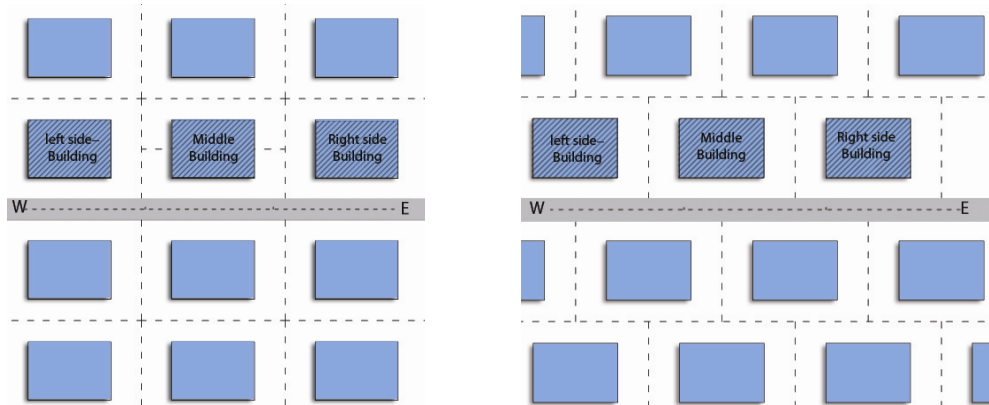


Figure (5.45): The two urban configuration simulated in the study

The results indicate that the regular configuration is more preferable in the cooling loads point of view. The maximum effects of the urban configuration doesn't exceed 5% and appears clearly in the case of north- south street orientation. As shown in figure (5.46), the percentage of increasing in the cooling loads between the regular and mutual configuration reaches to about 4.6%, 1.9% and 1% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively. The same trend can be observed in IES with the percentage of increasing in the cooling loads reaches to about 3.4%, 1.6% and 0.7% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively as a result of changing the urban configuration from the regular to the mutual one.

This can be explained due to the ability of the mutual configuration in decreasing the adjacent shading which adversely affects the cooling loads. As the building elongation increased, the surface affected by the adjacent shading increased and this explain why the building with width ratio equals to 0.4 is the more affected case of the mutual configuration. The orientation of this surface is also important. As the east façade is the exposed surface affected by the adjacent shading in the case of the north-south street orientation, the effect is more noticeable in this orientation more than other street's orientations.

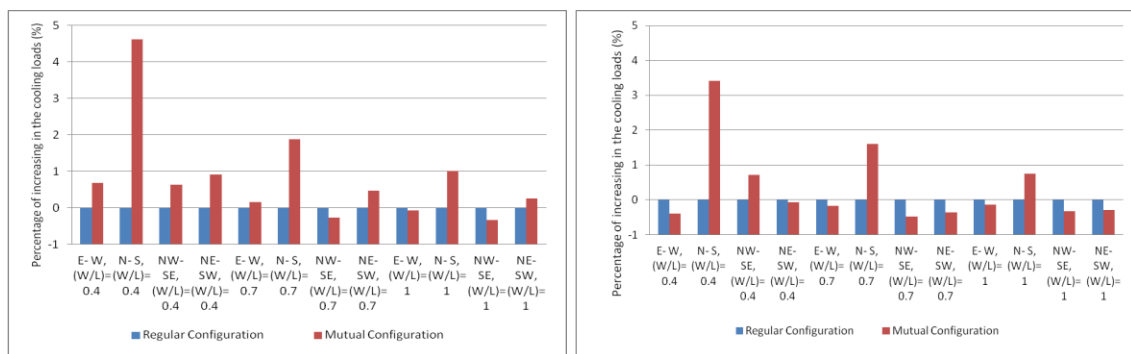


Figure (5.46): a: Percentage of increasing in the cooling loads by ECOTECT, b: by IES

Showing figure (5.47), it is evident that the urban configuration has a slight effect on increasing the total energy consumption. The mutual configuration has a bad effect on increasing the total loads from the regular configuration especially in the north- south street. It increases the total loads by about 1.7%, 1% and 0.3% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively in the north- south street in ECOTECT. Also, changing the urban configuration from the regular to the mutual increases the total loads by about 2.5%, 1.4% and 0.7% in the case of buildings with width ratio equals to 0.4, 0.7 and 1 respectively in IES.

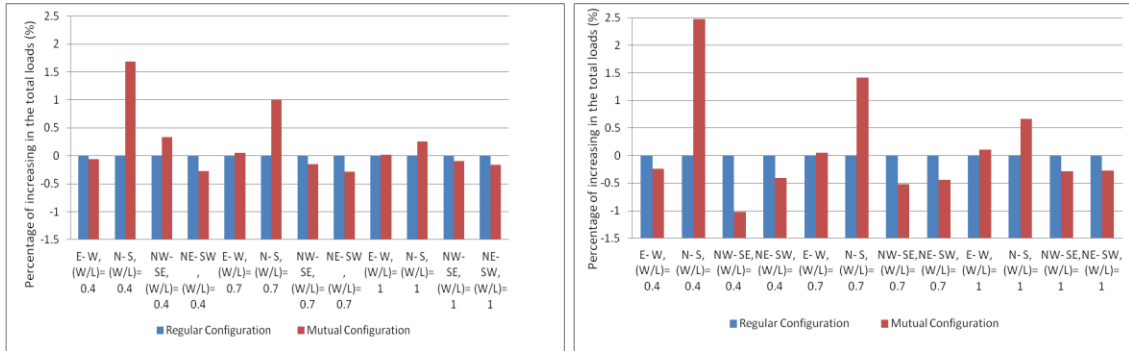


Figure (5.47): a: Percentage of increasing in the total loads by ECOTECT, b: by IES

5.4.3 Urban Configuration

The previous study compares two type of the urban configuration of the detached buildings which are the regular and the mutual horizontal configuration. This study presents another four types of buildings configuration which achieve the same site coverage and plot ratio. Figure (5.48) presents the four models assumed in this study. The models will be simulated in two street orientation which are the east- west and the north- south orientation.

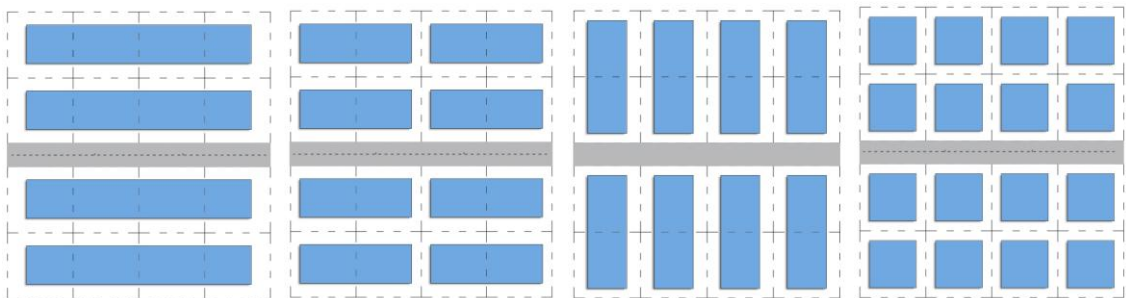


Figure (5.48): The four urban configuration simulated in the study

The results indicates that arranging buildings in a horizontally linear way is more thermally preferable for both cooling and heating requirements. Arranging the buildings in such a way can reduce the cooling, heating and total loads by about 27.9%, 13.8% and 18.9% respectively in the case of the east- west street orientation. This percentage of reduction decreased to reach about 16.3%, 13.6% and 14.6% in the case of the north- south street orientation. As shown in figure (5.49), the more effect of street orientation appears in the cooling loads.

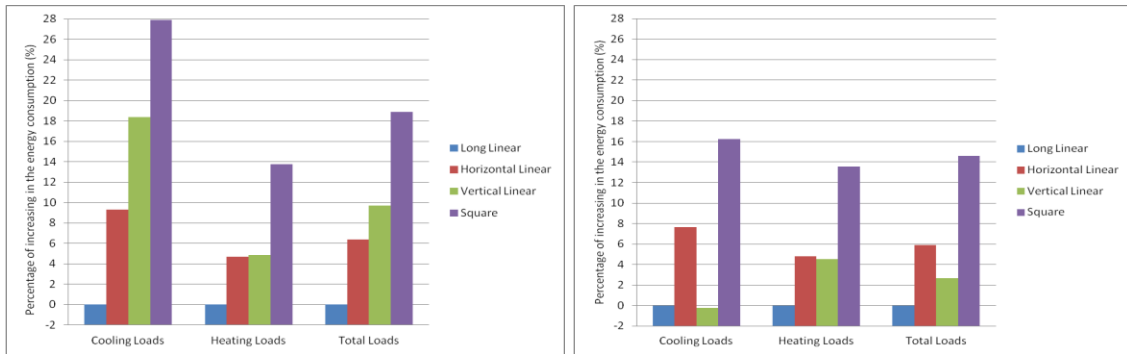


Figure (5.49): a: Percentage of increasing in the cooling loads by ECOTECT in the (E-W) Street, b: in the (N-S) Street

5.5 Conclusion

This chapter dealt with the buildings form in the context of the urban fabric. Buildings proportions such as height is an essential determinate of the urban form as it affects its density. Also, the form proportion has a joint relation with the urban canopy such as the street width and the spacing between building. The relation between the architectural proportions of the individual building and the urban parameters can affects the solar potential on the buildings surfaces and the mutual shading from the adjacent buildings. Building length have to be determined to provide a small spacing ratio (L_1/L_2). Also, building height have to be determined to provide a large aspect ratio (H/W) especially in the north- south street. Higher site coverage is more preferable. Increasing the plot ratio affects significantly the cooling loads with a slight effect on the total loads. The street orientation affects the thermal performance of the building but it is possible to avoid the negative effect of changing the street orientation by keeping the long axis of the buildings (plots) parallel to the east- west orientation. Also, increasing the aspect ratio in the north- south streets can enhance the thermal performance of their building and reduce the difference between them and the optimum orientation of the street.

Chapter 6: Conclusion

The world is facing a significant challenge represented in the lack of the conventional energy and the environmental pollution related to the ever increase in energy consumption. Climatic change and the global warming is another challenge which is linked to the CO₂ emission from the fossil fuels. The buildings contribute to these problems as they are considered the main consumers of energy and which contribute to increase the environmental pollution. The largest portion of the energy in buildings are used for the heating and cooling requirements in order to achieve a high level of thermal comfort. In the Gaza Strip -as one of the developing areas in the middle east which have a large increase in CO₂ emissions for residential buildings reached to 19% from 1971 to 2004 (Levine *et al.* 2007) - the problem is exacerbated by the fully reliability on Israel's energy. In the context of these challenges, the environmental design of buildings which respect the climatic factor comes as one of the most valuable solutions in achieving an acceptable levels of thermal condition. It can also be considered as an attempt in utilizing the renewable sources of energy and preserving the planet's resources. Many strategies of the passive solar design can be incorporated in the early stages of the design process and help to enhance the building's thermal performance.

The building's form is responsible for determining its envelop and the way it interferes with the surrounding environments. It constitutes the exposed envelop which is affected by the climatic factors. It also can be considered as the basic unit in determining the urban form. Other strategies such as glazing, insulation, ventilation and shading can be integrated with this envelop for better thermal response. Designing buildings to achieve thermal comfort is associated with studying the mechanisms of heat transfer between the building and the outdoor environment. Also, defining the means of heat gain and heat loss is essential in achieving the thermal balance. Selecting the suitable design of buildings has a great relation with the climatic factors; solar radiation, wind and humidity. In the Mediterranean climate of the Gaza Strip, the solar radiation is the most important factor in building design as both heating and cooling requirements have to be achieved. However, the building's design in the Gaza Strip doesn't take sufficient account to the climatic factor especially the solar radiation. Hence, this study came to overview the environmental design in the Gaza Strip's buildings especially in the form and orientation. It also intended to investigate the effect of these variables on the thermal performance of the residential complexes in the Mediterranean climate of the Gaza Strip. It aim to understand the relation between form and energy consumption in order to achieve comfort condition and energy saving.

From this standpoint, the theoretical study focused on the energy use in buildings and its related environmental pollution and climatic change. It highlighted the situation of energy in the Gaza Strip and the potential of renewable energy. The study clarified the aspect of building's thermal performance and its relation with the heat gain and loss between the building and the environment. Also, the study dealt with the factors affecting the building's thermal performance such as the climatic factors, the design variables and the physical properties of building's materials. The study overviewed the thermal comfort of buildings and its approaches. After that, the study referred to the climate responsive design and its strategies. It focused on the building's form and orientation and their variation according to the various climatic zones. In addition, the study handled with the Mediterranean climate of the Gaza Strip which is characterized with a long hot summer and a short cold winter which increases the importance of

cooling energy in summer. Furthermore, the study focused on evaluating the residential complexes in the Gaza Strip with regard to their form, building's and street's orientation, building's height and the sites coverage. It presented case studies for the residential complexes and summarized the more common geometries proportions and ratios in the Gaza Strip's buildings. The main findings of the theoretical study are:

- Buildings produce about 9% of global carbon dioxide (CO₂) emissions which increase annually at a rate of 2% from 1971 to 2004 with an annual increase of 1.7% for residential buildings.
- The developing Asia was found to have the largest increase in CO₂ emissions for residential buildings which reach 42%, followed by the Middle East with 19%.
- Gaza strip depends completely on Israel's energy and imports the fossil fuel required for electricity generation from Israel with high prices which results in high price electricity which estimated to be \$0.125 per kWh.
- The domestic sector consumes 70% of the total annual electricity in the Gaza strip.
- The electricity consumption of the Gaza Strip was increased by 80% during the period 1999 to 2005, and at about 10% average annual increasing rate.
- About 86% of households use a space heating facility while 80.7% of families used electrical devices for air conditioning and fans.
- Solar energy is considered the main renewable source of energy available in the Gaza Strip with an average duration of solar radiation range between (8-11) hours in summer period and between (5-7) hours in winter period which is useful for many applications. Solar heaters which are used to heat water are the most applicable application in Gaza houses.
- The building's form, spacing and configuration in its neighborhood affect both the solar and wind factors. They play a large role in determining the amount of solar radiation received by the building's surface and the airflow around it.
- Building envelope has a great influence on the total heat gain and overall heat transfer coefficient.
- Solar radiation is the most weather variable influences the air temperatures and affected by the reflections from the ground and adjacent buildings, shading from adjacent buildings and vegetation.
- Buildings height and distances between them can affect the formation of pressure zones which is inevitable in the direction of the wind.
- The passive solar homes generally require an average of about 30% less energy for heating than conventional houses, with some houses saving much more.
- Many factors affect the building shape such as planning considerations, building type and use, feasibility and initial cost. In all cases it have a large influence on reducing the building energy intensity.

- The geometry of buildings can affect the microclimatic conditions in the urban canopy layer (UCL) of open spaces of urban streets and courtyards which play an important role in the city's overall climate.
- The main factors that determine the relationship between solar insolation level and building shape are width to length ratio (W/L) and building orientation.
- Façade orientation affects the energy and comfort implications of solar shading, window to wall area ratio, window position and performance and choice of exterior color.
- Increasing the roof areas can play a significant role in the Mediterranean climates to increase the radiative exchanges in order to minimize the air temperature in external spaces especially near the ground.
- There are several design parameters in buildings of the Gaza Strip which can be utilized as a passive design elements in order to achieve thermal comfort. However, these elements were not selected according to thermal calculations.
- The residential complexes in the Gaza Strip don't pay a special attention to the climatic factors. Several shapes and proportions were found in the buildings which affect the amount of solar radiation.
- Orientation in some houses was taken into consideration in town, but in some cases the access to the lot of land affected the orientation and buildings take the same orientation of land plots due to the decrease in land area.
- The main form of buildings range between the square and rectangular as the rectangular shape is the most popular shape in parcels.

Accordingly, a parametrical studies were hold using the simulation programs ECOTECH and IES to investigate the effect of the form on the thermal performance and energy consumption. Hence, the study was divided into two parts. The first part concerned on understanding the relation between the building geometry, proportions, ratios and the thermal performance. This part dealt with geometries as a standalone building to avoid the effect of the adjacent buildings. On the other hand, the second part of the study was focused on the relation between the building geometry and the proportions of the urban canopy. Interaction between the building geometry and the urban canopy is a main determinant of the urban form and its thermal performance. For further clarification, the first part dealt with the main aspects which defines the building form which are the surface to volume ratio, the width ratio, the roof to walls ratio, the building height, the depth ratio in the convex shapes, the building geometry and the self shading. The building orientation is another aspect affecting the relation between the buildings' façades and the incident solar radiation falling on them.

Changing the building's geometry with constant area, height and volume was the subject of the first study. Changing the width to length ratio for the rectangular with the same area, height and volume and within ten orientations have been studied in the second study. The changing in the energy consumption as a consequence of varying the width ratio was related to the changing in the (s/v) ratio. The third study have focused on changing the width ratio with constant (roof/walls) ratio within various values of (roof/walls) ratio. As the (s/v) ratio was considered as the main factor affecting the

energy consumption in the three previous studies, the fourth study aimed to study the building morphology with a constant (s/v) ratio. Changing the building morphology was based on varying the building height with a regular interval equal to the storey's height (3 m). Also, a comparative study between a rectangular as a compact shape and the L, U and court shape as convex shapes was held in the fifth study. All the simulated cases have the same (s/v) ratio with varying in the depth ratio, (roof/walls) ratio and the geometric shape to investigate the effect of the self shading within various ratios.

The second part of the study concerned with the building's morphology in the urban context. The first study in this part focused on studying the building's dimensions as a function of the urban geometry. Hence, the spacing and aspect ratio were dealt in this study. The second study dealt with the building's height as a determinant of the urban density. So variation in the urban form based on two measures of the urban density; the site coverage and plot ratio were held in this study. Changing the building's orientation, street's orientation and the horizontal layout of building were held in the third study. The combination of these studies result in these conclusion:

- The surface to volume ratio is the main responsible for the thermal response in different geometric shapes.
- There is a slight difference between the refer shape and the square one which reaches to about 11%, 12.3% and 7.3% in the total, heating and cooling loads respectively. As the largest portion of buildings especially the residential have orthogonal polyhedral shapes, the square shape can be considered as the optimum thermal option.
- The rectangular shape can be adopted as it has a small difference from the refer shape which reaches to about 12.2%, 15.6% and 7.1% in the total, heating and cooling loads respectively.
- The rectangular, L, U and the court shapes increase in the (s/v) ratio from the refer shape by about (12.2%, 38.9%, 62.7% and 69% respectively). The percentage of increasing in the total loads for these four shapes are (7%, 23.9%, 38.6% and 44.7% respectively).
- Knowing the (s/v) ratio for the shape can help to predict the percentage this shape increases in the heating and cooling energy from the most compact shape with the same volume.
- The total loads are reduced by 39.6% with increasing the width to length ratio (W/L) from 0.1 to 1 at the East- West orientation (0E).
- The reduction in the total loads is more remarkable with increasing the (W/L) ratio from 0.1 to 0.5. About 37.4% of reduction in the total loads occurs with increasing the (W/L) ratio from 0.1 to 0.5 while only 3.5% of the reduction occurs with increasing the (W/L) ratio from 0.5 to 1.
- Changing the (W/L) ratio affects the total exposed surface and the relation between its two main components, the roof and the walls.
- The total loads for the simulated shapes are increased by 11% with changing the orientation from the East-West orientation (0E) to the North-South orientation (90E) for the shape with width ratio (W/L) equal to 0.1.

- The effect of changing orientation is not remarkable in the heating loads. While changing orientation from (0E) to (90E) increases the total loads, it reduced the heating loads by 1.6% in the shape with width to length ratio (W/L) equal to 0.1.
- The most effect of changing orientation can be noticed in the cooling loads. About 20.5% of the cooling loads can be increased with changing orientation from (0E) to (90E) in the shape with width to length ratio (W/L) equal to 0.1.
- Increasing the glazing ratio has the ability to decrease the effect of the (W/L) ratio in changing the required energy although the simulated cases have the same (s/v) ratio and orientation.
- Increasing the total loads required by the building geometries with the same (s/v) ratio as a result of increasing the height is more related to the decreasing in the (roof/walls) ratio which increases the vertical walls surfaces.
- Increasing the depth ratio in the convex shapes has the ability to increase the percentage of the shaded facades which help to reduce the required energy.
- Increasing the aspect ratio slightly decreased the cooling loads and greatly increases the heating loads in the East- West streets. In contrast, it largely decreases the cooling loads and slightly increases the heating loads in the North-South streets.
- The ground and middle floors adversely affected by the mix vertical configuration due to the increasing in the spacing ratio while the upper floors take the advantages of adjacent shading.
- The South- east apartment and North - east apartment are more adversely affected by the mix vertical configuration than the South- west apartment and the North– west one.
- Increasing the plot ratio from 2 to 6 reduces total loads by about 9%.
- Increasing the plot ratio affects significantly the cooling loads with a slight effect on the total loads.
- Changing the street orientation from the east- west to the north- south orientation can increase the cooling loads by about 7.2%.

6.1 Recommendation

- It is necessary to utilize renewable energy sources in buildings in order to mitigate the environmental problems and the ever increase in using the conventional sources of energy.
- It is important to eliminate the thermal transfer rate between the building envelop and surrounding environment in ways of conduction, convection and radiation in order to maintain the thermal balance.
- It is required to utilize passive solar design strategies by controlling the architectural elements and a building's material properties with respect to the climatic factors.

- Sufficient account must be taken in the Mediterranean climate especially to the building's form and configuration as the solar radiation is the most important parameter in this climate.
- The compact form which contain the same volume with the smallest (s/v) ratio is recommended in the climate of the Gaza Strip.
- More attention must be paid to the width to length ratio in the North- South orientation even between the shapes of width to length ratio ranging between 0.5 and 1.
- It is recommended to pay more attention in selection orientation especially in the shapes with smallest width to length ratio.
- The East-West orientation (0E) is considered the optimum orientation in all cases while the orientation from (70E) to (90E) is considered as the worst orientation in all cases except the square shape which have the worst orientation equals to (45E) with unnoticeable differ in energy consumption.
- It is recommended to use shapes with the (roof/ walls) ratio ranges between 0.4 to 0.6 which is more preferable for both cooling and heating requirements.
- It is recommended to use the horizontal arrangements of residential apartments which is better thermally than the vertical arrangements of the same (s/v) ratio.
- It is recommended to increase the depth ratio in the convex shapes in order to increase the percentage of the shaded façades which help to reduce the required energy.
- The court shape followed by the L shape and the U shape is more preferable option for building's arrangements than the rectangular shape of the same (s/v) ratio.
- It is advisable to use a spacing ratio (L1/L2) equals 0.1 and aspect ratio (H/W) equals 0.5 which is the preferable option in the (E-W) street in order to be applied in the Gaza Strip has. The more preferable option in the (N-S) street has a spacing ratio (L1/L2) equals 1.2, and aspect ratio (H/W) equals 4.
- A large aspect ratio is advisable for reducing the heating loads in the East- West due to the increasing in the solar potential on the south façades.
- Increasing the aspect ratio in the north- south streets can enhance the thermal performance of their building and reduce the difference between them and the optimum orientation of the street.
- A high site coverage is recommended in order to reduce the cooling and heating requirements with a possibility to enhance its heating performance by increasing the spacing in front of the south façades.
- It is recommended to utilize the advantages of the mutual vertical arrangements of building in achieving shading on the roof and building's façades by using different height of buildings.

- It is recommended that the Land Authority and the Stakeholders take into consideration the relation between street orientation and plot shape.
- It is recommended to avoid the bad effect of the north- south orientation of the building by protecting its east and west sides by adjacent buildings in order to increase the shaded area and enhance its thermal response.
- The regular horizontal configuration is more advisable than the mutual one due to the bad effect of the mutual configuration in decreasing the adjacent shading which adversely affects the cooling loads.

6.2 Limitations of Results

As a final remark, there are some limitations of the results. First, the study was based on the Mediterranean climate of the Gaza Strip and the simulation used AL-Arish weather data. Second, the simulation considered the solar radiation so all the results obtained from the study comes from the thermal point of view. Other environmental variable such as ventilation, day lighting, urban heat island effect, sky view factor, land and resources weren't considered. In real cases simulation, all of these factors have to be considered in a compromise manner to achieve the best scenario. Thus, further investigations with a range of environmental variable may carried out. Third, the study is fundamentally based on computer simulation namely ECOTECH and IES. Although the simulation programs employed have been widely validated, variations in architectural features could significantly affect the outcomes.

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Appendix 1

The basic equation of heat conduction is (Nayak, et al. 2006):

$$Q_{\text{conduction}} = \frac{k A (T_h - T_c)}{L} \quad (1.1)$$

where $Q_{\text{conduction}}$ = quantity of heat flow (W)

k = thermal conductivity of the material (W/m-K)

A = area (m²)

L = thickness (m)

T_h = temperature of the hot surface (K)

T_c = temperature of the cold surface (K)

The rate of heat transfer ($Q_{\text{convection}}$) by convection from a surface of area A , can be written as:

$$Q_{\text{convection}} = h A (T_s - T_f) \quad (1.2)$$

where, h = heat transfer coefficient (W/m²-K)

T_s = temperature of the surface (K)

T_f = temperature of the fluid (K)

The numerical value of the heat transfer coefficient depends on the nature of heat flow, velocity of the fluid, physical properties of the fluid, and the surface orientation, (Nayak, et al. 2006).

The radiation exchange ($Q_{\text{radiation}}$) between the exposed parts of the building and the atmosphere is given by (Nayak, et al. 2006):

$$Q_{\text{radiation}} = A \varepsilon \sigma (T_s^4 - T_{\text{sky}}^4) \quad (1.3)$$

where A = area of the building exposed surface (m²)

ε = emissivity of the building exposed surface

T_s = temperature of the building exposed surface (K)

T_{sky} = sky temperature (K)

a. Thermal Conductivity λ

Apparent thermal conductivity is defined based on test results as (Straube, 2007):

$$k_{\text{eff}} = Q L / (T A) \quad (1.4) \quad \text{where}$$

k_{eff} is the effective thermal conductivity

Q is the measured rate of heat flow

L is the thickness of the sample (equal to the length of flow path)

T is the temperature difference, and

A is the area through which heat flow is measured.

b. Thermal Resistance of a Material, R or R -value

R -value is defined by testing an assembly of known area exposed to a known temperature difference (Straube, 2007):

$$R = (T A) / Q \quad (1.5) \quad \text{where}$$

R is thermal resistance
 T is the temperature difference
 A is the area through which heat flow is measured, and
 Q is the rate of heat flow.

a. Heat Transfer Rate through the Building Walls

The heat transfer rate through opaque building walls per unit floor area, \hat{U}_{wall} , is expressed mathematically as (Utzing et al. 1997):

$$\hat{U}_{\text{wall}} = \frac{U_{\text{wall}} A_w}{A_f}$$

b. Heat Transfer Rate through the Building Roof

The heat transfer rate through the building roof per unit floor area, \hat{U}_{roof} , is expressed mathematically as (Utzing et al. 1997):

$$\hat{U}_{\text{roof}} = \frac{U_{\text{roof}} A_r}{A_f}$$

c. Heat Transfer Rate through the Building Glazing

\hat{U}_{glzg} , is given by (Utzing et al. 1997):

$$\hat{U}_{\text{glzg}} = \frac{U_{\text{glzg}} A_g}{A_f}$$

d. Heat Transfer Rate through the Ground

\hat{U}_{grnd} , is expressed mathematically as (Utzing et al. 1997):

$$\hat{U}_{\text{grnd}} = \frac{U_{\text{grnd}} \text{Perimeter}}{A_f}$$

1.5.4 Building Internal Heat Gains

The total internal heat gain rate per unit floor area, Q_{IHG} , can be estimated by

$$Q_{\text{IHG}} = Q_{\text{people}} + Q_{\text{light}} + Q_{\text{equip}}$$

Where Q_{people} is the heat gain from people occupying the building; Q_{light} is the heat gain from lights used in the building and Q_{equip} is the heat gain from electrical equipment used by the building occupants. All three paths for internal heat gains are given in Btu of heat added to the building per hour per square foot of floor area (Utzing et al. 1997).

Appendix 2

2.1 Passive Heating Strategies

Passive heating strategies depend upon the principle of avoiding heat loss and maximizing heat gain. This section will introduce the main types of passive heating which include direct gain, indirect gain, isolated gain and sunspace.

2.1.1 Direct Gain

one of the simplest and widely used approaches in the passive heating is the direct gain. Solar radiation enters the indoor environment by two paths, directly through windows and glasses and indirectly through walls and floors. Walls and floors must have a storage capacity in order to store heat and released it to the living space at night. Also, they must have a level of insulation to avoid heat loss at night. A large area of south windows in the northern hemisphere is necessary to maximize the amount of heat gain during winter with a suitable overhangs to avoid unnecessary heat gain in summer (Nayak and Prajapati, 2006). Figure (1) illustrates the components of a direct gain system.

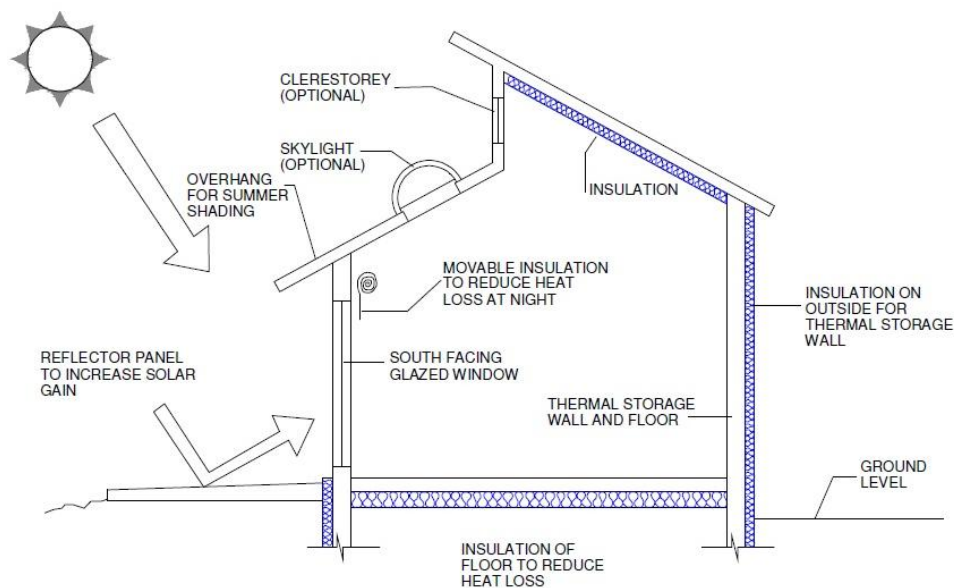


Figure (1): Components of a direct gain system

Source: Nayak and Prajapati, (2006)

2.1.2 Indirect Gain

In the indirect gain system the glazed area is separated from the living space by a thermal storage wall such as the Trombe wall, mass wall, water wall. This separating has an advantage of avoiding the direct admitting of solar radiation. The thermal storage wall which preferably laying in the southern facades in the northern hemisphere can be provided with glazing to provide light and view. The glazed have to be insulated to avoid heat loss at night with a suitable shading to reduce heat gain in summer (Nayak and Prajapati, 2006). Figure (2) clarifies the working principle of a Trombe wall as an example of a direct gain system.

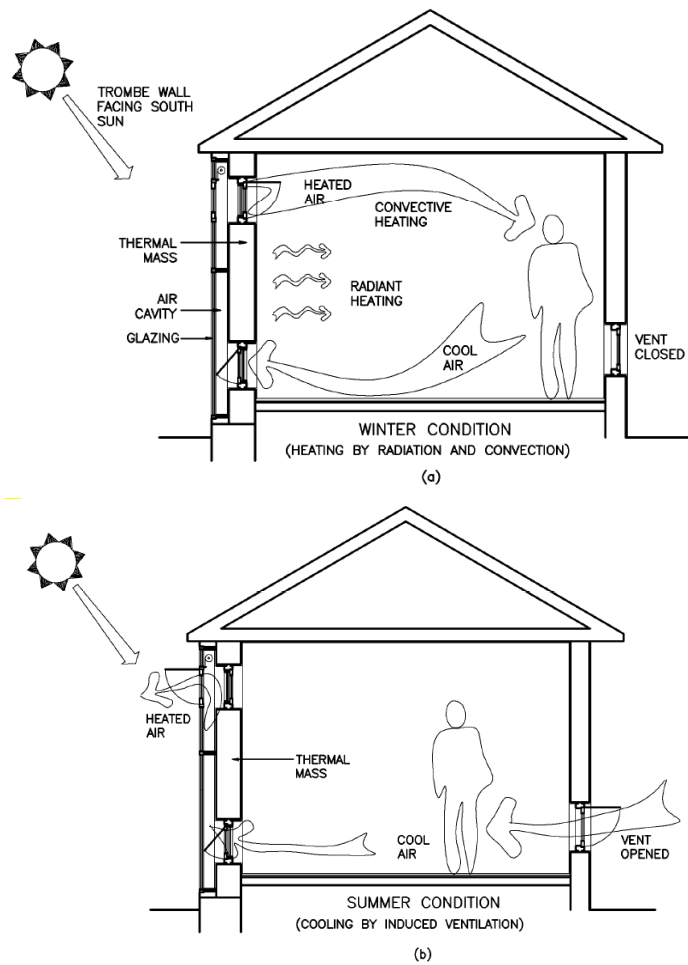


Figure (2): Working principle of a Trombe wall
Source: Nayak and Prajapati, (2006)

2.1.3 Isolated Gain

This system depends on isolating the solar radiation collection and storage from the living spaces of the building. The natural convective loop is an example of the isolated gain system. The loop contains air or water which heated by the absorbed solar radiation and thus rises and passes through the storage area, transferring its heat. The cooler air falls onto the absorber to get heated up again (Nayak and Prajapati, 2006). See figure (3).

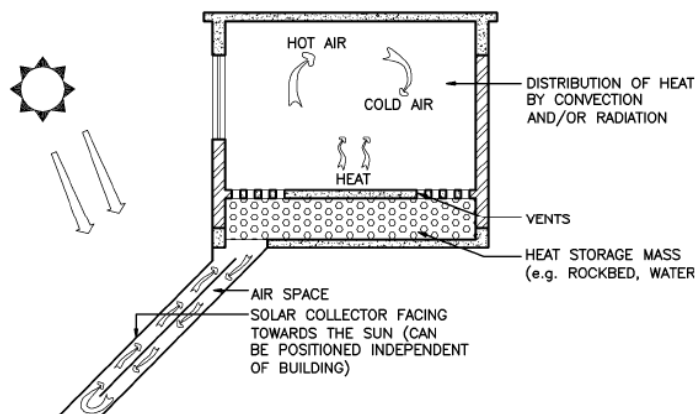


Figure (3): Working principle of isolated gain
Source: Nayak and Prajapati, (2006)

2.1.4 Solarium (Sunspace)

A solarium can be considered as a mixed system which integrates the direct gain system with the thermal storage system. Solar radiation admitted directly into the sunspace heats up the air, which, by convection and conduction through the mass wall reaches the living space (Nayak and Prajapati, 2006). The best orientation for sunspace is south, although deviation of up to 25° east or 15° west are acceptable. Optimum tilting is around 60° (Colombo *et al.* 1994). Figure (4) shows the working principle of a solarium.

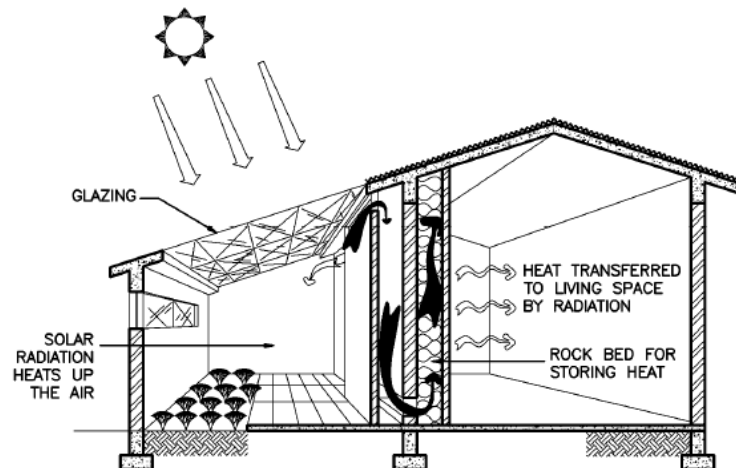


Figure (4): Working principle of a solarium
Source: Nayak and Prajapati, (2006)

2.2 Passive Cooling Strategies

Cooling is a main source of thermal comfort in building especially in summer season. Passive cooling strategies depend upon the principle of avoiding unwanted heat gain and creating cooling sources by utilizing the surrounding air and ground (Goulding *et al.* 1992). This section will introduce the main types of passive cooling which include ventilation cooling, ground cooling, evaporative cooling and radiative cooling.

2.2.1 Ventilation cooling

Ventilation provides cooling by using air to carry heat away from the building and from the human body. Air movement may be induced either by natural forces (wind and stack effect) or mechanical power. Air flow patterns are the result of differences in the pressure distribution around and within the building. Air moves from high pressure regions to low pressure ones.

When the outside air temperature is lower than the inside air temperature, building ventilation may exhaust internal heat gains or solar gains during the day and may flush the building with cool air during the night if required. Indoor air movement enhances the convective exchange at the skin surface and increases the rate of evaporation of moisture from the skin. Both the design of the building itself and its surrounding spaces can have a major impact on the effectiveness of natural cooling. Some ventilation strategies are wind towers and solar chimney (Goulding *et al.* 1992).

2.2.2 Ground cooling

There are a temperature difference between the earth surface and its ground. This difference can be utilized as a cooling source. Ground cooling can be used in building by keeping part of the building in direct contact with the ground and heat dissipation to the ground can be achieved by conduction or by convection. Another method is the

buried pipe in which air from the building or from outside is circulated through buried pipes where it is precooled before it enters the building (Goulding *et al.* 1992). See figure (5).

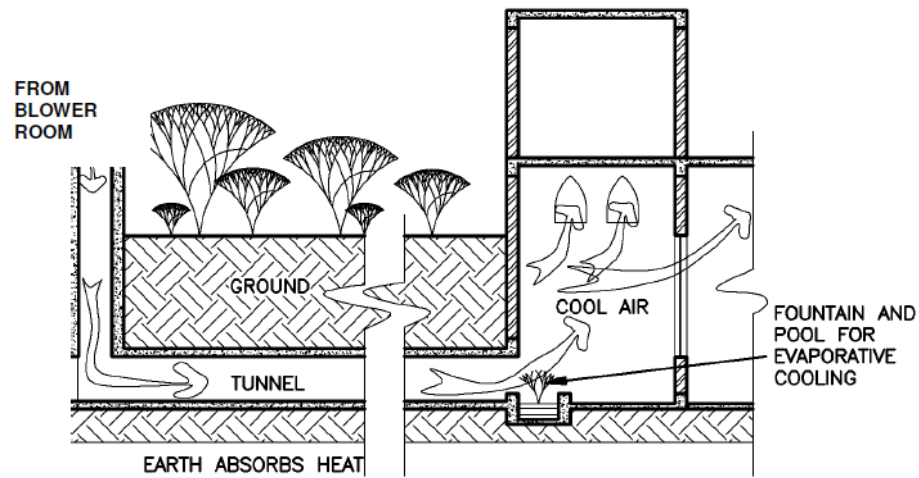


Figure (5): Working principle of buried pipes
Source: Nayak and Prajapati, (2006)

2.2.3 Evaporative cooling

Evaporation occurs when water change from its liquid statues to a vapor statues. This process required a quantity of sensible heat from surroundings to be released. Thus the evaporation process accompanied by reduction in the air temperature and this cooling effect is called evaporative cooling. There are two types of evaporative cooling; direct evaporative cooling which accompanied by increasing in air moister and indirect evaporative cooling which occurs without increasing in air moister. This process can occurs passively through the building envelop using wetted surfaces in the incoming ventilation stream (Goulding *et al.* 1992). Evaporative cooling towers that humidify the ambient air can be used. This is direct evaporative cooling. However, the building roof can be cooled with a pond, wetted pads or spray, and the ceiling transformed into a cooling element that cools the space below by convection and radiation without raising the indoor humidity and this is the passive indirect evaporative cooling, see figure (6) (Nayak and Prajapati, 2006).

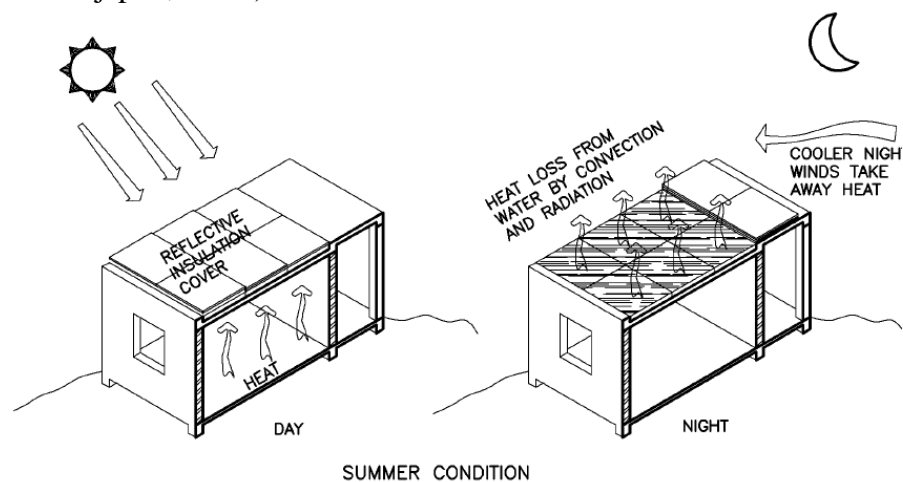


Figure (6): Working principle of a roof pond as indirect evaporative cooling system
Source: Nayak and Prajapati, (2006)

2.2.4 Radiative cooling

Heat transfer from warmer body to a cooler one through electromagnetic radiation. This process requires a mass which can absorb heat during the day and release it to the cool air at the night. Heavyweight materials in the building envelop (walls and roofs) such as concrete and masonry can absorb heat and release it to the sky at the night thereby cooling the envelope, see figure (7) (Goulding, et al, 1992). Building roof is considered the most effective element in radiative cooling as it expose the most part of solar radiation. Radiative cooling is most effective in hot-arid- climates where there are large difference of temperature between day and night (Nayak, et al, 2006).

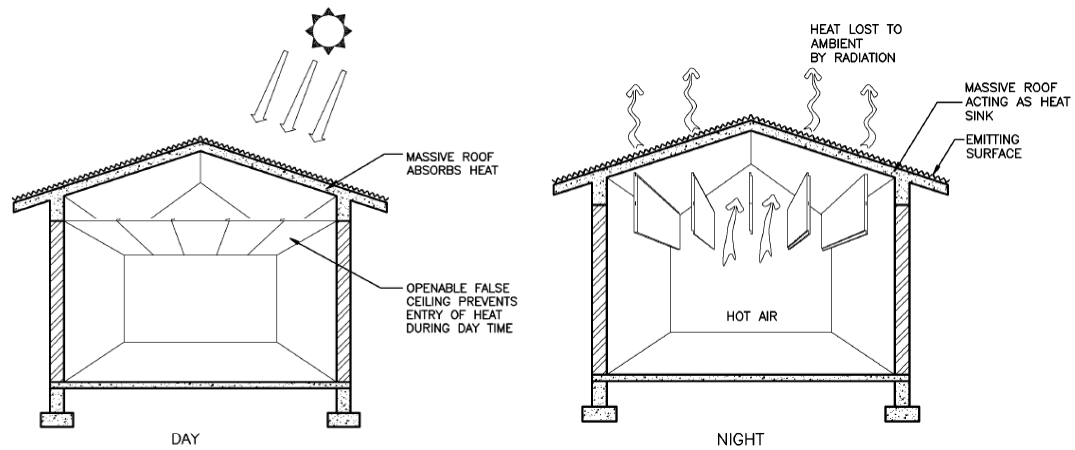


Figure (7): Working principle of a radiative cooling system
Source: Nayak and Prajapati, (2006)

Appendix 3

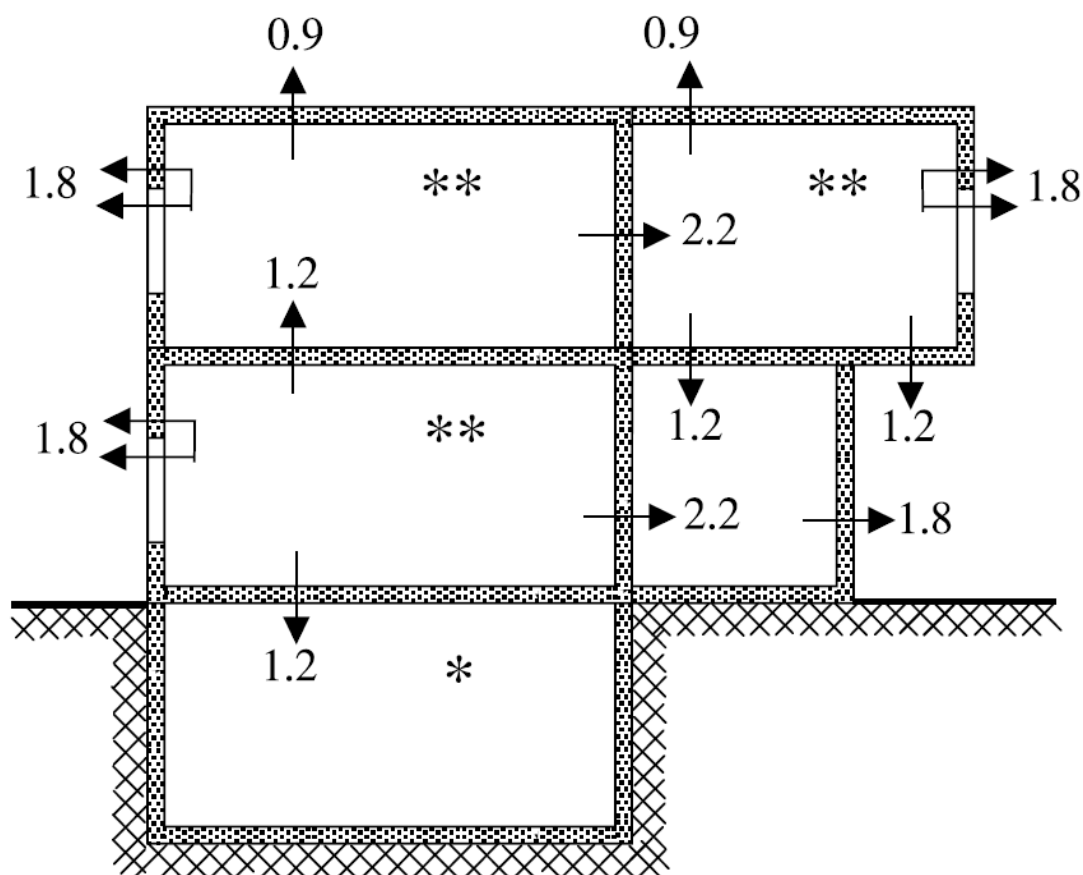


Figure (1): The minimum requirements of the maximum U-values ($W/m^2 \cdot K$) for walls, roofs and floors in Palestine

Source: Ministry of Local Government, (2004)

Table (1): Default settings for ECOTECH and IES

	ECOTECH	IES
Location and Site Data		
Location		
Weather File Data	El_Arish file	El_Arish file
Latitude	31.08 N	31.08 N
Longitude	33.82 E	33.82 E
Altitude (m)	32.0	32.0
Site Data		
Ground reflectance	0.2	
Terrain types	Suburbs	Urban
Wind exposure	Normal	Normal
Thermal Condition		
HVAC System	Full Air Conditioning	Full Air Conditioning
Thermostat Range	18.0 ⁰ C- 26.0 ⁰ C	18.0 ⁰ C- 26.0 ⁰ C
Heating set point	18.0 ⁰ C	18.0 ⁰ C
Cooling set point	26.0 ⁰ C	26.0 ⁰ C
Domestic Hot Water DHW Consumption	0.0	0.0
Use of the building/ Hours	On continuously	On continuously

of Operation		
Model settings		
Solar reflected fraction	-	0.05
Furniture mass factor	-	1.00
Design condition		
Clothing (clo)	1.0	-
Humidity	60.0	-
Air speed	0.5 m/s	-
Lighting level	300 lux	300 lux
Occupancy	0	0
Internal heat gain		
Sensible gain	0	0
Latent gain	0	0
Infiltration rate		
Air change rate	0	0
Wind Sensitivity	0	0
Construction		
Exterior walls		
U-value	1.77	1.9487
Roof		
U-value	0.896	0.9165
Ground-contact/exposed		
U-value	0.88	0.7059
Window		
U-value	6.0	5.5617

ECOTEECT Setting

Location and Site Data in ECOTEECT

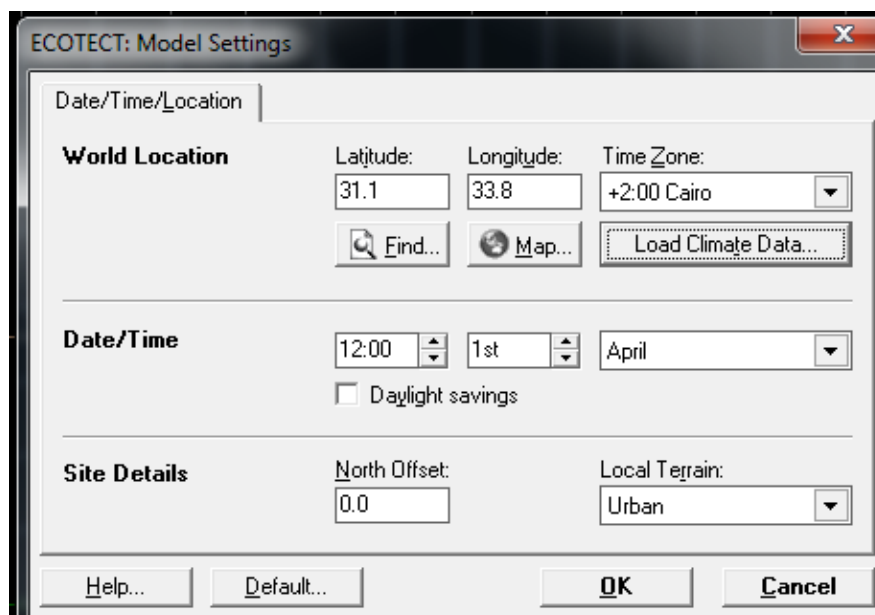


Figure (2): Location and Site Data in ECOTEECT

Thermal properties for zones in ECOTECT

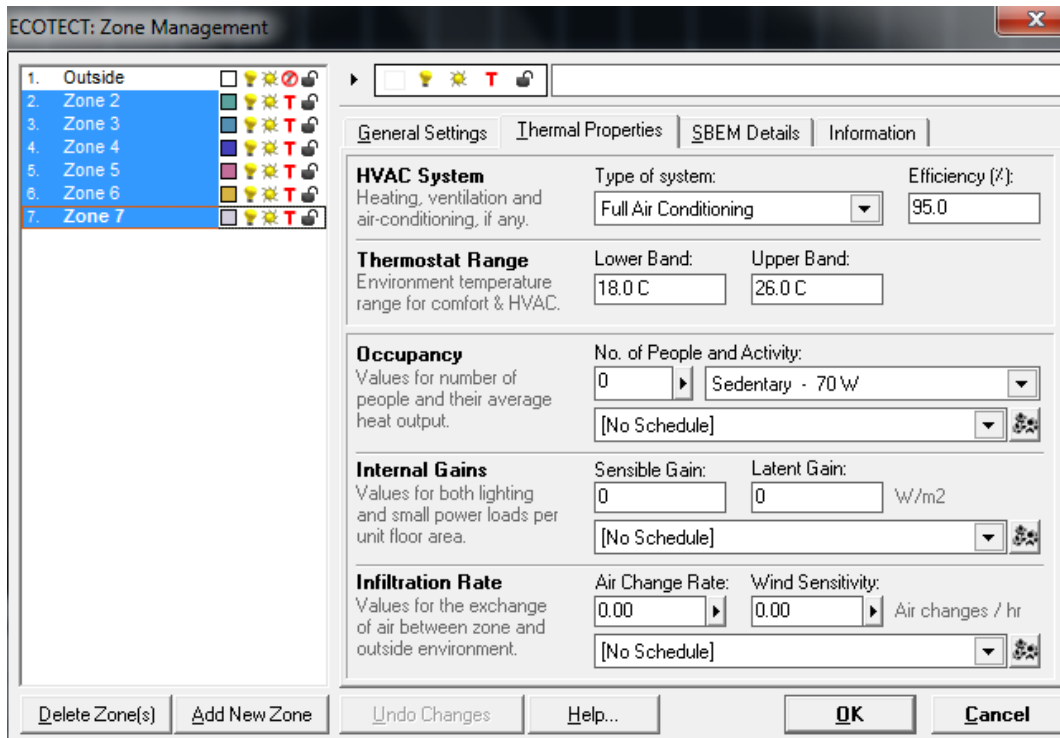


Figure (3): Thermal properties for zones in ECOTECT

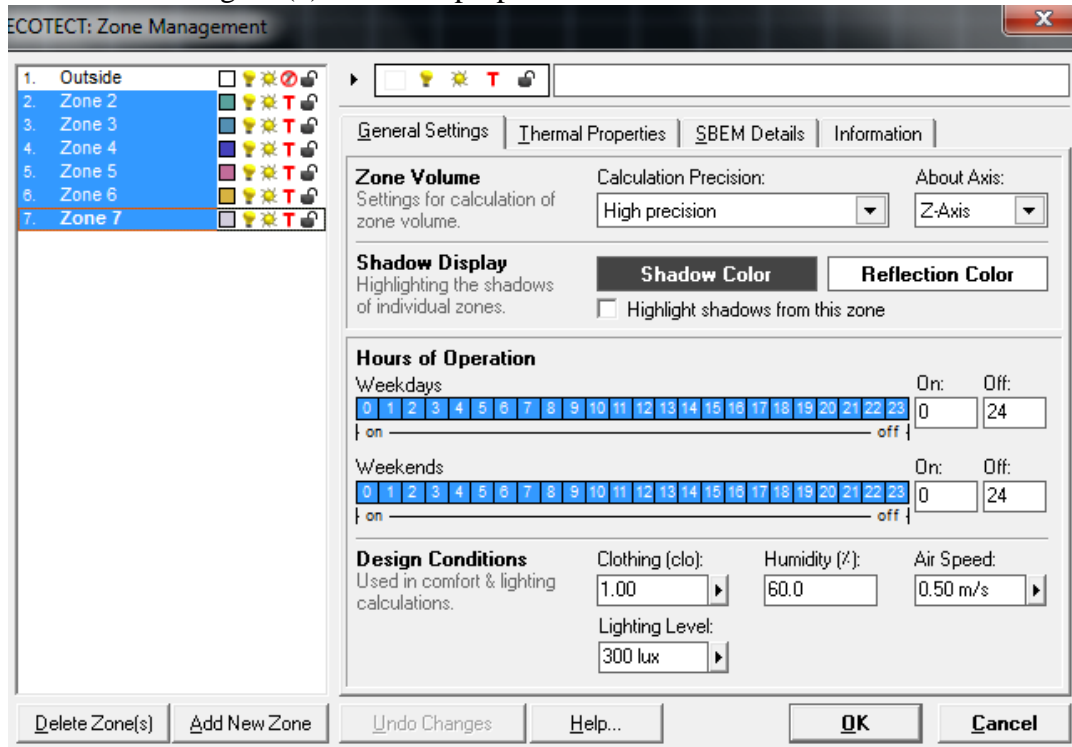


Figure (4): General Settings for Zones in ECOTECT

Materials Assignment in ECOTECT

Walls: U-value= 1.77 W/m² °K and Thermal Lag= 4 hrs, see figures (5) and (6).

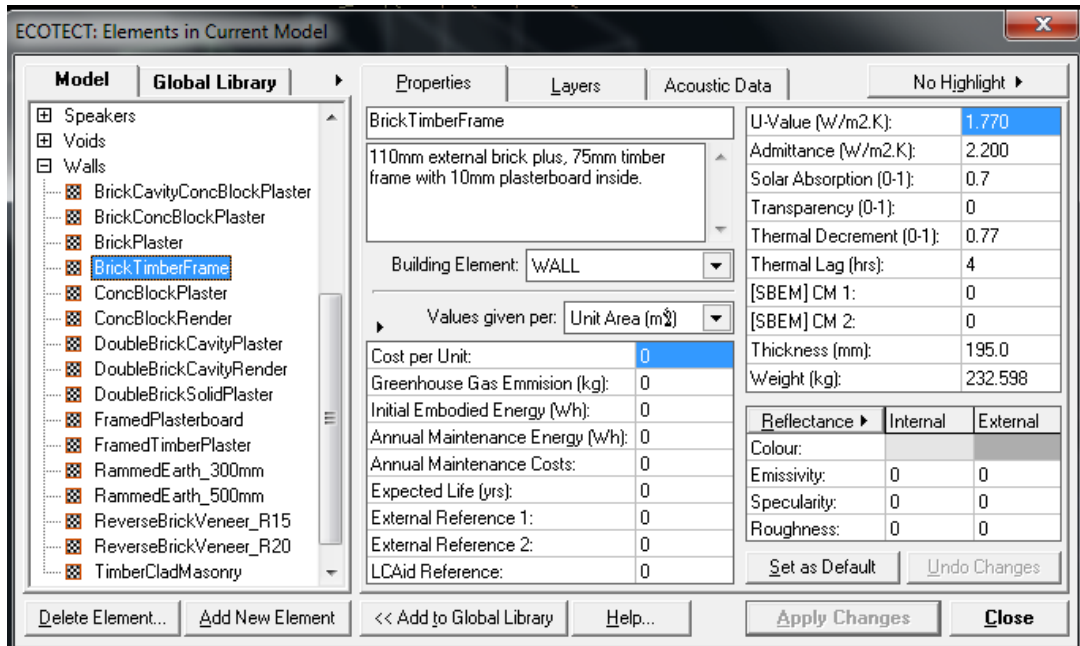


Figure (5): Properties of walls material in ECOTECT

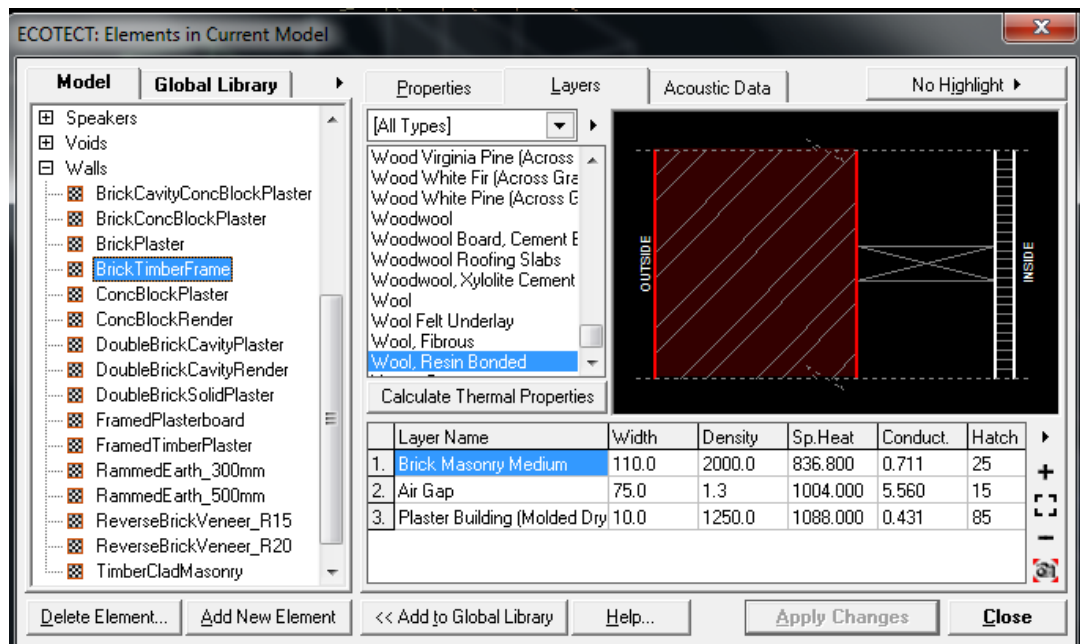


Figure (6): Layers of walls material in ECOTECT

Roof: ConcreteRoof_Aspphalt1 with U-value= 0.896 W/m² °K and Thermal Lag= 7 hrs, see figure (7) and figure (8).

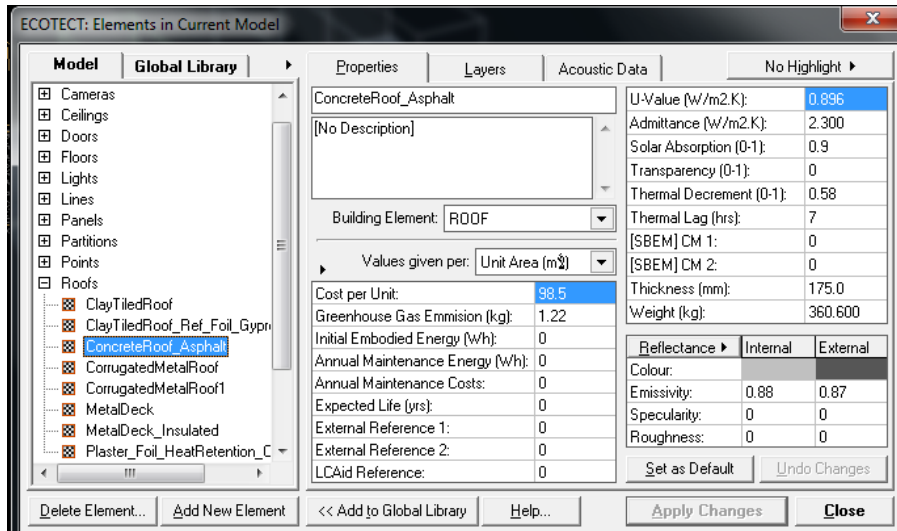


Figure (7): Properties of roof material in ECOTECT

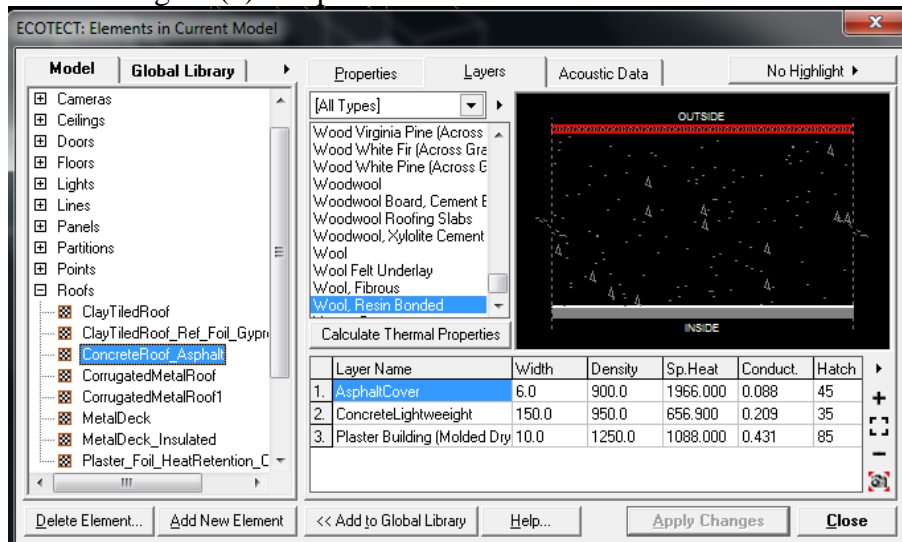


Figure (8): Layers of walls material in ECOTECT

Ground: ConcSlab_On Ground with U-value= 0.88 W/m² °K , see figure (9) and (10).

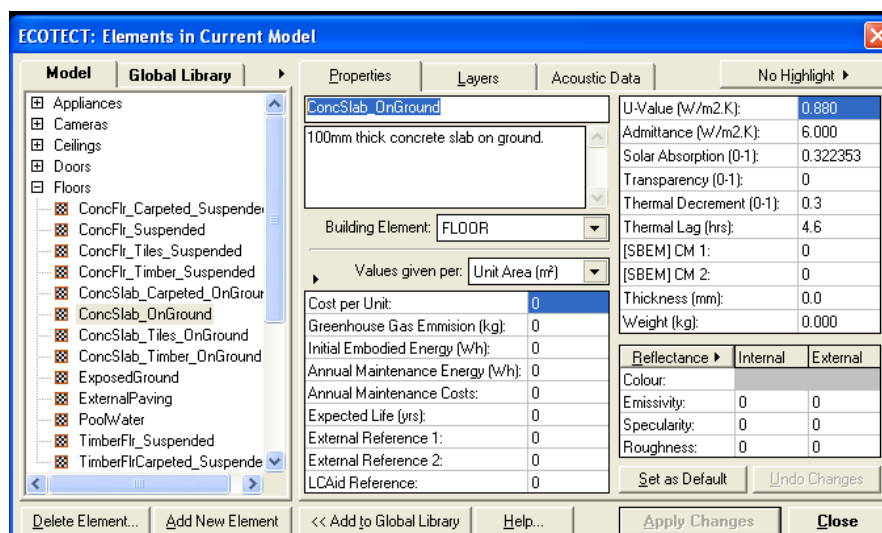


Figure (9): Properties of roof material in ECOTECT

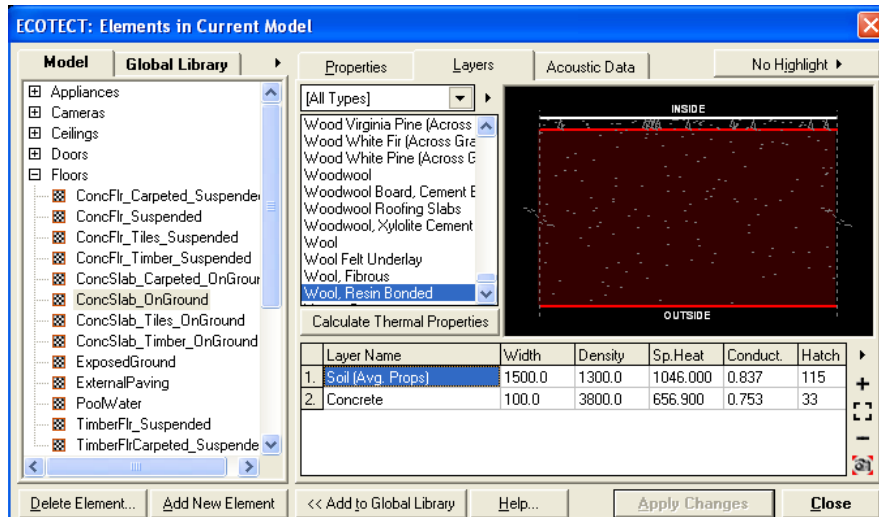


Figure (10): Layers of walls material in ECOTECT

Glass: Single Glazed with Aluminum Frame with U-value= 6 W/m² °K , see figure 16.

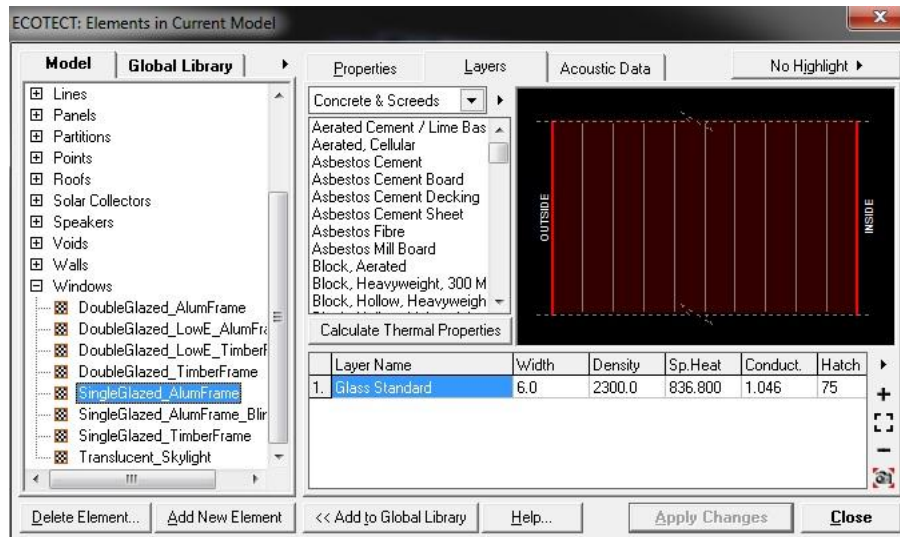


Figure (11): Layers of Glass material in ECOTECT

IES Setting

Location and site data

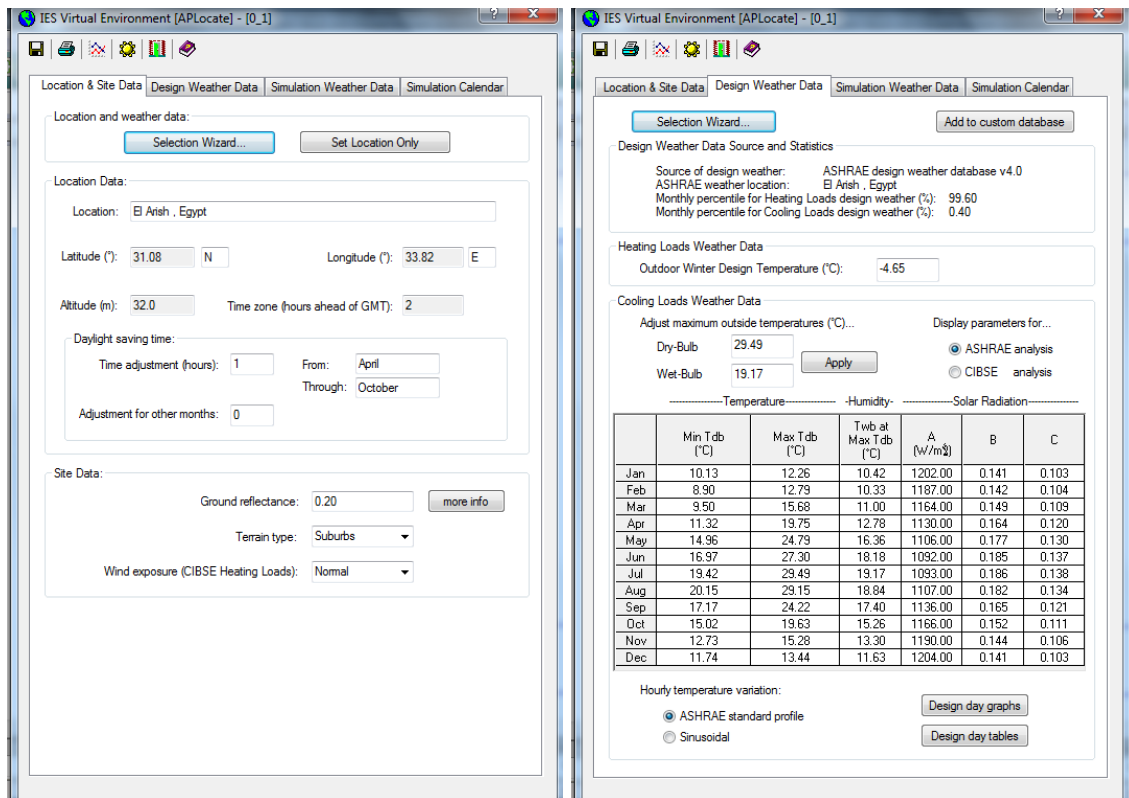


Figure (12): a: Location and site data, b: Design weather data

Setting of SunCast

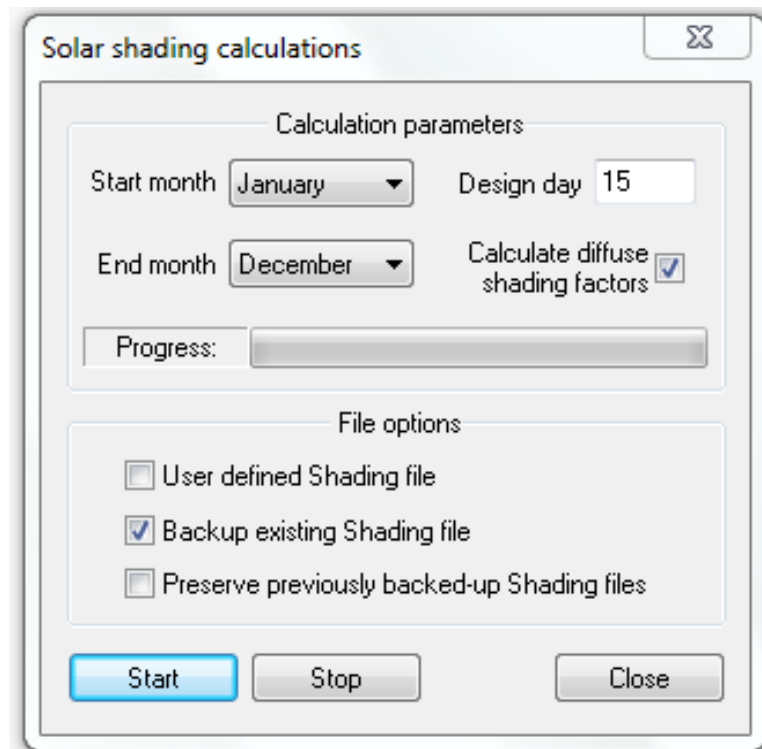


Figure (13): Setting of SunCast

Setting of ApacheSim

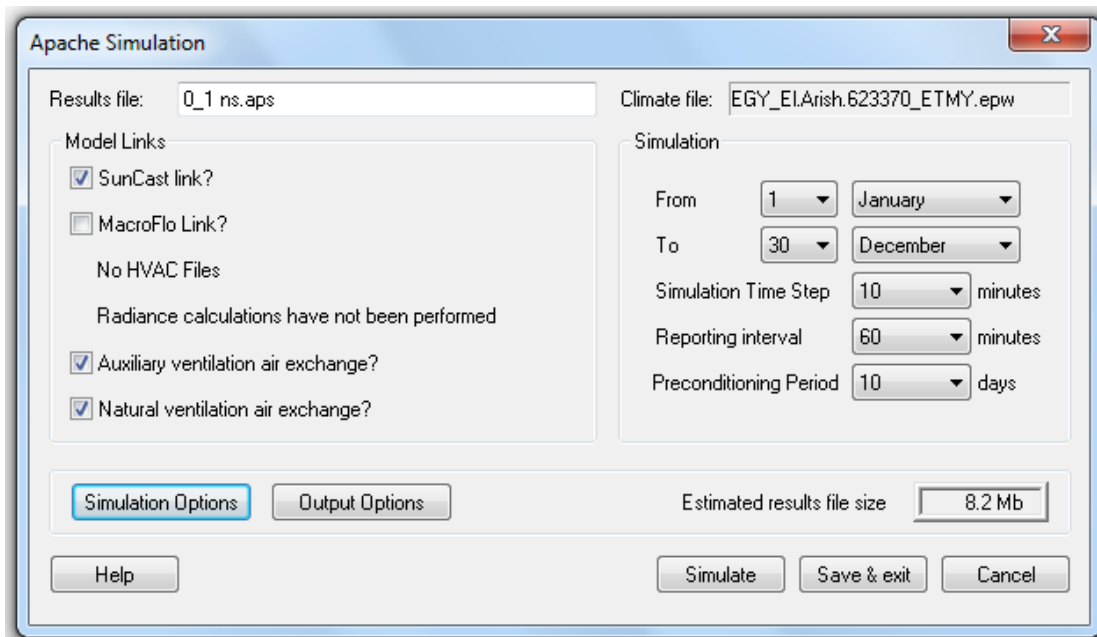


Figure (14): Setting of ApacheSim (dynamic simulation)

Building Template Manager

Thermal condition

Room condition

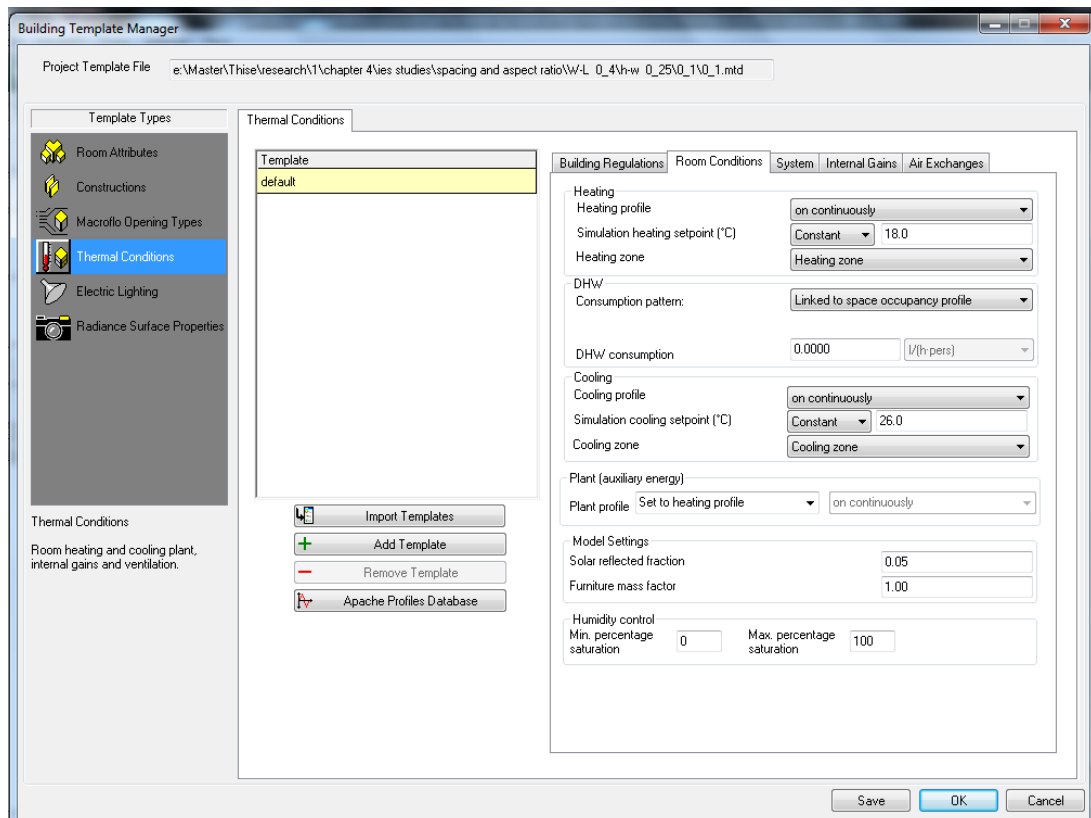


Figure (15): Room Thermal condition in IES

Construction in IES

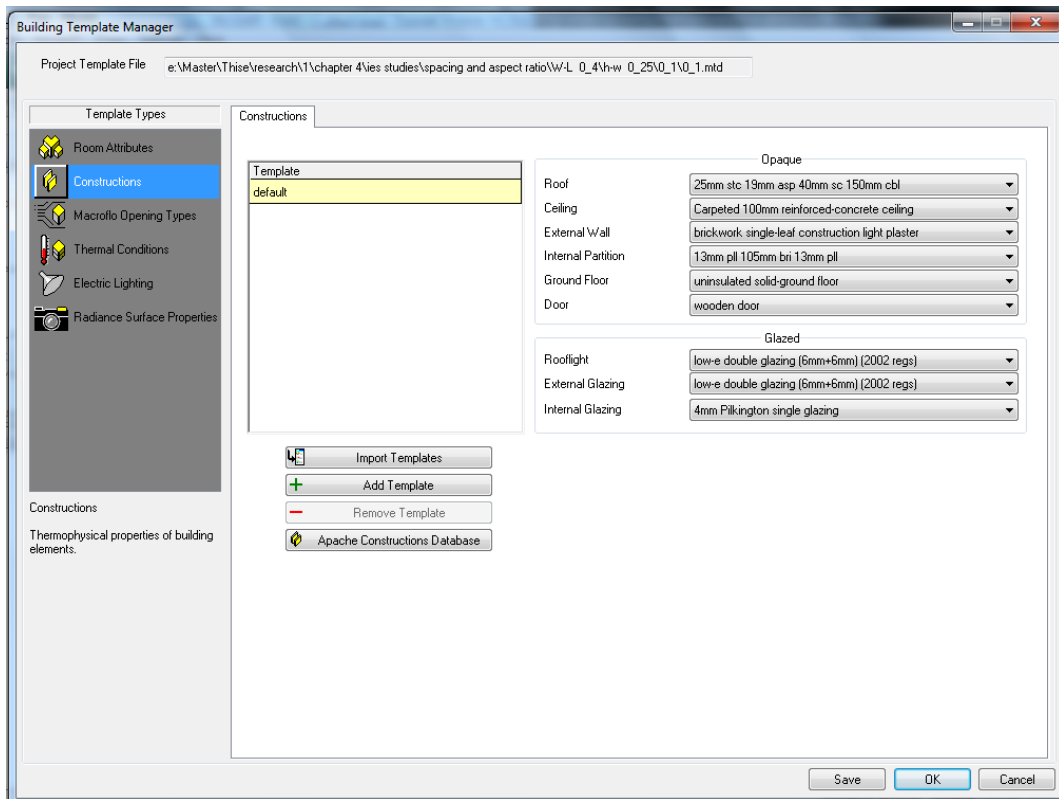


Figure (16): Construction in IES

Apache construction database

External wall: brickwork single-leaf construction light plaster

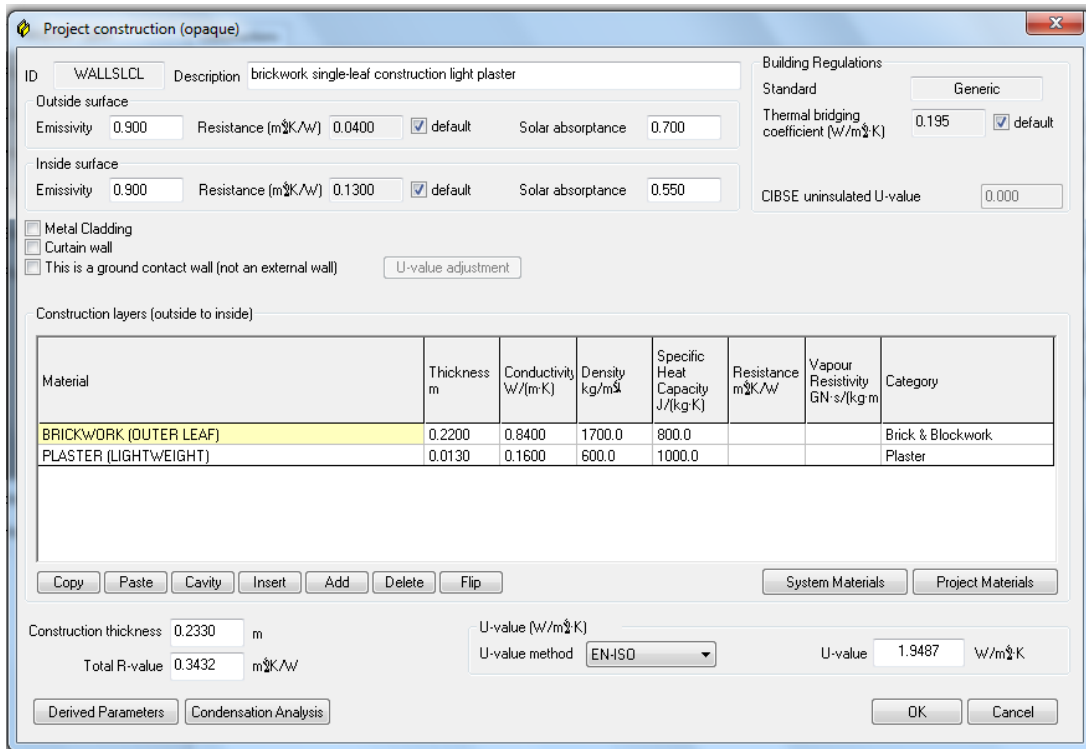


Figure (17): Layers of walls material in IES

Roof: 25mm stc 19mm asp 40mm sc 150mm cbl

Project construction (opaque)

ID: RF4 Description: 25mm stc 19mm asp 40mm sc 150mm cbl

Outside surface
 Emissivity: 0.900 Resistance (m²K/W): 0.0400 default Solar absorptance: 0.700

Inside surface
 Emissivity: 0.900 Resistance (m²K/W): 0.1000 default Solar absorptance: 0.550

Metal Cladding

Building Regulations
 Standard: Generic
 Thermal bridging coefficient (W/m²K): 0.092 default

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m.K)	Density kg/m ³	Specific Heat Capacity J/(kg.K)	Resistance m ² K/W	Vapour Resistivity GN s/(kg.m)	Category
STONE CHIPPINGS	0.0250	0.9600	1800.0	1000.0			Sands, Stones and Soils
ASPHALT	0.0190	0.5000	1700.0	1000.0			Asphalts & Other Roofing
SCREED	0.0400	0.4100	1200.0	840.0			Screeds & Renders
CONCRETE BLOCK (LIGHTWEIGHT)	0.1500	0.1900	600.0	1000.0			Concretes

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness: 0.2340 m
 Total R-value: 0.9511 m²K/W
 U-value method: EN-ISO U-value: 0.9165 W/m²K

Derived Parameters Condensation Analysis OK Cancel

Figure (18): Layers of roof material in IES

Ground: uninsulated solid-ground floor

Project construction (opaque)

ID: SGFLR Description: uninsulated solid-ground floor

Outside surface
 Emissivity: 0.900 Resistance (m²K/W): 0.0400 default Solar absorptance: 0.700

Inside surface
 Emissivity: 0.900 Resistance (m²K/W): 0.1700 default Solar absorptance: 0.550

Metal Cladding

This is a solid ground-contact floor (not an exposed floor) U-value adjustment

Building Regulations
 Standard: Generic
 Thermal bridging coefficient (W/m²K): 0.071 default
 CIBSE uninsulated U-value: 0.603

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m.K)	Density kg/m ³	Specific Heat Capacity J/(kg.K)	Resistance m ² K/W	Vapour Resistivity GN s/(kg.m)	Category
LONDON CLAY	0.7500	1.4100	1900.0	1000.0			Sands, Stones and Soils
BRICKWORK (OUTER LEAF)	0.2500	0.8400	1700.0	800.0			Brick & Blockwork
CAST CONCRETE	0.1000	1.1300	2000.0	1000.0			Concretes
SCREED	0.0500	0.4100	1200.0	840.0			Screeds & Renders
SYNTHETIC CARPET	0.0100	0.0600	160.0	2500.0			Carpets

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness: 1.1600 m
 Total R-value: 1.2066 m²K/W
 U-value method: EN-ISO U-value: 0.7059 W/m²K

Derived Parameters Condensation Analysis OK Cancel

Figure (19): Layers of ground material in IES

Floor plans for various width to length ratio (W/L)

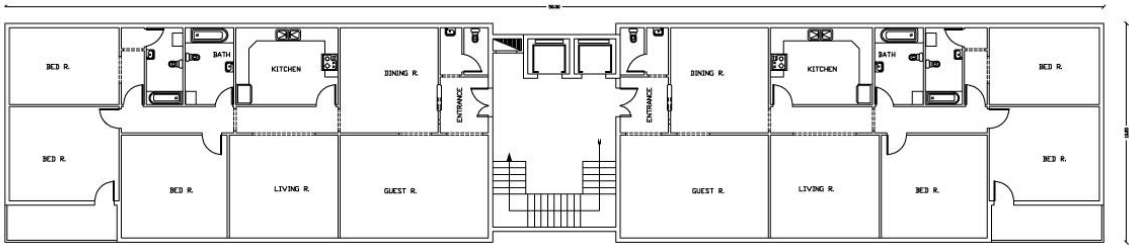


Figure (20): Floor plan of residential building with a width ratio (W/L) equals 0.2

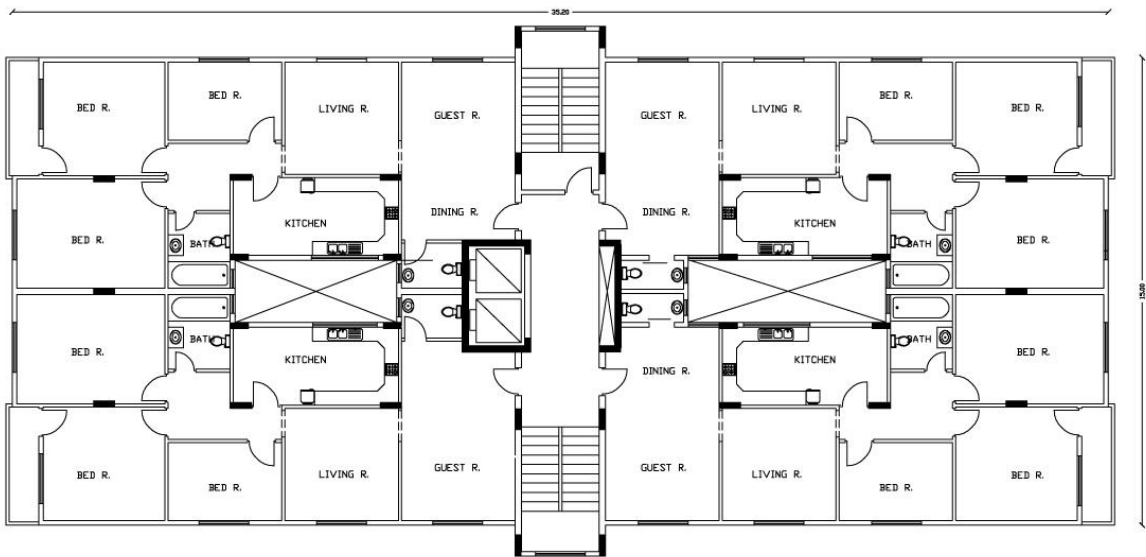


Figure (21): Floor plan of residential building with a width ratio (W/L) equals 0.4

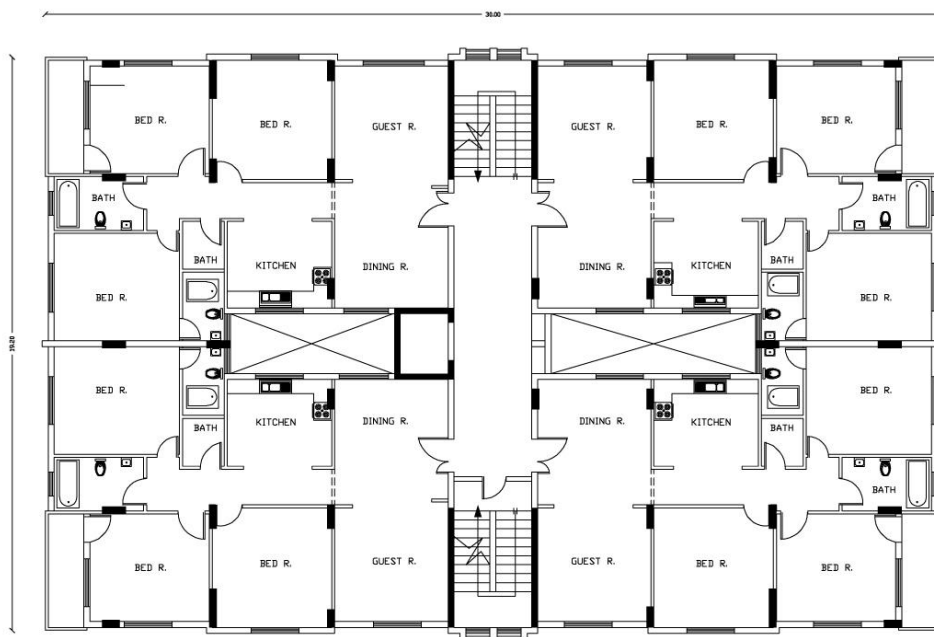


Figure (22): Floor plan of residential building with a width ratio (W/L) equals 0.6

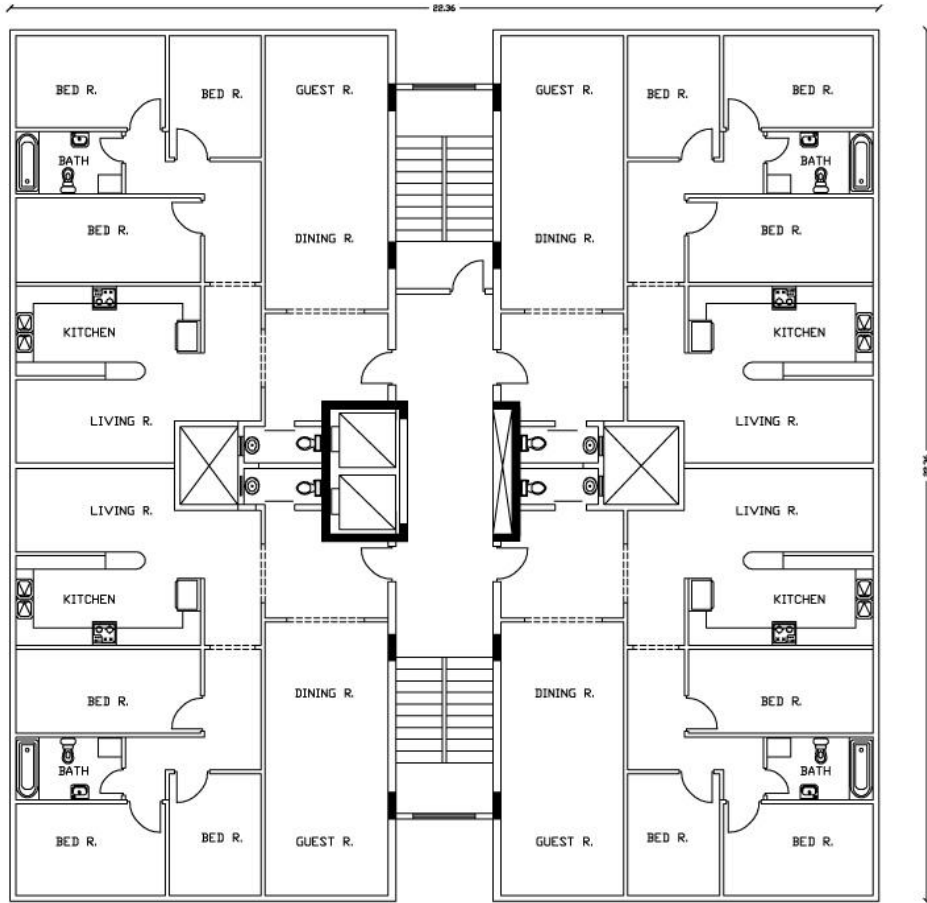


Figure (23): Floor plan of residential building with a width ratio (W/L) equals 1



الجامعة الإسلامية- غزة

عمادة الدراسات العليا

كلية الهندسة

قسم الهندسة المعمارية

تأثير لشكل المبنى على الأداء الحراري للمجمعات السكنية في مناخ البحر الأبيض
المتوسط لقطاع غزة

إعداد

هدى محمد حسين عابد

إشراف

د.م. أحمد سلامة محيسن

قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في الهندسة المعمارية
من كلية الدراسات العليا في الجامعة الإسلامية في غزة، فلسطين.

1433هـ - 2012م