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Energy-Efficient Building Design Strategies in Gaza Strip

(With Reference to Thermal Insulation)

إستراتيجيات التصميم الموفر للطاقة في مباني قطاع غزة

(العزل الحراري نموذجا)

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Declaration

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﴿ وَالَّذِينَ إِذَا أَنفَقُوا لَمْ يُسْرِفُوا وَلَمْ يَقْتُرُوا وَكَانَ بَيْنَ ذَلِكَ قَوَاماً﴾

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Abstract

Residential buildings in the Gaza Strip come in top of buildings that consume the largest share of energy which is estimated at about 70% of the total amount of energy consumed according to the 2009 estimations of Gaza Electricity Distribution Company. This consumption of energy is increasing over time as a result of the continued increase in population and housing stock, and the consequent need to provide services within those buildings (lighting, electrical appliances, heating, cooling, etc.). As a matter of fact, most residential buildings in Gaza Strip are constructed using concrete hollow blocks in walls and reinforced concrete skeleton structure. This has resulted in buildings that lack acceptable thermal comfort conditions due to being too hot in summer and too cool in winter, which reduces the efficiency of using air conditioning systems.

Accordingly, this study has focused on discussing and assessing the implementation of energy-efficient in building design strategies that suit Gaza Strip. These strategies are intended to effectively contribute to secure better thermal comfort conditions and to reduce residential buildings reliance on conventional energy sources. This has been done with the focus on passive design strategies, especially the good use of thermal insulation in walls and roofs. Thus, several case studies of low-energy buildings have been analyzed. Also, a thermal modeling study for a typical residential building in Gaza has been carried out using ECOTECT program to assess the effect of using thermal insulation on human thermal comfort.

The study concluded that the good use of thermal insulation in walls and roofs can effectively reduce the need for energy to reduce human thermal discomfort by 20% through the year. In this regard, the use of air cavity as thermal insulation in a double wall has been found more feasible than the use of polystyrene thermal insulation in the same wall. It has also been concluded that the use of thermal insulation has to be coupled with the use of night-time ventilation strategy in summer to limit the negative effect of the internal heat gains on the resulting human thermal comfort conditions inside the building.

الملخص

تأتي المباني السكنية في قطاع غزة في مقدمة المباني التي تستهلك النصيب الأكبر من الطاقة والذي تقدر بحوالي 70% من إجمالي الاستهلاك الحالي للطاقة وفقا لإحصائيات شركة توزيع كهرباء غزة 2009، ويتزايد هذا الاستهلاك للطاقة مع مرور الزمن، وذلك لاستمرار زيادة أعداد السكان والمساكن، وما يتبعه من الحاجة إلى توفير الخدمات داخل تلك المباني (إنارة، أجهزة كهربائية، تدفئة، تبريد، الخ)، ومن المعروف أن معظم المباني السكنية في قطاع غزة تشيد بمواد وطرق إنشائية نمطية باستخدام الأنظمة الإنشائية الهيكلية، والتي تستخدم الخرسانة المسلحة في عناصرها الإنشائية والطوب الخرساني المفرغ في الحوائط، مما يؤدي إلى وجود مبان لا تتوفر فيها الراحة الحرارية بالشكل الأمثل، وذلك لكونها حارة صيفا وباردة شتاءا وذات تكلفة مادية عالية في حالة استخدام أجهزة التكييف.

وبالتالي فإن هذه الدراسة ركزت على مناقشة وتقييم إستراتيجيات التصميم المعماري الموفر للطاقة الممكنة في قطاع غزة، التي يمكن أن تساهم بفعالية في توفير الراحة الحرارية والتقليل من الاعتماد على مصادر الطاقة التقليدية في المباني السكنية، مع التركيز على بعض إستراتيجيات التصميم السلبي (غير المباشر أو الكامن)، خاصة الاستخدام الجيد للعزل الحراري للحوائط والأسقف، وقد تم في هذه الدراسة تحليل بعض الحالات الدراسية لمبان موفرة للطاقة، ومن ثم استخدام أسلوب النمذجة الحرارية على نموذج مقترح لمبنى سكني في قطاع غزة، وذلك لمعرفة تأثير العزل الحراري على أدائه الحراري، وذلك من خلال برنامج (ECOTECT) كأداة تحليل.

وقد خلصت الدراسة إلى أن استخدام العوازل الحرارية في الجدران والأسقف العليا يقلل من عدم الراحة الحرارية بنسبة 20% خلال العام، كما تبين أن استخدام فراغ هوائي في جدار مزدوج كعازل حراري يعتبر أكثر جدوى بالمقارنة مع استخدام عازل البوليسترين في ذات الجدار، وأن الحصول على آثار ايجابية للعزل الحراري صيفا يجب أن يكون مقترنا بالتهوية الليلية للحد من التأثير السلبي للكسب الحراري الداخلي على مستويات الارتياح الحراري داخل المبنى.

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Chapter 1 : Introduction

1.1 Background

Man coexistence with his environment for a long time is a proof of his ability to adapt this environment in order to serve his interests and improve his life conditions, including the climatic conditions. Thus, man along the history has strived to protect himself from the outdoor climatic conditions by finding adequate shelter. This traditional shelter provided security and human comfort, and was ideal in integrating the building with its context and occupants. It is a result of long experiences and numerous observations of builders in response to the impact of climate on human. The main lesson that could be learnt from the traditional architecture that any design solutions should be intended to provide comfort to the users with a minimal negative environmental impact. This includes saving energy and protecting our eco system.

For example, it is possible to notice that many designers after the appearance of air conditioning in the last decades rely entirely on electrical devices to achieve thermal comfort inside buildings. This strategy unsuitable because it heavily consumes energy in a rate that our planet resources can not sustain. This is in addition to the high initial cost, maintenance requirements, and pollution of the environment. This is true for many other unsustainable design strategies that negatively affect our cities, and pollute the atmosphere by increasing the level of noise and harmful emissions including Carbon Dioxide and CFCs.

This puts a large responsibility on the architect to adopt using building design strategies that help reducing energy consumption in buildings. Some measures should be taken in the design of buildings to make them more comfortable with less energy consumption. For example, this could be achieved by reducing heat gains in summer, enjoy the sun and warm conditions in winter, thus reducing the reliance on electrical devices for cooling or heating. This in turn reduces the economic cost as well as the environmental one.

So this research discusses the different possible means and principles that help improving energy efficiency in buildings. This has been done with reference to Gaza Strip, which suffers from a severe shortage in conventional energy sources. Thus, several passive design strategies have been presented, and a numerical assessment of using thermal insulation in Gaza Strip residential buildings has been established. The ultimate aim of this trend is to improve human thermal comfort inside the building and to contribute to reduce the negative effects associated with the use of fossil fuels on the environment. This is expected to reduce the reliance on electricity and rationalize of energy consumption.

1.2 Study Limits

It is important to consider the following limitations of the study:

1.2.1 Study Place

Gaza Strip is located at the south-west area of Palestine. It is a narrow strip that stretches along the south-east corner of the Mediterranean Sea, 40 km long and between 6 and 12 km wide. It locates on Longitude 34^{o} 26' east and Latitude 31^{o} 10' north. Gaza Strip total area is estimated at 365 km^2. Its height above sea level may reach 50 m in some areas (Ministry of Local Government, 2004).

Figure 1.1: Map of Gaza Strip
Source: (BBC, 2009), adapted by author.

1.2.2 Climatic Conditions

Gaza Strip is considered a transition zone between the coastal area wetlands and the dry desert region (Negev desert in the south-east and Sinai desert in the south-west). According to (PEA, 2010), winter in Gaza area is rainy and mild, while summer is hot and dry, and extends over longer period of the year. the average daily mean temperature ranges from 24^{o}C in summer (May-August), to 15^{o}C in winter (November-February). The average daily maximum temperature ranges from 27^{o}C to 19^{o}C, and minimum temperature from 21^{o}C to 11^{o}C, in the summer and winter respectively (see Fig. 1.2).

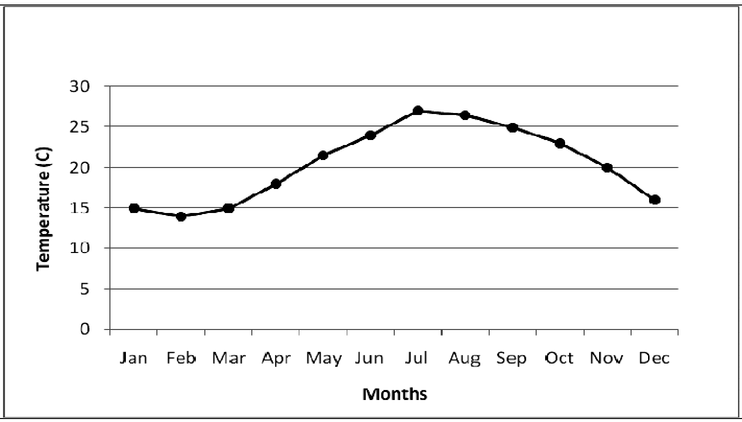


Figure 1.2: The annual average temperatures (C^{0}) in Gaza strip.
Source: (Ministry of Local Government, 2004), adapted by author

As for solar radiation Gaza Strip has a relatively high solar radiation. It has approximately 2861, annual sunshine -hour throughout the year. The daily average solar radiation on a horizontal surface is about 222 W/m^{2} (7014 MJ/m2/yr). This varies during the day and throughout the year (see Fig. 1.3).

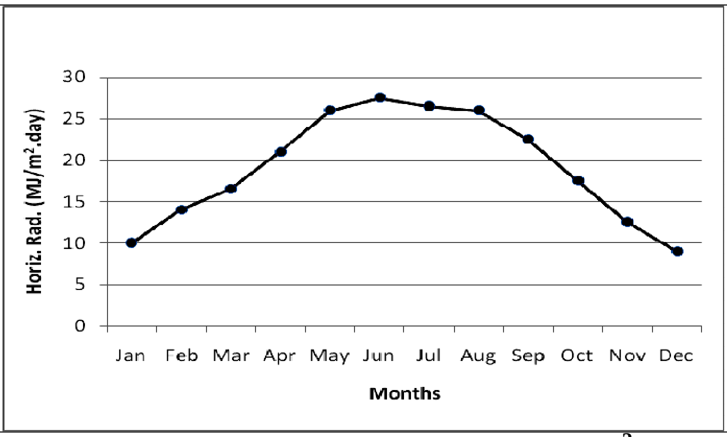


Figure 1.3: The annual variation in solar radiation (MJ/m^{2}/day) in Gaza Strip
Source: (PEA, 2010), adapted by author

According to (Ministry of Local Government, 2004), prevailing winds in the Gaza Strip northwesterly in the summer, and these variable speed wind speed up to the amount of (3.9) m/s during the afternoon. Differs from the prevailing wind direction and speed during the winter, as it turns to the southwesterly wind and increase speed to up to (4.2) m/s speed non-volatile, and sometimes blowing winds of up sometimes to (18) m/s (see Fig. 1.4).

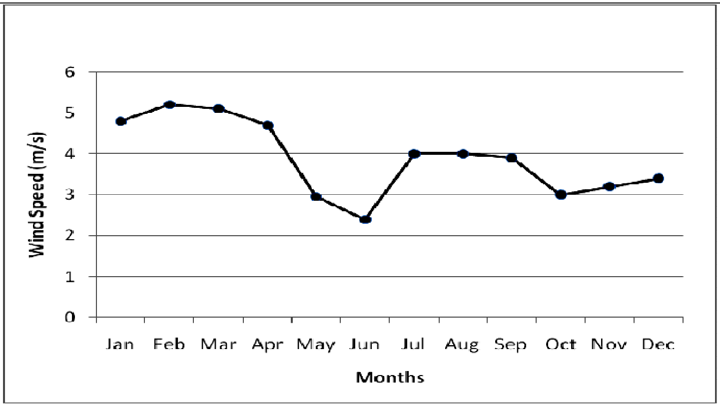


Figure 1.4: The annual average wind speed (m/s) in Gaza Strip
Source: (Ministry of Local Government, 2004), adapted by author

Relative humidity fluctuates between (65%) and (85%) in summer, and between (60%) and (80%) in winter. Figure (1.5) shows the annual average Relative Humidity in Gaza Strip (Ministry of Local Government, 2004). Rain is the main source of water in Palestine as it provides the underground water reservoir with water. Although rain fall in Gaza is unsteady, it is useful for irrigating farmlands. The amount of rain increases in the interior parts because these areas are higher than the sea surface. Annually, the amount of rain in Gaza Strip is between 100-130 million m^3 (ARIJ, 2003).

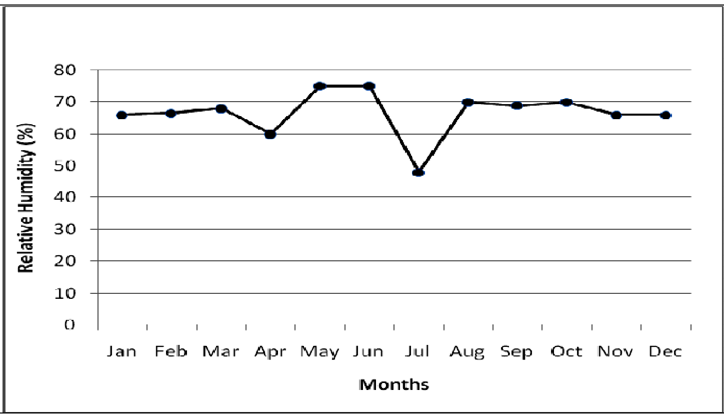


Figure 1.5: The annual average Relative Humidity (%) in Gaza Strip
Source: (Ministry of Local Government, 2004), adapted by author

1.2.3 Buildings Type

The Building type targeted in this study is the most common one in the Gaza Strip, which represents multi-storey residential buildings. This type is common as a response to the extended family culture. These buildings are often built with contemporary materials and construction methods, mainly the structural system (reinforced concrete foundations, columns, and ceilings). The walls are made of concrete hollow blocks, while the windows are single-glazed with aluminum frame.

1.3 Problem Statement

The recent climatic changes that the world witnesses, including global warming, are believed to be directly related to the increasing consumption of fossil fuels. This confirms the need to effectively introduce and implement design solutions that reduces buildings reliance on these energy sources without compromising the issue of human thermal comfort.

1.4 Hypothesis

Thermal insulation in Gaza improves the thermal performance of building envelope, including walls and ceilings, thus increases the level of thermal comfort and reduces energy consumption in buildings.

1.5 Study Objectives

The main objectives of this study are to:

- Study the problem of energy shortage, locally and globally and its expected impacts.
- Study the passive design strategies and the effect on saving energy in building
- Rationalize energy use in Gaza Strip buildings through proposing some design strategies and guidelines.
- Examine the effect of these strategies on occupants' thermal comfort and energy consumption, with reference to thermal insulation.

1.6 Study Methodology

This research will be carried out according to the following methodology:

1.6.1 Literature Review

In this phase, the study reviews the relevant literature and some previous research works. This has been carried out depending on the available paper and electronic resources (see the references list) including different text books, research papers, reports and conference proceedings.

1.6.2 Case Study Analysis

In this phase, several cases of low-energy projects and buildings are reviewed to assess the current state of implementing energy-efficient design strategies.

1.6.3 Thermal Performance Modeling

Quantitative assessment of these strategies is presented using computer simulation based on (ECOTECT) program. This is intended to evaluate the thermal performance of a residential building prototype that is designed according to the proposed strategies. Energy consumption and thermal comfort levels will be used as indicators of this performance.

1.7 Previous Studies

Several studies have been conducted to investigate the effect of using passive design strategies, including thermal insulation, in buildings. For example, Mohammed (2002) examined the importance of thermal insulation of buildings in the desert climate, and its role in reducing the energy used for air conditioning. To achieve that, the study relied on a survey method to find out the definition of thermal insulation, to identify thermal insulation materials in common use, and how to use them in buildings properly and efficiently. The research concluded that the thermal insulation is of great importance in the desert buildings, as it leads to lower energy consumption by as much as (50%) if it used properly, and thick enough to achieve the purpose of its usage.

Maghrabi (2005) studied the role of insulation in different wall and roof configurations, to sustain better thermal conditions indoors. The study aimed to find out the optimum design criteria of thermal insulation for wall and roof configurations of a prototype building in Makkah, Saudi Arabia. To achieve the goal of this study, experiments of various building forms, ratios and integration of wall and roof components were tackled, whilst thermal performance measures for each case were calculated. The conclusion of this study emphases the importance of considering a proper layer arrangement and configurations for walls and roofs, as they have major influence on energy efficiency of the interiors. Reduction of energy consumption of buildings and increased human thermal comfort are, therefore, anticipated as sustainable design features to be achieved.

Paipai (2006) carried out a parametric simulation to compute the relative impact of various passive cooling technologies with the aim of reducing the overheating risk in residential buildings. The cooling measures examined are shading, natural ventilation (with emphasize on night times). The type of buildings used for the parametric studies are apartments and double-storey single houses, both simulated for a Mediterranean climate (Athens and Greece), and middle-European one (Vienna and Austria). The results obtained showed that passive cooling methods can significantly contribute to the reduction of overheating in buildings. In particular, shading and night-time ventilation are considered to be very effective, especially if applied in combination.

Bolatturk (2007) made a comparative analysis, based on the annual heating and cooling loads to determine the optimum insulation thickness of external walls of buildings in Turkey. The degree-hours method as a simple and intuitive way of estimating the annual energy consumption of a building was used. The results obtained showed that the use of insulation in building walls, with respect to cooling degree-hours, is more significant for energy savings compared to heating degree-hours in Turkey's warmest zone. The optimum insulation thickness varies between (3.2 and 3.8 cm), the energy savings varies between (8.47 and 12.19 $/m^2), and the payback period varies between (3.39 and 3.81) years depending on the cooling degree-hours. On the other hand, for heating load, insulation thickness varies between (1.6 and 2.7 cm), energy savings varies between (2.2 and 6.6 $/m^2), and payback periods vary between (4.15 and 5.47) years.

1.6 Study Outline

This study is divided into seven chapters:

The first chapter introduces the dissertation and outlines its objectives and the targeted geographical zone. It describes the nature of the research problem and the methodology used to achieve its objectives. The second chapter discusses the evolution of the usage of energy and its impact on human being. It presents its importance in the contemporary life, and lists the global energy sources, both traditional and renewable. In addition, the future of conventional energy sources has been argued, and the current and expected negative environmental impacts of conventional energy use have been summarized. Then, the energy situation and shortage in Gaza Strip has been addressed, and the available alternatives of renewable energy sources and passive design means have been presented.

As an essential solution of the global energy problem, the third chapter illustrates the role that passive design means can play to reduce energy consumption in buildings and improve thermal comfort conditions. This includes some planning aspects like building orientation and form, and some design aspects like building materials, natural ventilation, and thermal insulation. After that, the chapter discusses the factors affecting thermal comfort in buildings, and the concept and implementation means of passive cooling and heating.

Then, the study moves to the specific issue that has been investigated, which is the use of thermal insulation in buildings. This has been discussed in the fourth chapter, where the objectives of thermal insulation and its relation to thermal properties of building materials have been presented. This has been followed by presenting some examples of thermal insulators in buildings, and some design techniques of the good practice of thermal insulation. The fifth chapter proves the possibility to implement energy-efficient design strategies to a large extent, including thermal insulation, through the analysis of three case studies of low-energy buildings.

Chapter six extends the empirical study by examining the use of thermal insulation in a typical residential building in Gaza. This has been done numerically using computer simulation based on Ecotect program to examine the resulting thermal comfort conditions before and after the use of thermal insulation. Finally, the seventh chapter summarizes the conclusions and recommendations of this study, and proposes some design guidelines and solutions that can be implemented in the residential buildings of Gaza Strip.

Chapter 2 : Global Energy Use and Sources

2.1 Introduction

Energy use and sources has dramatically developed since ancient times up to today. Several conventional energy sources have been discovered like coal, oil, and natural gas. Nowadays, energy has become an essential part of human civilization. However, the fact that conventional energy sources are non-renewable and subject to depletion has increased the global concern about the future of energy. Moreover, the negative environmental impact associated with the use of fossil fuels can not be ignored. This has recently motivated the efforts to find acceptable alternatives such as renewable energy sources.

The aim of this chapter is to shed some light on the current status of energy consumption in terms of energy sources, reserves, and relation to the building sector. It also tackles the issue of the negative impacts of conventional energy sources on the environment, and the available clean alternatives. In this context, energy situation in Gaza Strip has been also investigated and the potential of implementing renewable energies has been explored.

2.2 Development of Energy Use

Since ancient times, the human being kept thinking in finding energy sources to ensure fulfilling his needs. According to Boyle (1996), the primitive man made use of the energy to run his daily life, and the minimum use of this energy was estimated of about 2000 kcal (8.2 MJ). After about one million years, the primitive man discovered fire which helped him to light, cook food, extract metals, such as, iron, copper and bronze; and to burn clay that was used to make potteries and bricks. Renewable sources of energy, such as, waterfalls energy and wind energy have been used in production and transportation.

The use of fuel, particularly the use of fossil fuel, is incrementally associated with the industrial development. This matter is discussed below in four stages (Boyle, 1996):

2.2.1 Stage (1): In the 19th century

In the 19th century, coal-burned steam engines were invented, the matter that has led to quit the use of brook water, which was used 6000 years ago. In that period of time, there were developments in means of transportations and the productions of steel and metals. However, the negative environmental effects resulted from producing of coal were still neglected.

2.2.2 Stage (2): The last quarter of the 19th century

In the last quarter of the 19th century and the 1st quarter of the 20th century, there were many developments in manufacturing power generators and internal combustion machinery relying on petroleum and natural gas. Moreover, chemical industries have developed new sources derived from petroleum. During that time, getting energy has depended directly on burning gas and petroleum or indirectly on hydroelectric power stations and electricity resulting form burning them. At that time, the cheap price of fuel and the rapid industrial developments were running side by side.

2.2.3 Stage (3): Mid of the 20th century

The number of electricity stations networks and natural gas pipelines has increased and new petroleum wells were discovered in the Middle East and North Africa. At that period of time, industry has been depending on the use of fuel which has been supplemented by the discovery of nuclear energy at the end of World War II. This matter has been considered from that period of time as a new source of power, despite the environmental hazardous associated with it. The prices of fuel were still cheap.

2.2.4 Stage (4): The end of the 20th century

At the end of the 20th, the First World countries has significantly developed in science and technology. In the last 1960s, many countries became aware of the effects and impacts resulted form industrial developments, and became interested in the use of renewable energy, especially after the problem of the lack of petorleum (the energy crisis) that occurred in the late 1970s. During this crisis, the prices of energy have significantly risen due to the increase of demand of energy and the low supply. This crisis had a severe negative effect on economy, which caused crises for some countries, especially the developing ones.

2.3 The Importance of Energy

Energy at the present time is a very essential resource, as it is used in transportation, agriculture, industries, buildings, and almost all aspects of modern life. The increasing demand has motivated searching for additional fuel reserves and alternative energy resources. The problem of energy is highly complex and correlated with almost all environmental problems in the modern world. According to Hassan (2006), the problem of energy can be discussed in four main aspects:

- Energy is an essential component of contemporary life.
- Rates of consuming energy rapidly increase, and many countries become unable to supply this high demand (see Fig. 2.1).
- At the present time, there is a significant use of non-renewable energy, such as coal, oil and natural gas.
- However, the use of fossil and nuclear energy causes hazardous and harmful environmental effects.
- There are relationships between the future of energy and the future of food and water, particularly in hot climates.

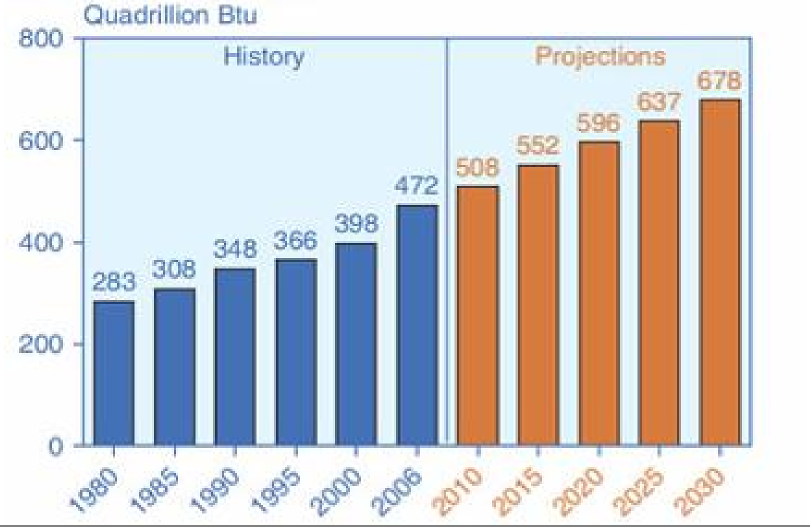


Figure 2.1: World marketed energy demand (1980-2030)
Source: (U.S. Energy Information Administration, 2008)

Energy markets around the world witnessed a great deal of concern in the latest months. The recent global financial crises have had dramatic impacts on the energy markets. The quicker the global economy recovers the more energy demand is expected. People around the world have responded to this threat. This has included measures to promote clean energy with the aim of tackling the long-term threat of energy shortage and the rapid increase in consuming the conventional energy sources (IEA, 2009).

2.4 World Energy Sources

There are many natural energy sources in the world. Energy sources can be divided into two main groups: non-renewable sources "conventional energy sources", and renewable energy sources, sometimes called, "alternative energy sources".

2.4.1 Sources of Conventional Energy

Fossil fuels are derived from limited sources and are vulnerable to depletion. The exact amount of fossil fuels reserves is practically almost unknown. Estimations pointed out that (57%) of petroleum and (41%) of natural gas reserves are found in the Middle East area and North Africa (Hassan, 2006).

A. Petroleum:

Petroleum has been discovered at the beginning of the 19^{th} century, and from that time until 1955, (38) billion tons have been consumed, and the consumption has doubled three times till 1968. Recently, the consumption of petroleum is estimated of about (5) billion tons annually, and the reserve is about (90) billion tons. It is expected that to rise in 2015 to (13.6) million tons per day. This means that the consumption will be (50%) higher than it was before in 1995 (Hassan, 2006).

It is important to mention about (80%) of the world's readily accessible reserves which are located in the Middle East, with (62.5%) coming from countries including: (Saudi Arabia, U.A.E, Iraq, Qatar and Kuwait). Fig. (2.2) shows oil consumption of different countries on individual level. Countries that have high personal consumption of petroleum include Saudi Arabia, Canada, South Korea and the United States as a result of high petroleum reserves. On contrary, there are countries that have lower personal consumption including India, China and Brazil.

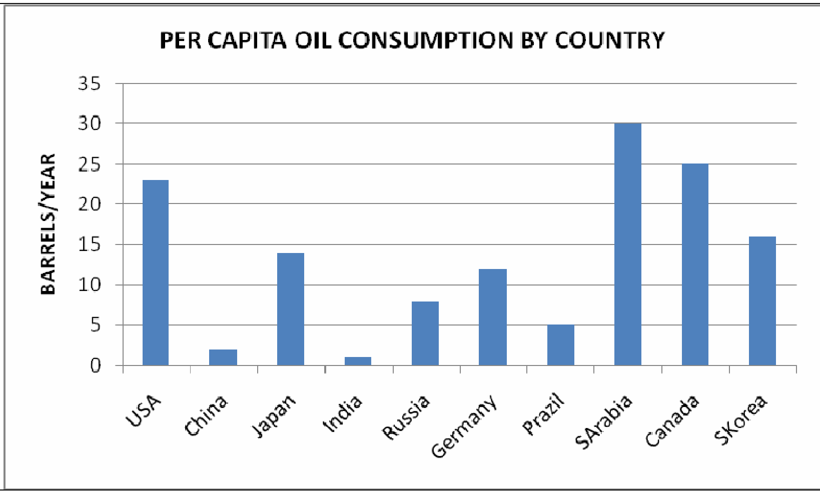


Figure 2.2: Oil consumption per person (barrel/day)
Source: (CIA, 2008), adapted by author.

B. Coal:

Coal is one of the oldest sources of non-renewable energy. While the size and location of reserves of petroleum and gas abound, coal remains abundant, and broadly distributed around the world. Recoverable reserves of coal are available in more than (70) countries worldwide, and are estimated as much as (847.5) billion tons in 2005 (WEC, 2007). This figure is much higher that the oil reserve mentioned above (90 billion tons). Thus, it is possible to expect an increased demand on coal in the coming years as a result of the expected ceased supply of oil. Fig. (2.3) shows the top ten countries in terms of coal reserves. The United States come at the top of these countries followed by Russia, China, Australia and India.

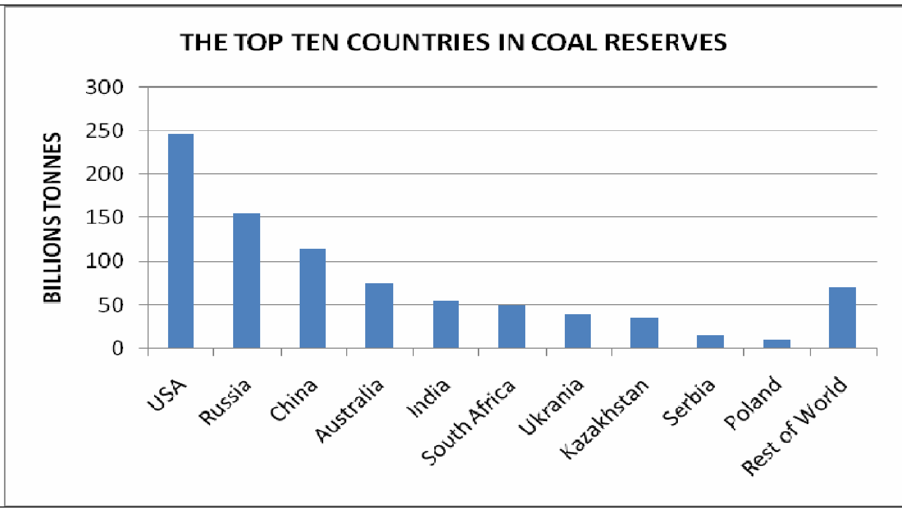


Figure 2.3: The top ten countries in coal reserves.
Source: (WEC, 2007), adapted by author.

C. Natural Gas:

Natural gas has now become the fuel of choice in many key consuming sectors in the industrial countries. It is available at competitive prices, and thus has a great potential in the energy sector. As shown in Fig. (2.4), there are several countries that are considered as main consumers of natural gas. The United States comes first followed by the European Union and Russia. However, the latter one has the largest reserve of natural gas, followed by Iran and Qatar. However, these potential developments imply the challenge of adapting the industry to allow gas sources to make a major contribution to the energy industry (WEC, 2007).

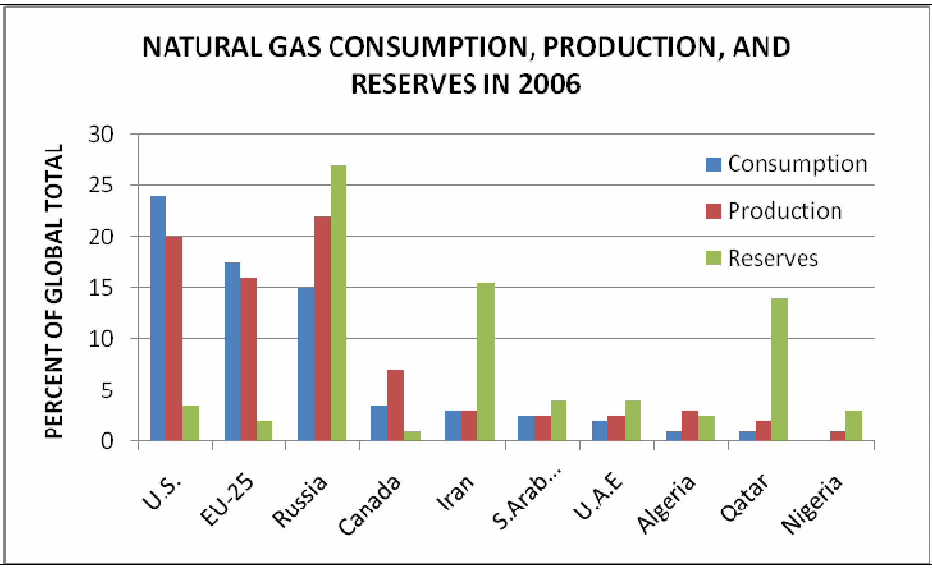


Figure 2.4: Natural gas consumption, production, and reserves in 2006.
Source: (WEC, 2007), adapted by author.

D. Nuclear Energy:

Fig. (2.5) shows the importance of nuclear energy through the ongoing growth demand on this type of energy. This is more pronounced in the areas of electricity generation, where nuclear energy accounts for (15%) of the energy generated in the whole world in 2009 (WNO, 2009). However, there is an ongoing opposition on the future of nuclear energy because of the high costs of building the reactors, and public concerns regarding the issues of human being safety, and the resulting environmental hazards including the proper disposal of the radiation wastes.

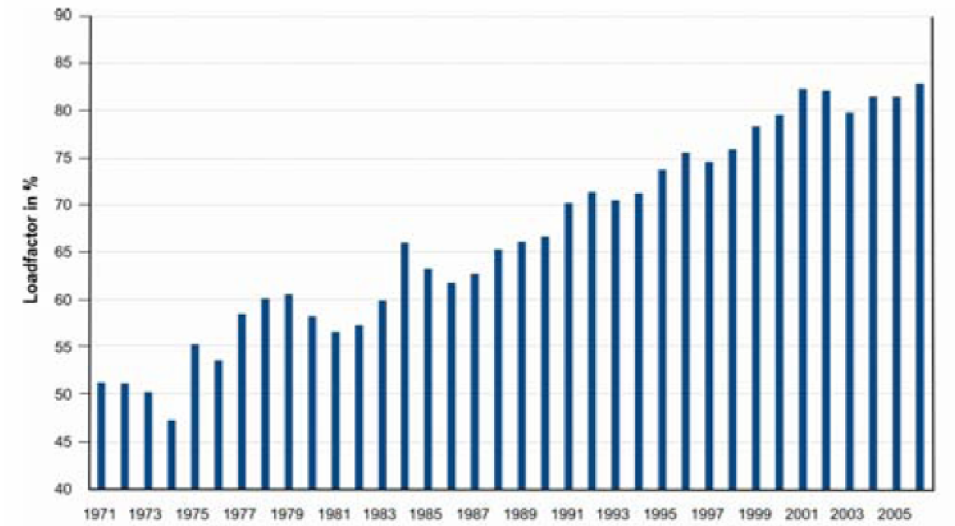


Figure 2.5: Average availability of nuclear power plants in the world.
Source: (IAEA, 2006)

So what the future of conventional energy would be like? It is clear from the previous discussion that the coming generations will suffer greatly from energy shortage. Statistics prepared by the UN (2009) showed that the increase of the world's population, expected to be (9) billion between 2040 and 2050, will lead to significant increases in consuming energy in the coming two decades. Studies showed that in the coming quarter of the 21st century, energy consumption will increase of about (54%), and in Eastern Asia countries, especially China and India, the increase will be double (IEA, 2009).

Consequently, the Middle East will be the center of oil industry because of its huge reserves. Thus, this area will supply the biggest amount of demand of energy. The fact that the sources of energy are vulnerable to depletion motivates the world to make use of renewable sources of energy. Although no sources of energy in the world can supply the whole need of energy alone, some renewable sources can supply significant amount of the needed energy in the coming few decades (Hassan, 2006).

2.4.2 Renewable Energy Sources

Renewable energies rely on natural resources such as sunlight, wind, rain, tides and geothermal heat. As shown in Fig. (2.6), about (18%) of global energy consumption in 2006 came from renewable sources, with (13%) coming from traditional bio-mass, such as wood burning, and (3%) from hydropower. New renewable sources (biofuels, power generation and hot water heating) accounted for together (2.4%), and they are growing (Renewable Energy Policy Network, 2007).

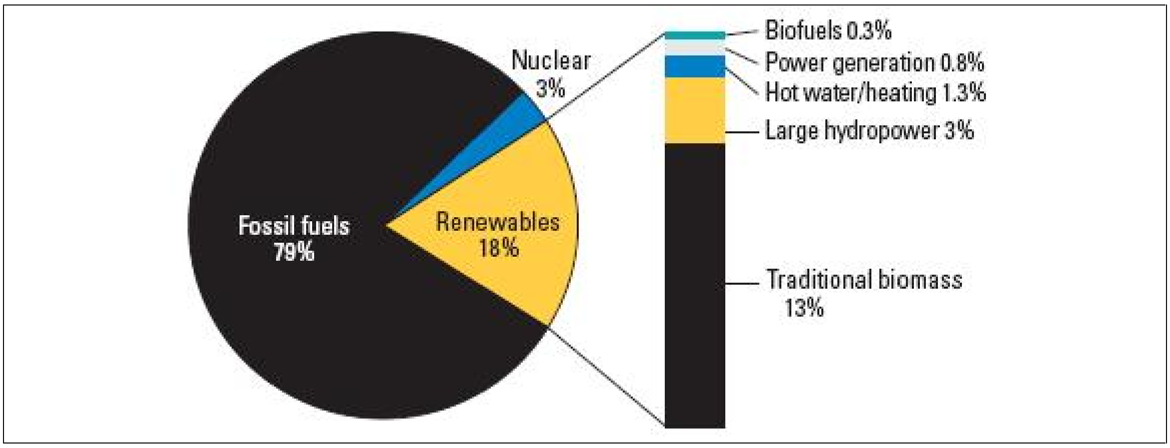
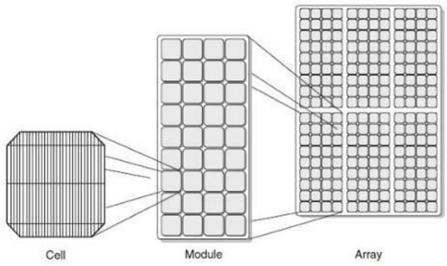


Figure 2.6: Renewable energy share of global energy consumption in 2006.
Source: (Renewable Energy Policy Network, 2007)

A. Solar Energy:

Almost all the renewable energy sources originate entirely from the sun through the hydrological cycle. The sun's rays that reach the outer atmosphere are subjected to absorption, reflection and transmission before reaching the earth's surface. This result in wind forces, vegetation growth (Sen, 2008). The emergence of interest in solar energy utilization has taken place since 1970's, principally due to the rising costs of energy from conventional sources. Solar radiation is the world's most abundant and permanent energy source. The amount of solar energy received on the surface of the earth per minute is greater than the energy used by the entire world in one year (Sen, 2008).

As a result of that, solar energy electricity generators in the form of photovoltaic cells, has been developed. For example, photovoltaic's (PV) can be used to generate electricity depending on the received amount of the incident solar radiation (insolation). This has been used widely to provide electricity for buildings as an example, see Fig. (2.7). Another example is used of solar energy for passive heating in buildings. This issue will be discussed in details in Chapter (4) in this study.



(a): Photovoltaic Cells, Modules and Arrays

(b): A Solar Farm

(b): Array of Photovoltaic Cells on Top of Buildings

Figure 2.7: Several forms of the use of photovoltaic cells to generate electricity
Source: (Gevorkian, 2008)

B. Wind Energy:

Wind energy is one of the most significant and rapidly developing renewable energy sources in the world. Recent technological developments have reduced wind energy costs to economically attractive levels. Wind energy farms nowadays are considered as an alternative energy source in many countries (Sen, 2008). It is possible to generate electricity from wind by using wind turbines that convert the kinetic energy of wind into electricity (see Fig. 2.8). This is widely used in buildings to provide electricity, although there are some objections regarding the resulting noise and threat to animals and natural patterns.

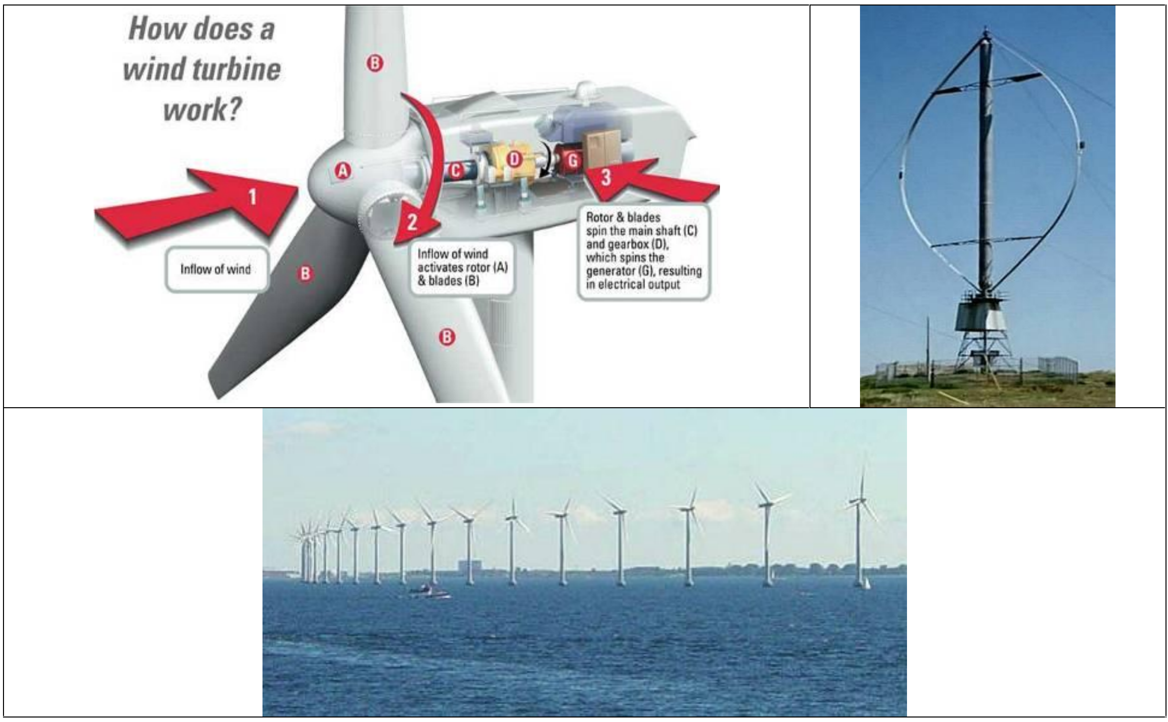


Figure 2.8: Different types of wind turbines
Source: (Solarnavigator website, no date)

C. Hydro Energy:

Hydro energy is energy that is taken from water and then converted to electricity. It is usually produced as a result of falling water caused by earth's gravity. This power has been used at the beginning of the 20th century to run electricity generators. Hydro-electric power projects are considered among the most important ones in the world as their lifespan is relatively long (100 years approximately) **(**Burch, 2001). One of the early major projects that have been established after the Second World War was the Aswan Dam Project in Egypt. (Smith, 2005). Fig.(2.9) shows the Sayano Shushenskaya dams which is used to generat electricity in Russia.

Figure 2.9: Hydroelectric power generation in Sayano Shushenskaya dams- Russia
Source: (Environnent Canada website, 2010)

D. Bio-mass Energy:

Bio-mass energy is a form of energy which is stored chemically in the remains of plants and animals. It has been used as a source of energy since discovering fire, and at the present time, it is used for warming houses and running vehicles and machines (Burch, 2001). Bio-mass energy is thought to be the most important source of renewable energy in the future, as it provides the greatest share of renewable energy as has been discussed at the beginning of this section. As shown in Fig. (2.10), bio-mass resources include forest lands (woods and residues of pulps and leafs), agricultural lands (grain crops, oil crops and woody crops), and animal and food wastes.

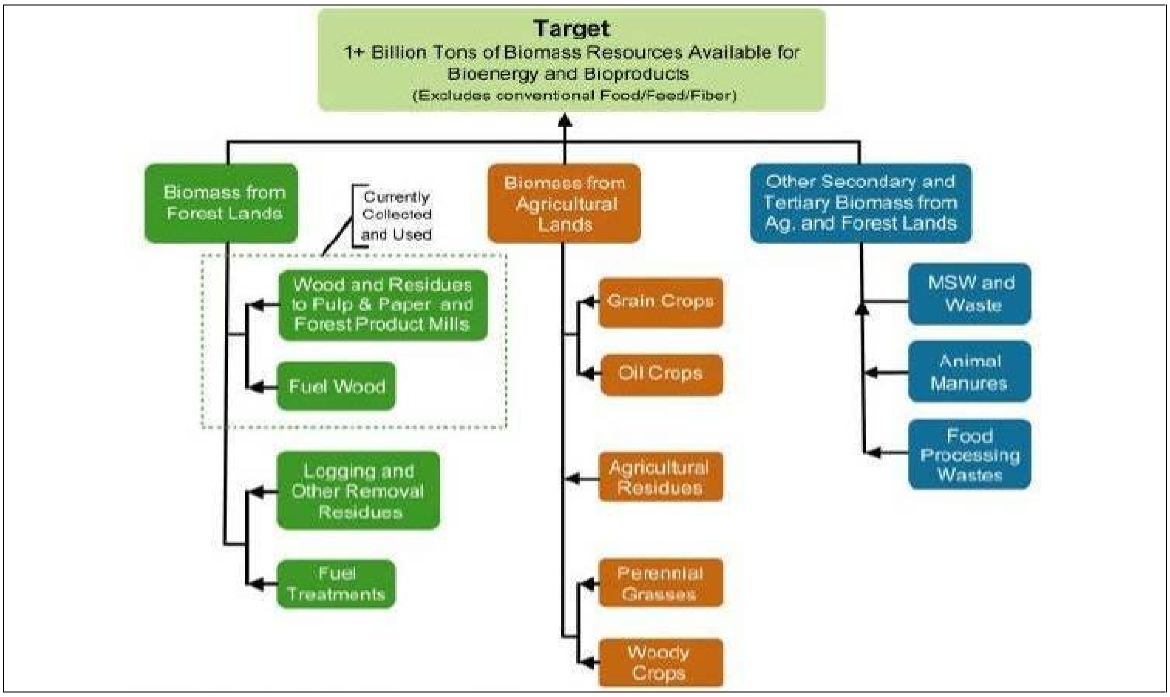


Figure 2.10: Bio-mass resource categories
Source: (Anaerobic Digestion Systems website, 2010)

E. Geothermal Energy:

Although geothermal energy is categorised a relatively new renewable energy source, it is useful to mention that people in many parts of the world have used hot springs for bathing and washing of clothes since the early times. Geothermal energy means extracting heat stored deeply in the earth through an approbiately designed plants and systems. Electricity has been generated by geothermal steam commercially since 1913 (Fig. 2.11). Geothermal energy has been used on the scale of hundreds of megawatts for the past five decades, both for electricity generation and direct us (WEC, 2007). A common examople of using thermal energy in buildings is the use of heat pumps. Geothermal heat pumps are commonly used to benefit from the heat stored in the earth for building heating through a deeply installed loop that is connected with on-ground heat exchager.

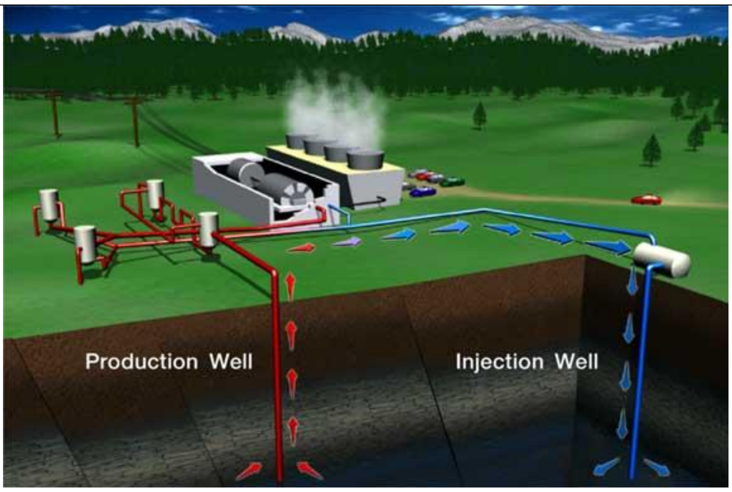


Figure 2.11: Natural steam from the production wells powers the turbine generator
Source: (Geothermal Education Office website, 2010)

2.5 Environmental Impact of Conventional Energy

The world became aware of the dangerous effects and impacts of the use of fossil fuels, and nuclear energy on environment. For example, the problems of global warming, the deterioration of the Ozone layer, and air and water pollution are all severe effects that significantly affect the future of humanity. These effects are discussed in the following sections.

2.5.1 The Greenhouse Effects

The greenhouse effect is a process by which long-wave radiation energy leaving the earth surface is absorbed by some atmospheric gases, called greenhouse gases, thus causing additional warming of the Earth's surface. The main greenhouse gases include water vapors, Carbon Dioxide, Methane, and Nitrous Oxide. However, Carbon Dioxide (CO^2) is the main greenhouse gas (Roaf *et al.*, 2007).

Carbon is a key element of life on Earth. Compounds of this element form the basis of plants, animals and micro-organisms. Carbon compounds in the atmosphere play a major role in ensuring that the planet is warm enough to support its rich diversity of life. The release of Carbon into the atmosphere is naturally balanced by the absorption of (CO^2) by plants. The system would be in equilibrium if not harmed by human interference. The combustion of fossil fuels and deforestation has resulted in an increase of (26%) in Carbon Dioxide concentrations in the atmosphere. In addition, rising population in the less developed countries has led to doubling of methane emissions from rice fields, cattle and the burning of bio-mass. If fossil fuels are burnt and vegetation continues to be destroyed at the present rate, the (CO^2) in the atmosphere will treble by 2100, which will, in turn, push up the global temperature (Smith, 2005).

2.5.2 Global Warming

Global warming is believed to be a direct result of the green house effect. It is the increase in the average temperature of earth. Global surface temperature increased by about (0.18 ± 0.74)°C between the beginning and the end of the 20th century. The Intergovernmental Panel on Climate Change (IPCC) concludes that most of the observed temperature increase since the middle of the 20th century was caused by increasing concentrations of greenhouse gases resulting from humans activities, such as, fossil fuel burning and deforestation (IPCC, 2007).

However, there is some uncertainty in the global warming estimates. This uncertainty arises from the use of models with differing sensitivity to greenhouse gas concentrations and the use of differing estimates of future greenhouse gas emissions. Most studies focus on the period up to the year 2100. However, warming is expected to continue beyond 2100 even if emissions stopped, because of the large heat capacity of the oceans, and the long lifetime of Carbon dioxide in the atmosphere (Archer, 2005).

2.5.3 Ozone Depletion

The Ozone layer protects the earth from the high frequency ultraviolet light of sun, which is harmful to life on earth. If the Ozone layer is depleted, the effects on the planet could be catastrophic. Ozone is present in the stratosphere. The stratosphere reaches (30) miles above the earth, and at the very top it contains Ozone. The sun's harmful rays are absorbed by the Ozone layer in the stratosphere, and thus do not reach the earth (IPCC, 2007).

In the recent years, the Ozone layer has been a subject of concern of humans. Antarctica Continent was an early victim of Ozone destruction as a result of release of large quantities of the man-made harmful compounds, especially the (CFCs). A massive hole in the Ozone layer right above it threatens not only that continent, but also many other countries through the melt of icecaps. Fig. (2.12) shows the increase observed in the Ozone Hole from 1979 – 2004.

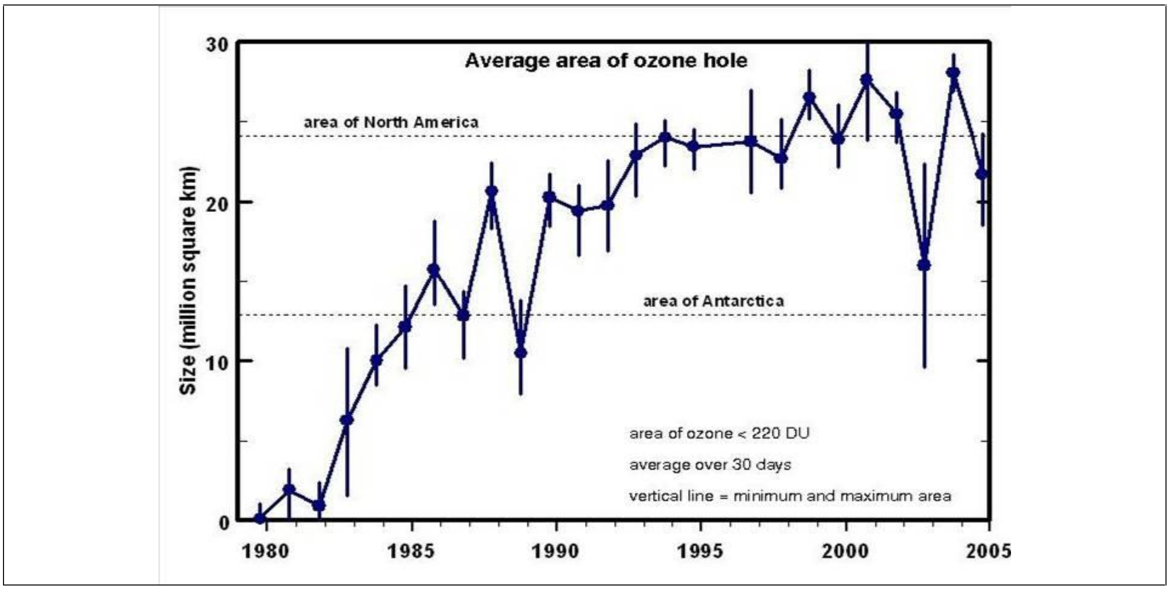


Figure 2.12: The Ozone hole size from 1979 to 2004.
Source: (NASA, 2009)

2.6 Energy Problem in Gaza Strip

2.6.1 Energy Status in Gaza Strip

Gaza Strip is a high-density populated area with very limited resources, especially sources of energy. So, it suffers from a serious energy problem. This problem increases by time, due to the rapid population growth and unstable political situation that has negatively affected Gaza development. Currently, Gaza depends mainly on fossil fuel to produce electricity from a local generating plant. This is in addition to electricity imported from Israeli and Egyptian electricity companies, with a total capacity of about (197) MW. As depicted in Fig. (2.13), electricity energy demand increases by about (10–15) MW annually, as a result of the natural population growth and the expansion in different sectors requiring electricity supply (Muhaisen, 2007).

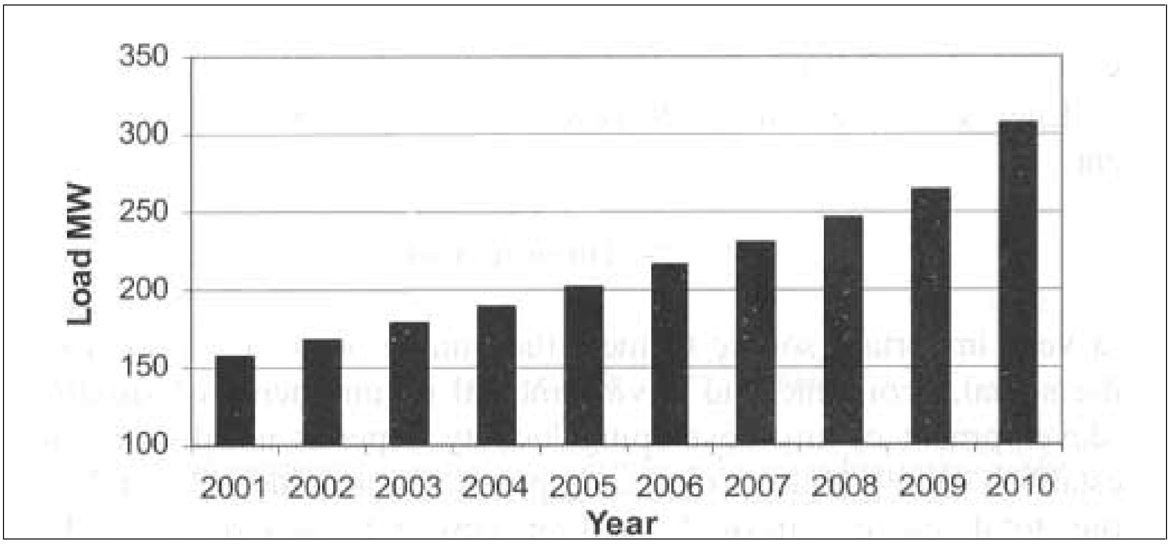


Figure 2.13: The electricity load required for Gaza Strip until the year of 2010
Source: (Muhaisen, 2007)

As for natural gas, two natural gas fields were discovered in the territorial water of Gaza Strip in 2000 at commercial quantities. One of these fields is entirely within the regional boarders of Gaza Strip, while (67%) of the second field is located within them. Tests made on this discovered gas proved its high quality (Abu Hafeetha, 2009). However, this has not been invested yet due to the unstable political situation. However, it still represents a promising potential for the future.

As for oil, petroleum products (gas, kerosene, gasoline, diesel, oil and liquefied petroleum gas (LPG) are imported directly from Israel to Gaza Strip. Some quantities of those petroleum products come indirectly from Egypt (see Table 2.1).

Table 2.1: The annual amount of Petroleum products consumed and needed in Gaza Strip in 2009
Source: (The Palestinian General Petroleum Corporation, 2009)

Type of Product	Consumed (liter/ year)	Needed (liter/ year)
Gasoline	325,070	30,000,000
Diesel	371,410	120,000,000
Gas	34,783,000 Ton	60,000 Ton
Industrial diesel	107,710,000	120,000,000

2.6.2 Energy Shortage in Gaza Strip

According to Gaza Electricity Distribution Company 2007 statistics, it is likely to conclude that about (70%) of the total electricity consumption in Gaza Strip, which was (244) MW at that time, is consumed by domestic sector **(**Muhaisen, 2007**).**

However, there is a significant shortage in electricity supply to Gaza. According to Gaza Electricity Distribution Company (GEDC, 2009), statistics show that Gaza Strip needs (270) MW of electricity. The available quantity is (197) MW, coming from the Israeli Electricity Company (120) MW (60%), Gaza Power Plant (60) MW (32%), and the Egyptian source of (17) MW (8%).

Therefore, Gaza shortage of electricity is about (25%), assuming that all sources work well**.** The matter that deteriorated the issue of electric energy in Gaza Strip is the destruction of Gaza power plant in 2006. This should motivate the efforts towards looking for acceptable alternatives that can contribute to solve this shortage. One option is to encourage the use of renewable energy sources, which is discussed in the following section.

2.7 Renewable Energy Sources in Gaza Strip

2.7.1 Solar Energy

Gaza Strip has a good potential opportunities of solar energy around the year, with an average solar radiation of (5.33) kWh/m² (see Table 2.2). Solar energy is currently used in the residential sector in Solar Water Heaters (SWH). A survey has shown that (70%) of households are equipped with (SWH) and a limited percentage in other sectors and photovoltaic applications (Hasan *et al.*, 1996). Moreover, Gaza Strip has approximately (2861) of sunshine hours across the year (PEA, 2010).

Table 2.2: Insolation levels in different cities in Palestine

Source: (Hasan *et al.*, 1996).

Month	Jerusalem 3146N 3511E	Jericho 3125N 352E	Bethlehem 3151N 3507E	Gaza 3131N 3426E	Average Solar Radiation (kWh/m^2)
Jan.	3.06	2.78	2.93	2.78	2.9
Feb.	3.71	3.28	3.28	3.89	3.54
Mar.	5.03	4.85	4.89	4.86	4.9
Ap.	6.35	6.61	6.61	5.83	6.35
May.	7.55	6.89	6.89	6.94	7.06
Jun.	8.42	8.06	8.06	7.78	8
Jul.	8.31	8.12	8.12	7.5	8
Aug.	6.91	7.3	7.3	7.22	7.2
Sept.	6.66	6.36	6.36	6.25	6.4
Oct.	4.99	4.93	4.93	4.72	4.9
Nov.	3.8	3.25	3.25	3.61	3.5
Dec.	3	2.61	2.61	2.5	2.7
Average	5.70	5.45	5.45	5.33	5.48

2.7.2 Wind Energy

Palestine can be considered as a country of moderate wind speed. The annual wind speed is expected to be in the range of approximately (4-6 m/s) in hilly regions. In the coastal region of Gaza Strip, wind speed is relatively low and ranges from (2.5-3.5 m/s). Table (2.3), shows wind speeds and potential to generate electricity in some areas of Palestine at different levels based on data from (49) stations distributed throughout the area (Hasan *et al.*, 1996).

It also appears that the annual wind speed in Gaza strip is relatively low. Thus, it can not be used to produce sufficient electrical energy.

Table 2.3: Wind speed and potential in some areas in Palestine
Source: (Hasan *et al.*, 1996).

Location	Annual Wind Speed (m/s)	Wind Potential (kwh/m²) Elevation		
		10m	20m	40m
Jenin	3.65	285	431	626
Ramallah	4.8	407	659	1013
Jerusalem	4.12	334	541	831
Jericho	3.3	146	286	505
Gaza	2.9	152	201	261

2.7.3 Bio-mass Energy:

Bio energy includes biogas and biomass. The production of biogas is still under research in Palestine. However, Palestine is an agricultural country which means that several biomass products are used as energy sources such as charcoal, wood, wood cake (Jefit) which is the reject of olive oil pressers, and other agricultural wastes. These biomasses are used in households for heating, baking and cooking specially in rural area. 76,000 tons are the annual average of olive mills solid waste, which is produced by 265 olive mills in Palestine [Abu-Hafeetha 2009].

2.8 Conclusion

This chapter has discussed the evolution of energy consumption and its importance in the contemporary life. It has presented in a summarized manner the global energy sources, both traditional, such as petroleum, coal and gas, and renewable, such as solar, wind and hydro energy. It has been concluded that the problem of energy is an economic and environmental one. The fact that conventional energy sources will eventually cease threatens the modern civilization. Also, the fact that several negative environmental impacts, such as greenhouse effect, global warming and Ozone depletion, are associated with the use of these conventional sources which threatens human future and the entire life on earth. Thus, there is a great need to make use of renewable energy sources and improve them as they offer clean alternative which imposes no harmful effects or impacts on environment.

Reviewing the energy situation in Gaza Strip revealed the existence of a severe shortage of conventional energy. Given that residential buildings consume the largest deal of energy in Gaza, it is possible to conclude that there is a need to reduce energy consumption in order to efficiently manage the limited availability of energy. This can be done through promoting energy-efficient building design strategies. This includes active strategies like the use of renewable energies available in Gaza. The abundance of solar radiation in this area puts more emphasis on the necessity of adopting solar energy as a green alternative. This also includes passive building design strategies, which will be the topic of the following chapter.

Chapter 3 : Principles of Building Passive Design

3.1 Introduction

The previous chapter has tackled the issue of energy: its importance in contemporary life, the world's energy resources, both conventional and renewable energy, the future of these recources, as well as the negative effects of conventionl energy use on the environment. This chapter aims to discuss one viable solution of reudcing our reliance on conventional energies, which is the use of passive design techniques in buildings.

Passive design is a key element and the main factor of sustainable buildings. It aims to improve thermal comfort of people and reduce the rate of consuming energy. It means making use of natural sources of energy, such as solar energy, and using the wind in order to cool, ventilate and light buildings without polluting the environment. Thus, this chapter explains the issue of passive design considering its definition, design aspects, and role in the provision of thermal comfort inside buildings and saving energy consumption.

3.2 Definition of Passive Design

Passive design is defined as: "an approach to building design that uses the building architecture to minimize energy consumption and to improve thermal comfort" (Mikler *et al.*, 2008, p3). The building form and thermal performance of its elements (including architectural and structural ones) should be carefully considered and optimized for interaction with the local microclimate. The ultimate aim of passive design is to fully eliminate requirements for active mechanical systems (and associated fossil fuel-based energy consumption), and to maintain residents' comfort at all times.

Building shape, orientation and composition can improve residents' comfort by harnessing on-site renewable energy sources and reducing reliance on other forms of energy. Through properly applied passive design principles, we can greatly reduce building energy requirements before we even consider mechanical systems.

Designs that do not consider passive solar technical behavior, mostly rely on extensive and costly mechanical (HVAC) systems to maintain adequate indoor conditions. Furthermore, even the most efficient technologies will use more energy than it is necessary with a poorly designed building. According to (Mikler *et al.*, 2008), to successfully implement the passive design approach, one must first accomplish the following:

1. Understand and define acceptable thermal comfort criteria.
2. Understand and analyze the local climate, preferably with site-specific data.
3. Understand and establish clear, realistic and measurable energy performance targets.

3.3 Passive Design and Energy Savings

Buildings include the modern world's most widespread technological systems, and the most direct expression of a people's culture of life and work. Most of the energy we use, around (40%), of primary energy goes into heating, cooling and lighting building interiors and into running a growing number of devices used in buildings (Wynn, 2000). Designing buildings and managing energy efficiency with low environmental impact is an ongoing challenge.

In this context, there are several design approaches that discussed the issue of energy and take into consideration respecting the environment. For instance, there are many attempts to reduce the rate of consuming energy to a reasonable level. Besides, other attempts are done to dispense any external source of energy and replace this by self reliance on energy, generating electricity through photovoltaic cells, wind turbine systems, and systems of combined heat and power (Dzioubinski & Chipm, 1999).

Thus, building roofs and walls have been continually transformed by the incorporation of new energy-related elements such as insulating materials, high-performance windows, solar-assisted heating, and electricity generation systems. This has encouraged building designers to switch to what is called the "Whole Building" design approach, which tackles the various problems and solutions, including passive design techniques, as a whole in an integrated and intelligent way right from the beginning of the design process.

This approach is based on the fact that while designing buildings, the consumed energy in all stages of establishment and operation should be taken into consideration. This includes (Edwarwds & Hyett, 2002):

- The stage of constructing the building (embodied energy).
- The stage of operating the building (running equipments, lighting, cooling, and heating).
- The stage of completing the building (removal, recycling, and reconstructing).

This happens firstly through passive means including using building materials based on renewable resources and reducing the consumption of new materials. It is also advisable to use durable and recyclable materials. Also, choosing a suitable location, building shape and orientation, building envelope design including openings and shading device, etc. The use of these passive design strategies should be consistent with the following strategies of improving energy efficiency in buildings (Metz *et al.*, 2007):

- Reduction of heating, cooling and lighting loads.
- Utilizing active solar energy and other heat sources and sinks.
- Increasing efficiency of appliances, heating and cooling equipment and ventilation.
- Improving operation and maintenance.

3.4 Passive Design Aspects in Buildings

It is evident from the above section that passive design in buildings is a vital strategy. Thus, it is now important to focus on the basic principles that can bring about energy efficiency in buildings through this design strategy. The basic passive principles for designing energy efficient buildings are discussed below (Ahsan, 2009):

3.4.1 Planning Aspects

A. Site Selection and Orientation:

Many site considerations can affect passive design, including building orientation on the site, shadows from other buildings, wind patterns, noise and urban character. All of these aspects need to be considered to optimize heating or cooling, and day lighting. However, it is important in this regard to consider the local architectural context.

According to (Ministry of Local Government, 2004), there are some factors that affect the orientation of a building:

- Thermal effects such as: the sun and the wind.
- Visual effects (natural lighting through the light).
- Sound effects and inconvenience.
- The nature of the landscape which surrounding a building.
- The degree of privacy, that has a very important role to direct a building, and its external appearance and design.

Considering the first factor, two important issues should be highlighted here: relation of the building with the prevailing wind, and its orientation with respect to the sun (solar radiation). As for the wind, its speed and direction vary in different climate zones and areas. In the hot and relatively warm areas, such as Gaza Strip, wind should be captured to enhance passive cooling. In cold climates, buildings should be protected from undesired wind currents to enhance passive heating.

As for solar radiation, buildings in cold climates should be oriented to capture solar radiation and use it for passive heating. This is done for example through the use of large glazing area on the south. In the hot climates, the opposite is true, and can be achieved through the use of shading elements for instance. For this, the sun position and path should be studied throughout the year. Thus, in hot climates, the main streets should be oriented north–south, and the axis of the building should be parallel to the axis of street. This results in relatively small southern facades, which reduces exposure to direct solar radiation (see Fig. 3.1).

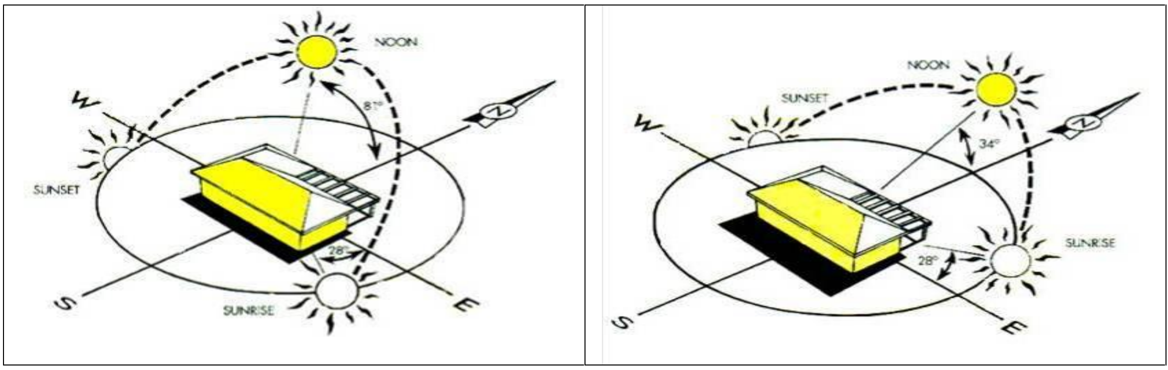


Figure 3.1: The Sun's Movement in Mid-summer (Left) and Mid-winter (Right)
Source: (RISE website, no date)

B. Building Form:

Climatic region has an effect on the shape of buildings and spaces between them. It is worth mentioning that in cold areas, exposed forms are used to regulate the relationship between the solar path and the living space. In hot dry areas, compact configuration is used to reduce the rate of heat gain through external walls. Studies proved that, the rectangular shape is the best shape of buildings in hot and relatively hot areas, as it provides energy and reduces heat gains. Nevertheless, it was proved that the quadrate shape is the best shape in cold areas, as it helps reducing the rate of heat loss (Ministry of Local Government, 2004).

C. Wind Breaks:

Wind breaks are barriers used to reduce and redirect undesired wind in both hot and cold climates. They usually consist of trees and shrubs, but may also be fences. The reduction in wind speed behind a wind break modifies the environmental conditions or microclimate in the sheltered areas. As wind blows against a wind break, air pressure builds up on the windward side (the side towards the wind), and large quantities of air move up, and over the top or around the ends of the wind break (Brandle, 2000).

D. Landscaping and Vegetation:

Landscaping and vegetation, economically speaking, could save up to (25%) of a household's energy consumption for heating and cooling systems. In fact, trees are very effective means of shading in summer. In addition, it could reduce air temperatures when water evaporates from vegetation and cools the surrounding air (Heinberg, 2009). However, landscaping must be located to provide shade in summer and permit sun in the winter through the use of deciduous trees for example.

3.4.2 Design of Building Envelope

Building envelope is the part that separates between the internal and the external environments of a building. It serves as the outer shell to protect the indoor environment and facilitate its climatic control. Building envelope design is an important area of architectural and engineering practice that is based on buildings physics. The physical components of building envelope include the foundation, roof, walls, and doors and windows. The dimensions, materials, and details of connection are the main factors which determine the effectiveness and durability of the building envelope.

A. Building Materials:

Construction materials used in building envelope, such as external walls and openings, have an important role in determining the rate of heat gain and loss. Consequently, those materials should be chosen carefully in the design stage taking into consideration their thickness, colors and thermal properties. For example, to reduce thermal transfer through the external walls of a building, a material with high thermal resistance and larger thickness should be used. This will be discussed in details in Chapter 4, which focuses on thermal insulation and thermal properties of building materials.

B. Openings:

Openings provide access to views, daylight and natural ventilation. Thus, they have significant impact on resident thermal comfort. However, windows are the weakest thermal links in a building envelope as they allow for heat transfer in different ways including transmittance of solar radiation into the space. This heat gain is beneficial during winter and undesirable during summer, when it could overheat the space (Mikler *et al.*, 2008).

Thus, controlling the solar energy passing through those openings has a great role in controlling the required thermal comfort conditions. For the process of designing openings, the following elements should be taken into account (Ministry of Local Government, 2004):

- Location and direction of the openings.
- Area of the openings.
- Type of the materials (glazing and frame).

C. Day Lighting:

Day lighting is the controlled admission of natural light into a space through windows, to reduce or eliminate artificial lighting. Day lighting helps create a visually stimulating and productive environment for building residents, while reducing as much as one third of total building energy costs. The art and science of proper day lighting design is not so much how to provide enough daylight to an occupied space, but how to do so without any undesirable side effects. This means the careful balancing of heat gain and loss, glare control, and variations in day light availability. In addition, window size and spacing, glass selection, the reflectance of internal finishes, and the location of any internal partitions must all be evaluated (Ander, 2008).

Some building elements that can effectively contribute to the day lighting strategy are: atrium space, light shelves, skylights and light tubes, and clerestories (see Fig. 3.2).

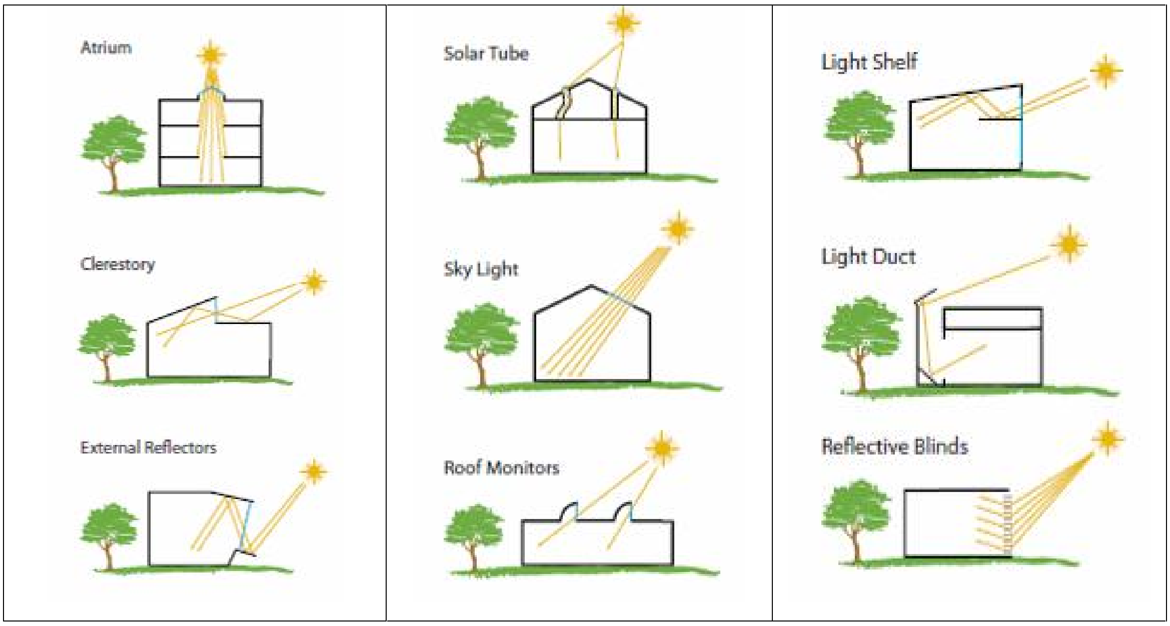


Figure 3.2: Types of Day Lighting System
Source: (Light House Sustainable Building Centre & Wimmers, 2008)

Day lighting reduces energy requirements for electrical lighting. Indirectly, it could, also reduce energy requirements for space heating. Thus, detailed building modeling and analyses is required to achieve an effective day lighting design.

D. Natural Ventilation:

Ventilation refers to the movement of air within a building and between a building and the outdoors. The control of ventilation is one of the most important concerns of building designs, and aims to make air moves in a way that satisfies the residents (Roaf *et al.*, 2007). In general, maximizing natural ventilation potential through windows, the building should be oriented according to the prevailing wind direction. Also, the use of some architectural elements is useful, such as courtyards and wind catchers.

According to Watson & Labs (1983), ventilation has three useful functions in buildings, as it is used to:

- Satisfy the fresh air needs of the residents.
- Increase the rate of evaporative and sensible heat loss from the body.
- Cool a building internal space by the exchange of warm indoor air by cooler outdoor air.

As a matter of fact, air moves easily down a pressure gradient. Positive pressure exists on the windward side of a building where air is pushed with some force against a building. Negative pressure occurs on the leeward side of a building, in the wind shadow, and drags air from the structure. In fact, the design challenge is to create or enhance that pressure gradient. This could be done in two ways (Roaf *et al.*, 2007):

- Using pressure differences caused by wind. Using wind pressure to ventilate is usually common, particularly in hot climates. There are many challenges in designing properly for ventilation, including the variability of the wind, its speed and direction (see Fig. 3.3).
- Using pressure differences caused by temperature variations within the space. It is known that warm air is less dense than cold air. Thus, pressure variation causes warm air to rise and cold air to replace it. This is called the (Stack Effect), and could be used as a ventilation driving force.

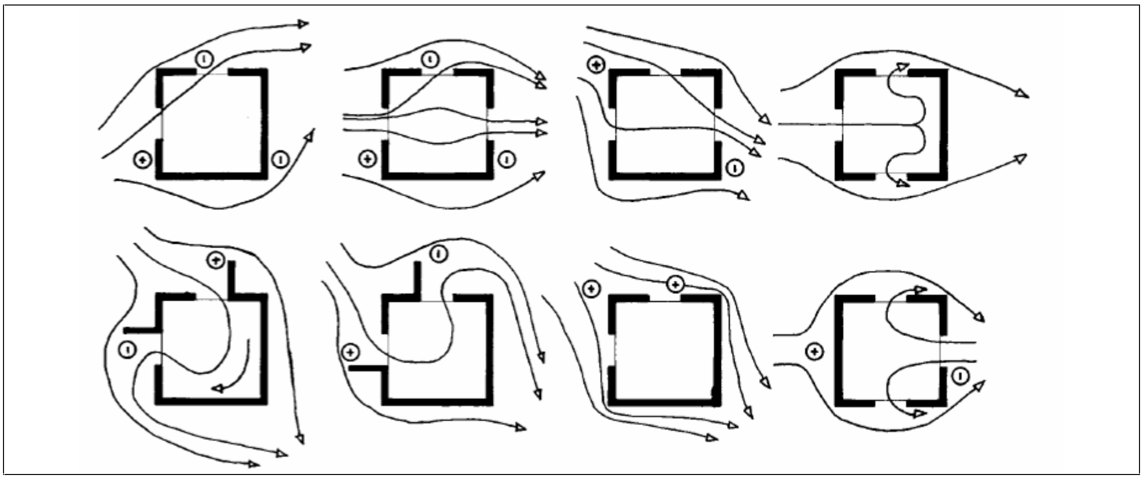
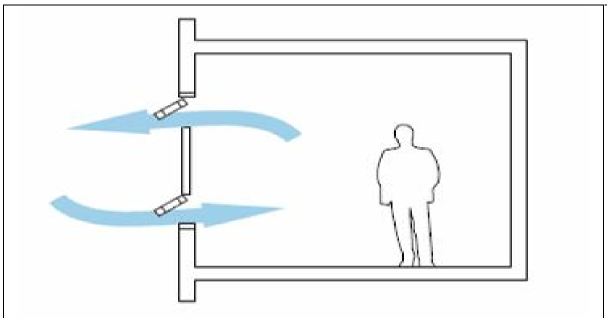
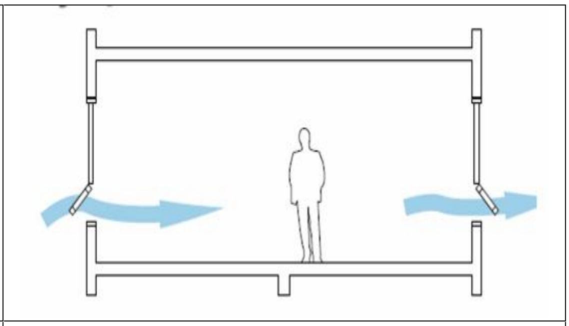


Figure 3.3: Positive and Negative Wind Pressures around Different Building Configurations
Source: (Roaf *et al.*, 2007)

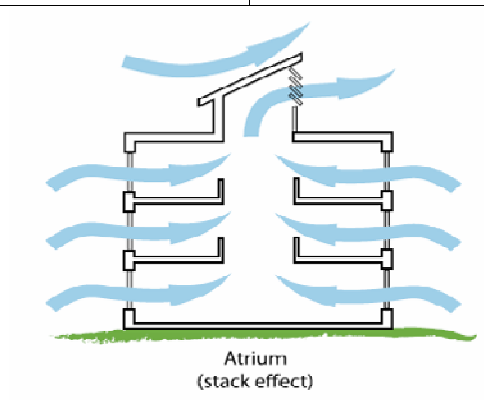
The above-mentioned ventilation driving forces result in several methods for natural ventilation (Mikler *et al.*, 2008). The first method is the single-sided ventilation, which is the simplest form of using operable windows. Air here enters and leaves through windows located on the same side of the occupied space.



(a): Single-sided Ventilation



(b): Cross Ventilation



(c): Stack Effect Through an Atrium

Figure 3.4: Several Methods of Natural Ventilation
Source: (Mikler *et al.*, 2008)

More effective is the cross-ventilation strategy, where operable windows on adjacent or opposing walls draw air across the occupied space. This requires the provision of at least two exposed walls to allow for cross-ventilation. In larger buildings with significant core spaces, such as atria, both stacks and wind effect through the central space and opposite windows may be necessary to provide adequate ventilation (see Fig. 3.4).

E. Shading Devices:

In warm, sunny climates excess solar gain, may result in high cooling energy consumption. In cold and temperate climates, winter sun entering south-facing windows could positively contribute to the passive solar heating. Depending on the amount and location of openings, reductions in annual cooling energy consumption of (5%) to (15%) have been reported (Prowler, 2008). In this context, shading devices offer the opportunity to control solar radiation admittance into the space. As shown in Fig. (3.5), there are several types of shading devices, as follows (Ministry of Local Government, 2004):

1. Horizontal devices: on the southern elevations.
2. Vertical devices: on the eastern and western elevations. However, they should be inclined to the north side of a building to reduce radiation form the south.
3. Combined devices: on the southern-eastern and south-western elevations. It is recommended to use these types of elevations in hot climatic areas, or areas located at low latitudes.

Some recommendations of using shading devices are:

- Shading devices should be located in a way that prevents the reflected solar radiation from entering to the space.
- Shading devices should be made from materials with low heat capacity (materials that don't save heat).
- To leave a small gap between the device and the building elevation to allow for hot air movement.
- To use suitable colors with high reflectivity without compromising the aesthetic quality of the building.

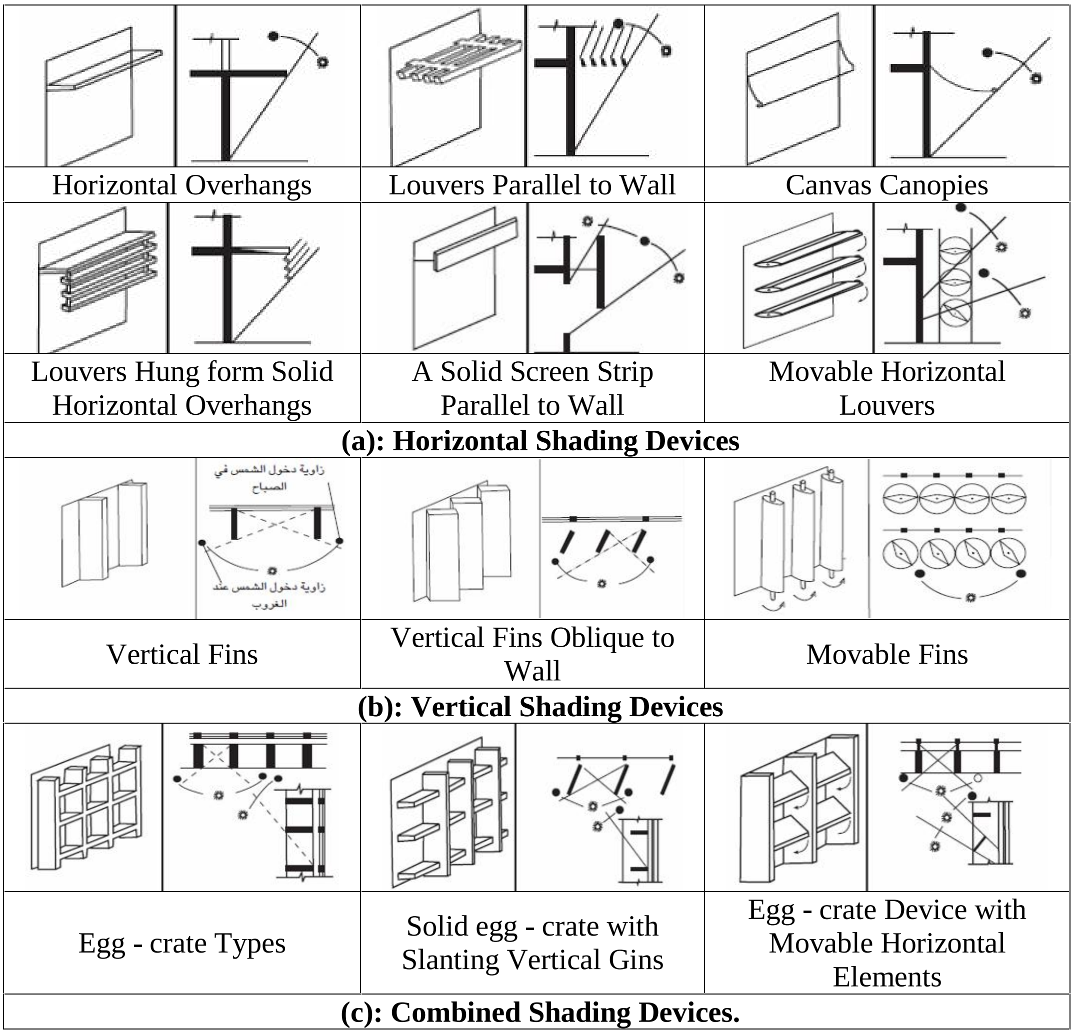


Figure 3.5: Several Types of Shading Devices.
Source: (Ministry of Local Government, 2004)

G. Thermal Insulation:

Thermal insulation in buildings is an important factor to achieve thermal comfort for its resident. Insulation reduces unwanted heat loss or gain, and decreases the energy demands of heating and cooling systems. However, this shouldn't be done on the account of natural ventilation. Insulation doesn't only refer to the mere use of insulation materials employed to slow heat loss, such as cellulose, glass wool, and polystyrene, but also refers to the correct design of their interaction with the thermal environment. Thermal insulation will be discussed in details in chapter (4) of this study.

H. Thermal mass:

Thermal mass is a building material property that enables a material to absorb, store, and then release heat. Buildings constructed of thick concrete and masonry have a unique energy storing advantage because of their thermal capacity. These materials absorb heat slowly, and hold it for longer periods of time (Galloway, 2004). This delays and reduces heat transfer through building components, leading to two important results, as shown in Fig. (3.6):

- Stabilizing internal temperatures and reducing its swing, by providing heat sink surfaces.
- Delaying occurrence of the internal temperature peak.

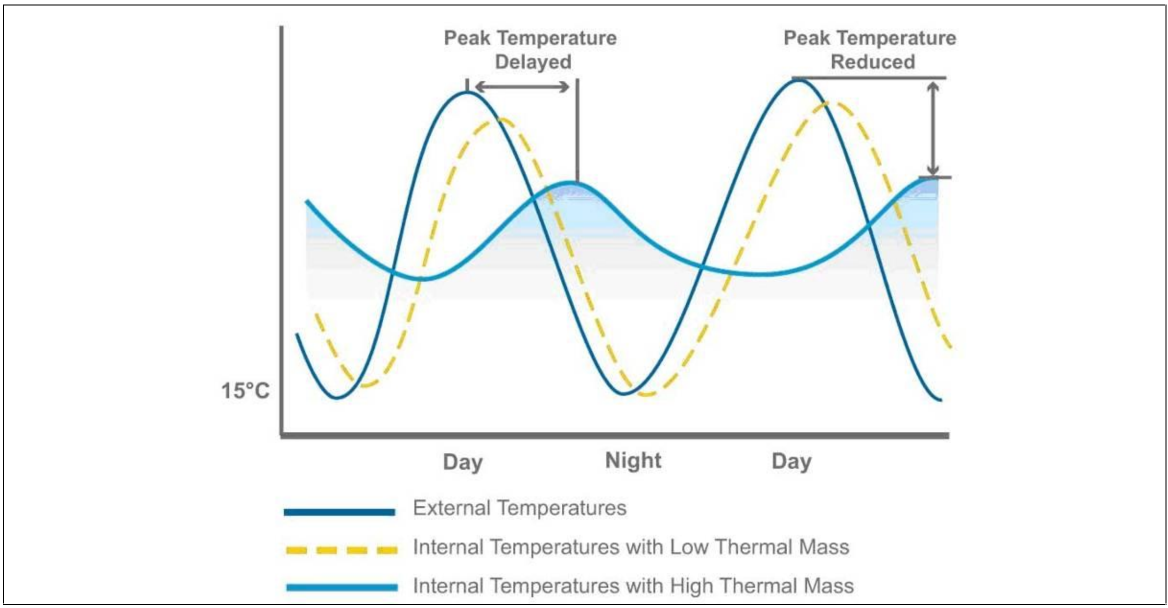


Figure 3.6: Effects of Thermal Mass
Source: (New4Old website, 2008)

3.5 Passive Design and Thermal Comfort

Passive design has been introduced at the beginning of Section 3.2 of this chapter. It was clear from the definition that the ultimate objective of passive design is to improve thermal comfort. Thus, the following sections discuss the issue of passive design and thermal comfort.

3.5.1 Definition of Thermal Comfort

Thermal comfort could be defined as: "the state expressing satisfaction with the surrounding environment, to be achieved within certain range of conditions including temperature, ventilation, humidity and radiant energy." (Busato, 2003, p.14). This definition shows that thermal comfort is highly dependant on the thermal status of a person. Thus, it is essential to understand how heat transfer from or to the human body. This is explained in the following section.

3.5.2 The Bodily Heat Transfer Mechanisms

Temperature of the human body should remain around (37^{o}C), depending on the activity performed. The human body continuously produces heat by its metabolic processes. The heat output of an average human body is often taken as (100W), but heat could vary from about (40W) during sleeping, to over (400W) during heavy work or vigorous activity (Szokolay, 2008).

Heat is transferred between the human body and the environment through the following ways:

- **Convection**: Heat energy here is transferred through fluids by the physical movement of particles. Convective heat transfer rate is in proportion with temperature difference between skin and ambient air. This means that skin loses heat by convection when cold air passes over it.
- **Radiation**: Heat energy here is transferred by electromagnetic waves. Human skin ability to lose heat by radiation depends on the temperature of the surrounding objects.
- **Evaporation**: In this case, evaporation of sweat encourages more heat transfer between skin and ambient air, causing skin to cool down.
- **Conduction**: Heat energy here is transferred through materials without molecules movement. It occurs when human body is in a direct contact with another material, which has effective thermal capacity and conductivity, like ground tiles for instance.

3.5.3 Factors that Determine Thermal Comfort inside Buildings

There are several factors that affect the residents' thermal comfort inside a building. These factors are of two types: environmental factors, and personal factors (see Fig. 3.7). These factors are discussed below (Occupational Health and Safety, 1999):

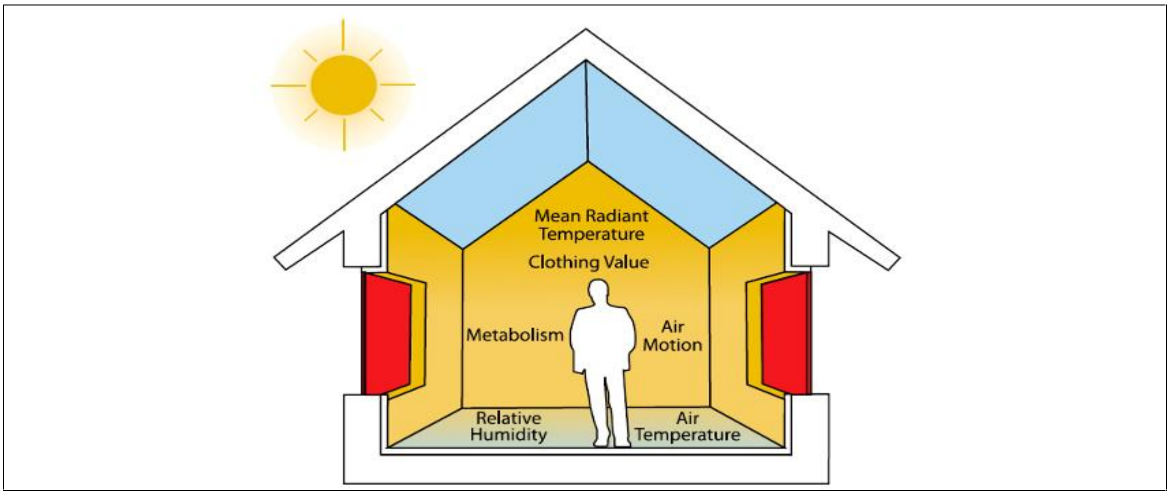


Figure 3.7: Key Thermal Comfort Factors
Source: (Mikler *et al.*, 2008)

A. Environmental factors

These factors are (Occupational Health and Safety, 1999):

- Air Temperature: Air temperature is the most important factor contributing to thermal comfort. The best temperature in a space is the temperature that most people find comfort, as it is impossible to please everyone. The best temperature depends on clothing level, and the type of work being performed. For public office work, it has been found that (20-24^{o}C) is comfortable for most people in winter season, when winter clothes are used, and (23-26^{o}C) in summer season, when summer clothes are used.

- Relative Humidity (RH): Relative humidity refers to the amount of moisture in a specific amount of air. For people who perform very light or sedentary activities, the influence of humidity on personal comfort is not great. However, higher humidity makes a person feels warmer, as it limits the evaporative heat transfer particularly where air speed is low. Generally speaking, people are much more sensitive to temperature than relative humidity.

- Air Speed: As explained above, air speed enhances the human body heat transfer through convection. However, too high air speed might cause discomfort. In addition, increased air speed encourages sweat evaporation, consequently leading to cooling effect. However, this is less effective when the temperature or humidity is too high.

- **Mean Radiant Temperature (MRT):** Mean radiant temperature is the average temperature of surfaces that surround a human body. Solar radiation contributes to the mean radiant temperature. This may be controlled by simple measures, such as shading devices.

B. Personal Factors:

- **Clothing Level:** During cold weathers, layers of insulating clothing could help keep a human body warm. At the same time, if the human body is doing a large quantity of physical activity, lots of clothing layers could prevent heat loss, and possibly lead to overheating. Clothing level is measured in "*clo*" value. Table (3.1) shows the typical insulation values for clothing.

Table 3.1: Some Standard Clothing Values

Source: (CIBSE, 1988), summarized by author.

Clothing	m^2 K/W	*clo*
Nude	0	0
Light summer ensemble	0.08	0.5
Typical indoor winter ensemble	0.16	1.0
Heavy business suit	0.23	1.5
Note: Clothing Thermal Transmittance (R) = 1/U with unit (m^2 K/W).		

- **Activity Level:** Every human body has a different metabolic rate. This rate fluctuates when one performs variant activities. Thus, people who are in the same room could feel significant temperature differences due to their metabolic rates. Table (3.2) shows metabolic heat generation for various body activities, which is measured in "*met*" value.

Table 3.2: Metabolic Heat Generation for Various Activities

Source: (Markus & Morris, 1980), summarized by author.

Activity	Heat from the human body (W/m^2)	Metabolic Rate (Met)*
Sleeping	41.0	0.70
Standing relaxed	70.0	1.20
Seated relaxed	58.0	1.00
Walking on the level, 2.3 km/h	116.0	2.00
Walking on the level, 8.4 km/h	151.0	2.60
Walking on the slope, 15%	267.0	4.6
Cleaning	116-198	2.00-3.40
Typing	70.0-81.0	1.20-1.40
Dancing	140-256	2.4-4.4
Hand Knitting	232-280	4.0-4.8
Heavy work	-	4.1-5.4

3.6 Passive Cooling

Passive cooling is usually used to maximize the ability of a building envelope to minimize heat gain from the external environment, and generate cooling potential wherever possible. These two aspects are discussed below (Autodesk, 2008):

3.6.1 Excluding Heat Gain

There are three main sources of heat gain in summer: direct solar radiation, high outside air temperatures and internal gains from occupants, lighting and equipment.

As for solar radiation, it could enter the space either directly through a window, or indirectly through opaque elements of a building fabric, which may overheat the space. The best method for dealing with either one is to prevent it from reaching building surfaces in the first place. A range of techniques could be used in this regard including: shading devices, surface colouring, and thermal insulation.

As for the high external temperatures, its effect could be minimized by using thermal insulation, and by minimizing glazing area, as glass which is considered to be a very good thermal conductor. The last measure is to deal with the unwanted internal heat gains. The simplest method to deal with these gains is to reduce them initially, and then remove them from the space. This could be achieved through maximizing day lighting, using energy efficient lights, and building zoning by dividing the space into several thermal parts, in order to avoid heat gain transmittance from one zone to another.

3.6.2 Generation of Cooling Potential

Once all of the unwanted gains have been dealt with, it is often necessary to provide additional cooling in hotter months. Two methods are commonly used to generate a passive cooling potential: natural ventilation and evaporative cooling. Natural ventilation has been discussed in details in Section 3.4.2 of this chapter.

As for evaporative cooling, it is based on the fact that when water evaporates, it consumes an amount of sensible heat from its surrounding objects. Some design solutions for evaporative cooling include the use of pools, ponds and water features, immediately outside windows or in courtyards to pre-cool air before entering the space. Such phenomenon is used to cool buildings in two different ways (Paipai, 2006):

- Direct evaporative cooling: by spraying water into the air. This lowers the temperature but raises the humidity. In this context, the use of evaporative coolers is common, which are simple, inexpensive and use little energy.
- Indirect evaporative cooling: by using heat exchanger to prevent air to get in direct contact with water vapour. This offer the advantage of cooling without increasing the indoor humidity (see Fig 3.8).

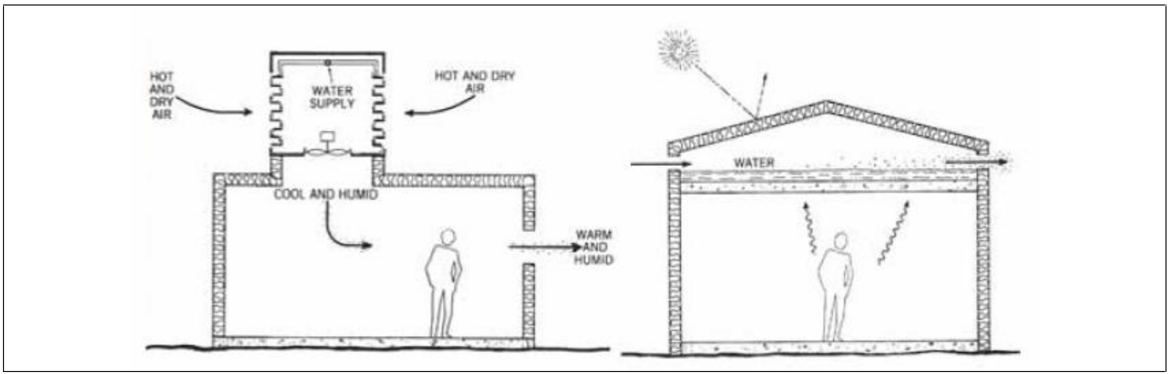


Figure 3.8: Direct Evaporative Cooling with the Usage of Evaporative Coolers (Left), and Indirect Evaporative Cooling (Right).
Source: (Paipai, 2006)

3.7 Passive Heating

Passive heating encourages the usage of architectural elements to take advantage of the natural sun heat in order to reduce the cost of building heating. Passive heating aims to minimize heat loss from a building and to generate a heating potential through maximizing heat gains. These two aspects are discussed below (Autodesk, 2008):

3.7.1 Minimizing Heat Losses

Heat could easily escape through the building fabric via heat transfer or air infiltration. As mentioned previously, this could be dealt with using thermal insulation. However, infiltration losses could be minimized by the use of airtight construction by sealing cracks and gaps, and by avoiding thermal bridges through which heat could travel faster with less resistance.

3.7.2 Generation of Heating Potential

This could be achieved through maximizing heat gains in the building. The typical processes involved in generating heating potential are (Roaf *et al.*, 2007):

- Collection: to collect solar energy, double-glazed windows are used on the south-facing side of the house.
- Storage: after the sun's energy has been collected, some heat is immediately used in the living spaces, and some is stored for later usage. The storage, called thermal mass, usually occurs into the floors and internal thick walls, which are characterized by their ability to absorb heat, store it and release it slowly as the temperature inside the house falls. Thermal mass effect has been discussed in Section 3.4.2.
- Distribution: heat stored in floors and walls is then slowly released by radiation, convection and conduction. In a hybrid system, fans, vents and blowers may be used to distribute the heat.

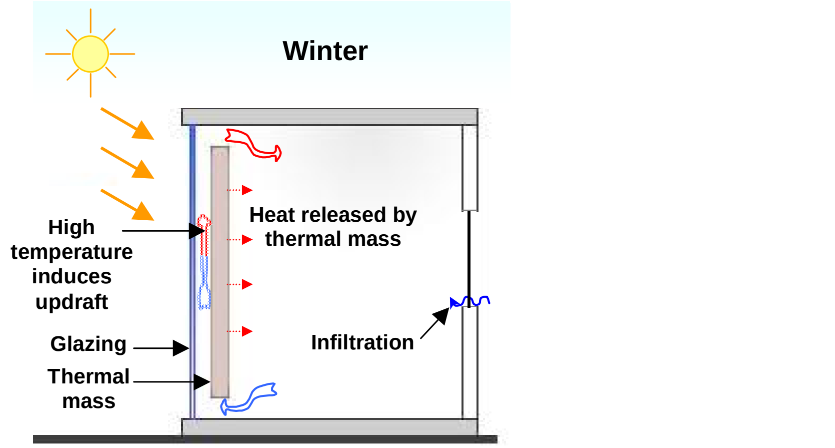
To implement these three processes, several passive heating systems could be used. Some of these systems are discussed below:

A. Trombe Wall Systems:

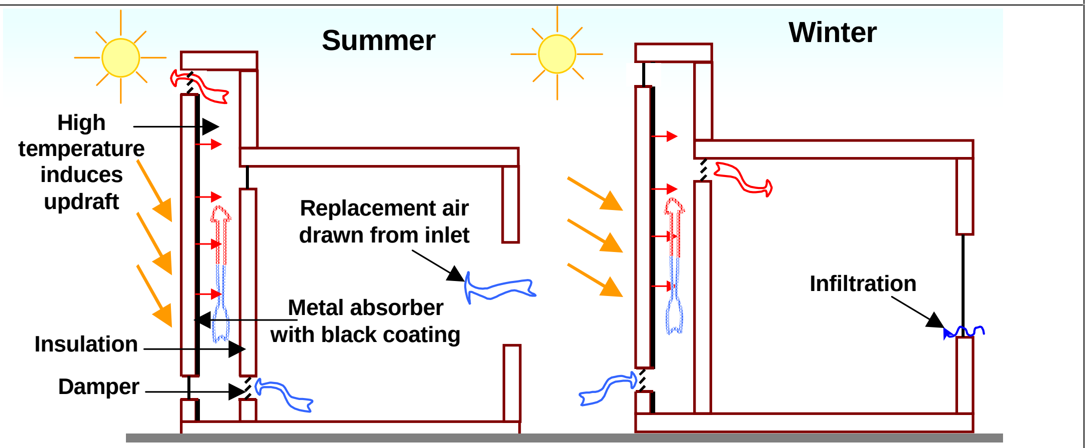
Trombe wall system (see Fig. 3.9-a) is a sun-facing massive wall separated from the outdoors by glazing, and an air space, which absorbs solar energy and releases it selectively towards the internal side at night. Modern variations include insulating glass to retain more of the stored solar heat, and include high and low, sometimes operable, vents to allow convective heat transfer to the indoors (Ben Yedder and Belgin, 1991).

B. Solar Chimney:

Solar chimney system is similar to the Trombe Wall system. However, solar chimneys could be used for both passive cooling and heating, where the entire height of a building can be utilized to promote the stack effect, as shown in Fig (3.9-b).



(a): Trombe Wall System



(b): Solar Chimney System

Figure 3.9: Typical Trombe Wall and Solar Chimney Systems
Source: (Asfour, 2006)

C. Sunspace:

This is an attached glazed space separated from the internal spaces of building by a massive wall. The wall absorbs solar radiation, and converts it into heat. This heat is gradually transferred by conduction into the building mass and the internal spaces of the building. This storage wall should have a high thermal capacity, and a low conductivity rate. Means of controlling the high winter season heat losses, particularly during the night, can be ensured by using double-glazing method, (see Fig. 3.10), (Roaf *et al.*, 2007).

Figure 3.10: Attached Sunspace.
Source: (Energy Savers, 2009)

3.8 Conclusion

This chapter presented a wide range of ideas and solutions to achieve an energy-efficient design of buildings. This has been done with considering the passive design concepts and techniques, and their potential on site planning level and building design level. The principles of passive design and its relationship with human thermal comfort have been highlighted, with a review on the bodily heat transfer mechanisms

It has been concluded that passive design is one of the most important aspects that should be considered in designing energy-efficient buildings. Its advantage of incorporating no mechanical components makes it a desired option to reduce buildings reliance on non-renewable energy sources. However, good understanding of the human thermal comfort requirements should be ensured in order to offer effective passive design solutions and systems like passive cooling and passive heating. Designers should also integrate passive design techniques in accordance with the requirements of building codes, aesthetic qualities, and building function.

Chapter 4 : Thermal Insulation Design in buildings

4.1 Introduction

Thermal design of building envelope includes designing all external structural elements that are in contact with the external environment. One aspect of this design is to implement thermal insulation in order to reduce heating and cooling loads, while providing healthy and comfortable indoor environment. Thermal insulation targets the external elements, such as roofs, external walls and windows, where thermal properties of these elements should be carefully selected.

Therefore, this chapter aims to study the issue of thermal insulation as a passive design mean. This includes objectives of thermal insulation, the effect of thermal properties of building materials on thermal insulation, and some common insulators that are used in buildings. Finally, it presents some technical recommendations and details on implementing thermal insulation in buildings considering the components of the external building envelope.

4.2 Objectives of Thermal Insulation

Thermal insulation is primarily used to limit heat gain or loss from buildings surfaces, which operate at temperatures above or below ambient temperatures. Thermal insulation may be used to satisfy one or more of the following design objectives (National Mechanical Insulation Committee -NMIC, 2009):

- To reduce unwanted heat losses, or heat gains through roofs, walls, doors, windows and floors. Insulation could reduce the rate at which heat flows through buildings fabric either outwards in winter time or inwards in summer time.
- To create a comfortable and refreshing climate, and increasing the level of comfort for buildings residents, throughout the year. This, consequently, reduces energy required for heating or cooling.
- Fire safety: to protect critical building elements and slowing the spread of fire in buildings.

- Condensation control: to minimize condensation and the potentiality for mold growth, by keeping surface temperature above the dew point of surrounding air.
- Personnel protection: to control surface temperatures to avoid contact burns (hot or cold).
- Noise control: to reduce noise in mechanical systems.
- Avoiding Thermal Bridges: thermal bridges may occur at building envelope with significant high heat losses or gains. Typical areas of thermal bridges include frames of windows and doors, junctions between walls and roofs, and wall corners (see Figure 4.1).

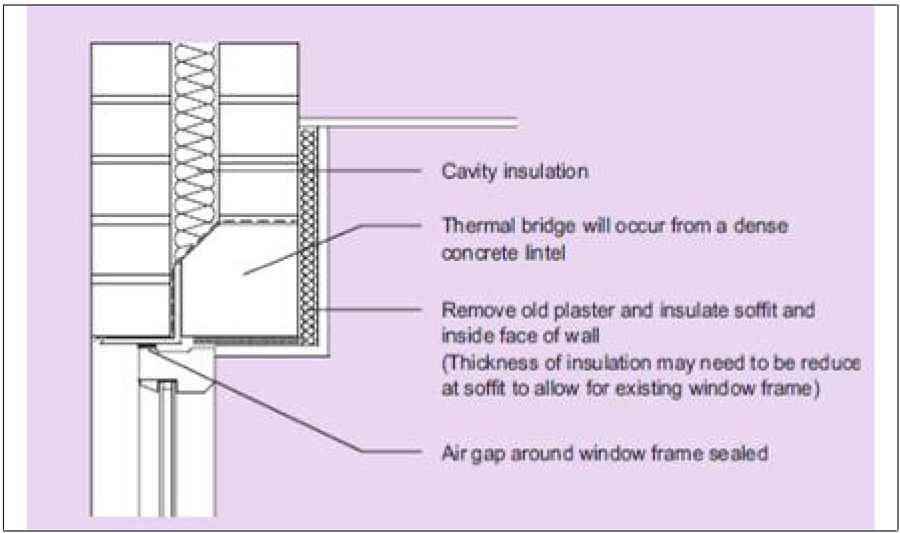


Figure 4.1: Insulating thermal bridge at opening lintel
Source: (Energy Saving Trust, 2007)

It is obvious, from these objectives, previously mentioned that thermal design of building external envelope is an economic investment, which leads to energy and money saving. In addition to that, it is necessary and indispensable to meet the requirements of healthy and comfortable housing through the protection of moisture damage, and the extreme climatic conditions of the external environment.

4.3 Thermal Properties of Building Materials

The quantity of transmitted heat through a building envelope is mainly related to the thermal characteristics of materials that make up these elements. This is in addition to their thickness and exposure to the affecting atmosphere factors. This could be judged depending on the amount of heat loss or gain, and the resulting level of thermal comfort. Therefore, thermal properties of the external elements of any building should be selected to offer acceptable level of thermal insulation in order to achieve thermal comfort. So, the following sections discuss some of these thermal properties as follows:

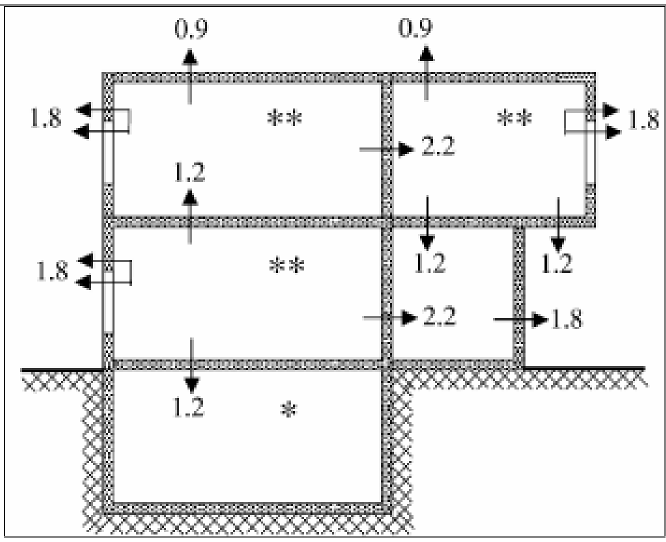
4.3.1 Thermal Transmittance (U-Value)

Thermal transmittance (U–Value), also known as the U–Factor or coefficient of heat transmission, is a measure of the rate of non-solar heat loss or gain through a material or assembly. U-Values measure how well a material allows heat to pass through. The lower the U–Value is, the greater a product's resistance the heat flow, and the better its insulating value is. (U) is the inverse of (R), i.e. (R=1/U) with (SI) units of (W/m^2K) and (US) units of ($BTU/h°F\ ft^2$). (U–Value) in the present time is considered one of the most important parameters of thermal design in modern buildings. Its importance comes from the fact of being a measurement and a significant indicator of knowing the thermal efficiency of a building. Table (4.1) and Fig. (4.2) show some recommended U-Value in the cases of ceilings, floors, and walls.

Table 4.1: The whole maximum U-value for ceilings, floors, and walls in the Palestinian Code of Low-Energy Buildings (W/m2.K)
Source: (Ministry of Local Government, 2004).

Ceilings and Floors		**Type of building**	
		A	**B**
		Equipped with central heating – Air conditioning ($W/m^2.K$)	None Equipped with central heating – Air conditioning ($W/m^2.K$)
Exposed to the external air	Upward Thermal Transition	0.9 (1.1)*	1.8
	Downward Thermal Transition	1.2	2.2
Ceilings and floors separating two levels, each of which has a separate energy source.		1.2	-
Floors located above parts, or adjustments, that are not heated or air conditioned		1.2	-
* This value is the value of the whole maximum U-Value of exposed roofs that contain the elements of skylights.			
Walls		**Type of Building**	
		A	**B**
		Equipped with central heating or air conditioning ($W/m^2.K$)	Not equipped with central heating or air conditioning ($W/m^2.K$)
The total of the external walls, including windows, doors and any other openings.		1.8	2.5
Walls separating two parts of a building, each of them has a separately source of energy.		2.2	-
Walls separating two parts of a building, one of them has a central heating, one of them only is heated or air conditioned.		2.2	-

According to these recommendations, the whole U-Value of any element should not exceed these values. It should be noted that the whole U-Value of walls includes windows, doors and any other openings.



** Parts that are provided with an independent system of central heating or air conditioning.
* Parts of a building that are not heated or air conditioned.

Figure 4.2: Maximum U–value requirements for ceilings, floors and walls ($W/m^2.K$).

Source: (Ministry of Local Government, 2004).

Table 4.2 illustrates an example of U-Value calculation method in a wall that consists the following layers:

Table 4.2: An example of calculating Thermal Transmittance (U-Value) in walls

layers	Thickness (m)	Thermal Conductivity ($W/m^2.C$)	Thermal Resistance, *R* ($m^2.C/W$)
Internal plaster (sand cement)	0.01	1.2	0.0083
Internal concrete block	0.15	0.9	0.166
Air space	0.05	0.28	0.1785
External concrete block	0.10	0.9	0.111
External plaster (sand cement)	0.02	1.2	0.0167
Total			**0.48**
R = Thickness (m) / Thermal Conductivity ($W/m^2.C$) **R_{total} = 0.48 $m^2.C/W$** **$U=1/R_{total}$ =1/ 0.48=2.10 $W/m^2.C$**			

4.3.2 Thermal Lag

Thermal lag of a building is the time taken for heat energy to pass through a building element from one side to the other one. Thermal lag is always measured in hours. The external elements of building are exposed during the summer season to periodically heat waves, which leads to the transfer of periodical heat flow through the elements to the interior space. The heat wave moves to the internal surfaces of the components, like ceilings and external walls, in a delay time that might range from a relatively short period of time to long hours. (Baggs, & Mortensen, 2006)

For most low-rise buildings in temperate climates, massive external walls could achieve a time lag of (10–12) hours, and could be effectively used without the need for external insulation (Baggs, & Mortensen, 2006). Table (4.2) shows time lag figures, for a variety of building materials

Table 4.3: Time lag figures for some building materials.
Source: (Persily, 1993)

Material (thickness in mm)	Time lag (hours)
Concrete (250)	6.9
Double Brick (220)	6.2
Adobe (250)	9.2
Rammed Earth (250)	10.3
Compressed Earth Blocks (250)	10.5

4.3.3 Thermal Decrement

Thermal decrement represents the ratio of peak amplitude temperature fluctuation on one side of a material, compared to the other side of a one. It is always give as a ratio of (0 - 1) (Square One, 2005).

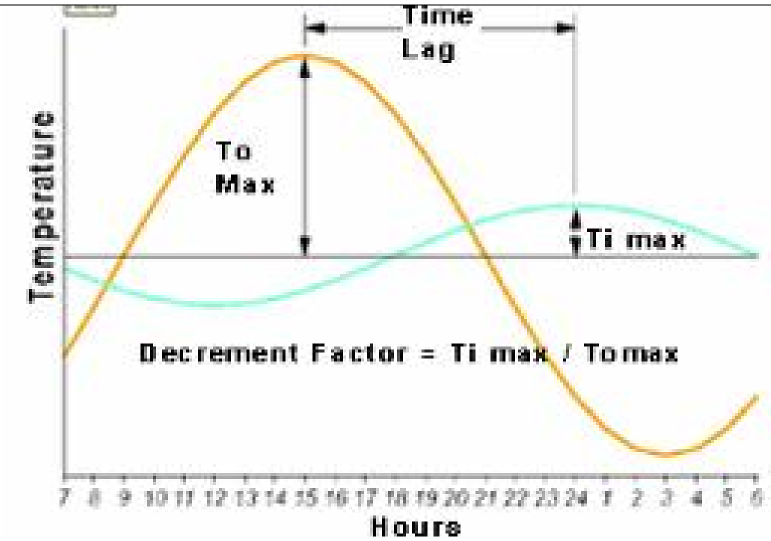


Figure 4.3: Time lag and thermal decrement factor
Source: (Square One, 2005)

4.3.4 Solar Absorption

Solar absorption refers, to the portion of incident solar radiation that is absorbed by the surface of a building, and not reflected away or transmitted through. This affects thermal calculations through indirect solar gains, and the sol-air temperature. For windows, this value becomes the shading co-efficient, a value between (0 and 1) which represents the relative quantity of a solar radiation passing through the material. This value is available from glass suppliers (Square One, 2005).

4.4 Building Insulation Materials

Walls, roofs, floors, chimneys and windows are all considered escape routes of heating or cooling. It may be necessary to provide additional layers of insulation around them to prevent such elements acting as weak links or Thermal Bridges in the design. Well-determined levels of insulation are a cost-effective way of reducing heating or cooling energy consumption. Therefore, the additional cost of insulation could be recovered through the reduced cost of heating and cooling systems in buildings.

There are numerous alternatives when it comes to choosing insulation materials. They differ in thermal efficiency and in offering certain important properties, like resistance to fire and avoidance of ozone depleting chemicals. Some other, also, lose much of their insulating efficiency if affected by moisture. According to Smith (2005), Insulation materials fall into three main categories:

- **Inorganic / Mineral:** These include products based on silicon and calcium (glass and rock), and are usually evident in fibre boards, e.g. glass fiber and Rock-wool.
- **Synthetic organic:** Materials derived from organic feed stocks based on polymers.
- **Natural organic:** Vegetation-based materials, like hemp and lamb's wool, which must be treated to avoid rot or vermin infestation.

4.4.1 Inorganic (Mineral) Insulators

This category includes two common types of thermal insulators (Smith, 2005):

A. Fiber:

This insulation material includes rock wool and glass wool. They are produced by melting a base substance at high temperature and spinning it into fibers with a binder added to provide rigidity. It is air permeable due to its structure. Moisture could build up in the insulant reducing its insulating value. It might degrade over time. Lambda Value of this insulator is (0.033 – 0.040) W/m K. Figure (4.4) shows different types of fiber insulation.

Figure 4.4: Some forms of fiber insulation
Source: (Therm-O-Comfort website, 2004)

B. Cellular:

This insulator is manufactured from natural materials and over (40%) recycled glass. It is impervious to water vapor and is waterproof. Also, it is dimensionally stable, non-combustible, has high compressive strength, as well as being (CFC) free. Lambda Value of this insulator is (0.037 – 0.047).

4.4.2 Organic / Synthetic Insulants

This includes the following types (Light House Sustainable Building Centre & Wimmers, 2008):

A. Rigid Polystyrene:

This product displays fairly low U–Value, and is durable and relatively affordable. There are, however, issues with (CFC's) and other hazardous substances that go into the production of polystyrene panels. Furthermore, this material is a derivative of crude oil, and therefore displays a large carbon footprint. There are two main types of rigid polystyrene: extruded and expanded (see Fig. 4.5).

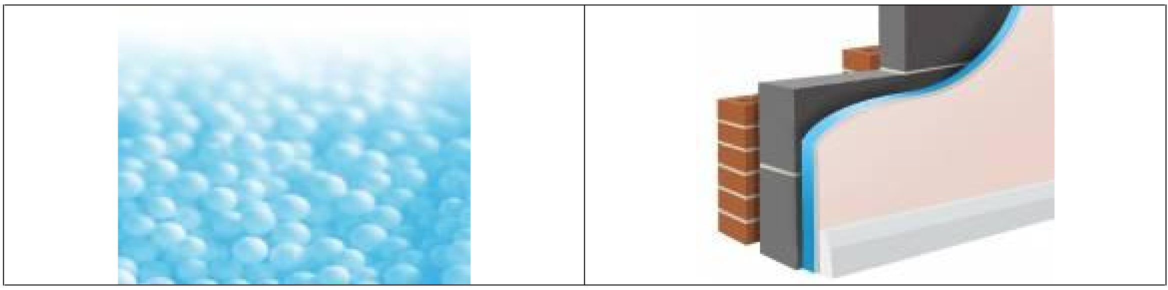


Figure 4.5: Expanded polystyrene (left), and extruded polystyrene (right)
Source: (BuildingTalk website, 2010)

B. Aero gels:

Aero gels are forms of frozen silica smoke with extremely small pores, making this material extremely durable and light, with high insulation value. Many are also translucent, and they could be used to insulate windows and sky lights, or create translucent walls. Usage of Aero gels is not very common, especially in commercial buildings (see Fig. 4.6).

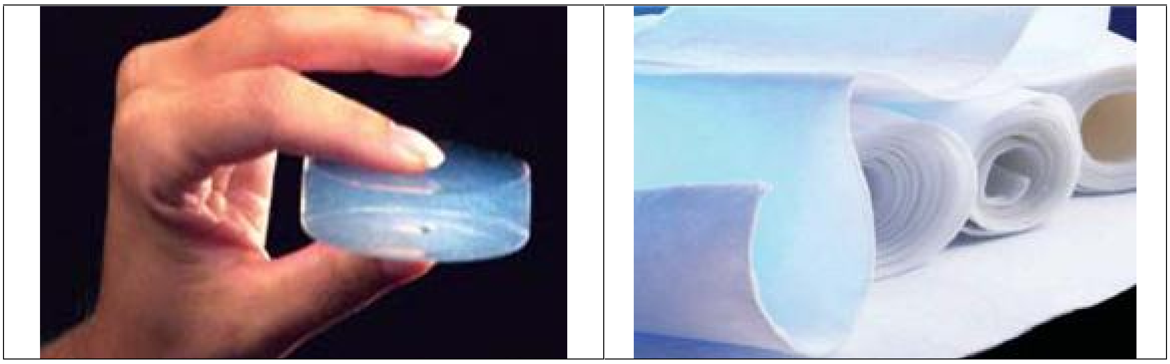


Figure 4.6: Aero Gels translucent insulation.
Source: (Light House Sustainable Building Centre & Wimmers, 2008)

4.4.3 Natural / Organic Insulants

A. Cellulose:

This substance is mainly manufactured from recycled newspapers, and transformed into fibers, bats or boards. Lambda value of this insulator is (0.038–0.040 W/m K). There are three major types of cellulose products that have been developed to deal with different applications of the material in different locations in buildings. These major types are: dry cellulose, spray applied cellulose, and low dust cellulose as illustrated in Fig (4.7) (Smith, 2005).

(a): Dry Cellulose (Loose Fill)

(b): Spray Applied Cellulose

(c): Low - Dust Cellulose

Figure 4.7: The three major types of cellulose insulation.
Source: (Low Energy House website, 2010)

B. Cotton Insulation:

Natural Cotton Fiber insulation offers an outstanding thermal performance. It is non-toxic and sound proofing. Cotton Fiber contains no chemical irritants, or volatile organic compounds (VOCs), which pose serious health risks. Moreover, it contains (85%) of recycled natural fibers making it an ideal choice for anyone looking to use a high quality sustainable building materials (see Fig. 4.8), (Light House Sustainable Building Centre & Wimmers, 2008).

Figure 4.8: Natural cotton insulation
Source: (Light House Sustainable Building Centre & Wimmers, 2008)

C. Wood Fiber:

Wastes of wood fiber panels are popular insulations of building materials. With a small ecological footprint, this material also provides sound reduction and high thermal mass. It is suitable for internal usage as thermal and acoustic insulation on floors, walls and ceilings. It could also be used as an external insulation with render protection, and could receive lime and earth based clays. Fig. (4.9) shows some types of natural wood fiber insulation (Light House Sustainable Building Centre & Wimmers, 2008).

			
(a): Flexible Wood Fiber Insulation Bat	(b): Sarking & Sheathing Tongue & Groove Insulation Board	(c): Rigid Square Edge Insulation Board	(d): External Natural Insulation Board

Figure 4.9: Types of the natural wood fiber insulation
Source: (NatureRRO website, no date)

4.5 Design Recommendations

Good thermal insulation is a key factor for achieving more comfortable and energy-efficient buildings. On contrary, low insulation levels and gaps or voids in the insulation materials could provide paths through which heat and air could easily flow to or from the building. More care must be taken to the insulation material around piping and electrical work. Consequently, this section presents some technical advices related to good installation of thermal insulation for different elements in the building envelope.

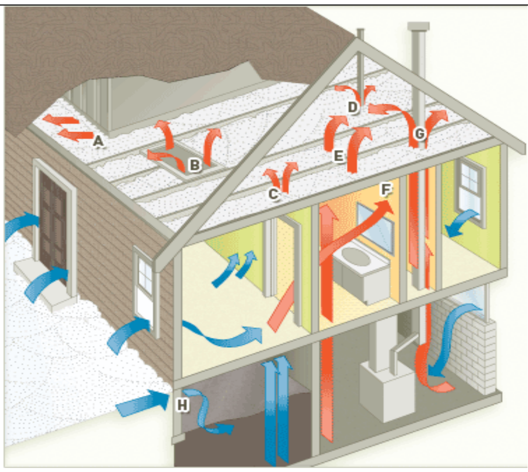
4.5.1 Walls

External walls of a building are considered among the most complex components of the building envelope. External walls are the first defense line against external thermal conditions and air leakage.

In fact, the problem of air leakage through building fabric (walls, windows and ceilings), is one of the most serious problems when it comes to thermal insulation. There are many paths of air leakage through building fabric, as illustrated in Fig. (4.10).

According to Persily (1993)**,** there are some defects that lead to air leakage in buildings including:

- Discontinuity of air barriers.
- Inappropriate usage of insulation, or insulation adhesives as air barriers.
- Punctured or displaced air barriers.
- Polyethylene: inadequate support, lack of continuity.
- Lack of internal finishing.



Effects of Air Leaks

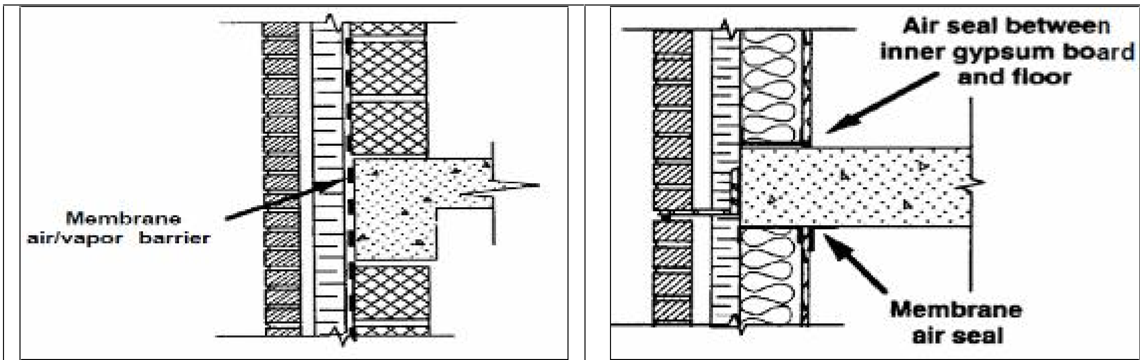
- Cold outside air drawn into the house (blue)
- Heated inside air drawn into the attic (red)

Common Household Air Leaks

- **A-** **Between Floor joints behind knee walls**
- **B-** **Attic hatch**
- **C-** **Wiring holes**
- **D-** **Plumbing**
- **E-** **Open soffit (box hiding recessed lights)**
- **F-** **Recessed light**
- **G-** **Furnace flue or Duct chase ways**
- **H-** **Basement Rim joist**

Figure 4.10: Typical air leakage paths in exterior walls
Source: (Efficiency Vermont website, 2006)

Generally, one suggested solution of air leakage through building fabric is the usage of air barriers. The purpose of an air barrier is to prevent air flow through buildings envelope. This includes, both the prevention of external air from entering buildings through walls and roofs, and the prevention of indoor air from ex-filtration through buildings envelope to the external environment (Persily, 1993). Fig. (4.11): shows some examples of the usage of air barriers in walls.



(a): Masonry Wall Air Barrier | (b): Accessible Drywall Air Barrier

Figure 4.11: The use of air barriers in walls
Source: (Persily, 1993)

In general, the methods of isolating external walls in buildings may be summarized as follows (Maghrabi, 2005):

A. Internal insulation of walls:

This is done by using composed boards of polystyrene, which are fixed on gypsum or wood boards. Boards must be installed on walls using cement mortar or glue. This way leads to save in the costs of internal finishes, and ensures the complete insulation of walls and columns (see Fig. 4.12).

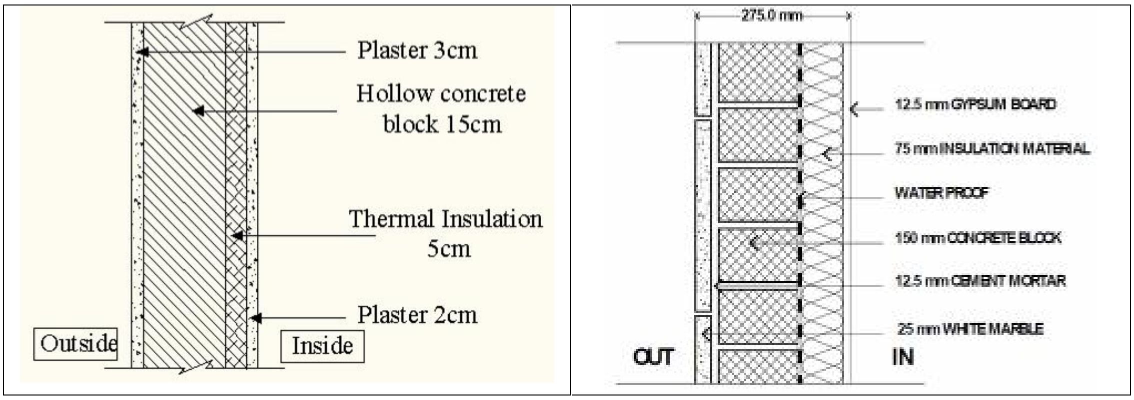


Figure 4.12: Two different ways to insulate external walls from inside
Source: Left: (Maghrabi, 2005), right: (Ministry of Local Government, 2004)

B. External insulation of walls:

This consists of thermal insulation installed on the outside surface with a layer of mortar applied to it using a reinforce fiber net. After that, it can be finished using any desired type of finishing. This kind of insulation is characterized with the achievement of full insulation for the external walls, including columns and roof slabs, and prevents heat leakage. Also, it is lighter than the way of insulating walls at the middle, and could be used for old and new buildings.

C. Core insulation of walls:

Insulation boards are usually placed between the two layers of the external wall. Alternatively, air cavity could be left between these two layers to act as an insulator. Core insulation is easy to install and had high efficiency in resisting high temperature up to 300% compared to the normal wall (see Fig. 4.13).

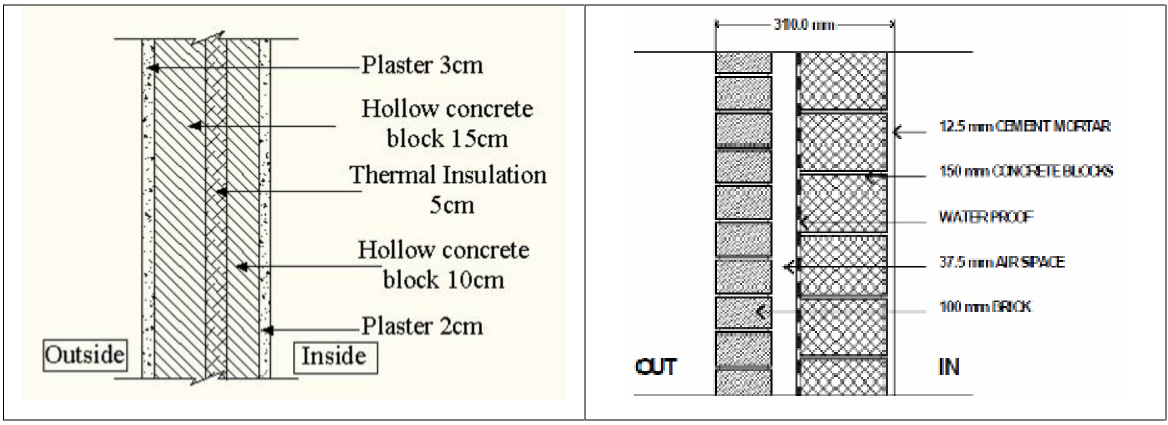


Figure 4.13: Two different ways to insulate the external walls from the middle
Source: Left: (Maghrabi, 2005), right: (Ministry of Local Government, 2004)

D. Insulation using the red bricks:

This is commonly implemented through placing strips of an appropriate thermal insulation inside the concrete blocks, which are then used to build single external walls. However, this method does not assure the minimum requirements for thermal insulation, as it only improves wall insulation efficiency by about 15% compared to the usual wall section. Using the red block may increase this efficiency up to 45%. However, mortar joints between blocks act as thermal bridges between internal and external surfaces of the wall (see Fig. 4.14).

(a):Concrete and red blocks with foam insulation

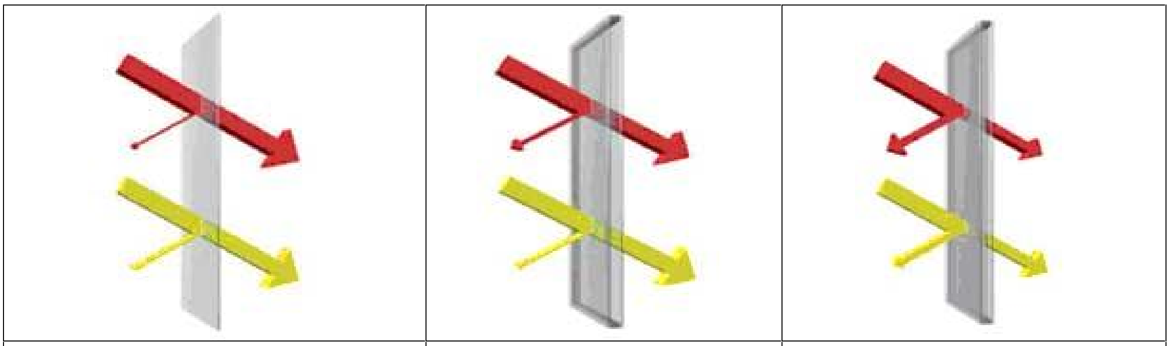
(b): Red bricks walls insulated with polystyrene

Figure 4.14: Insulation of red and concrete blocks
Source: (Almuhands website, 2008)

4.5.2 Windows

Windows are significant and important components of any building. They provide natural light, views to outside world, ventilation and solar heat gain in winter. However, windows could cause significant amounts of heat transfer from or to buildings. The overall insulation quality of a window is a key issue here, which could be determined by the thermal quality of its glass and frame. Using low U–Value of windows could offer better insulation for buildings (see Fig. 4.15).

Moreover, the style of the window could have an effect too. Slider windows may be poorer air barriers, as the sealing system is harder to design. Fixed windows are permanently sealed, however, they do not offer the benefits of ventilation, while hinged windows use compression seals (Light House Sustainable Building Centre & Wimmers, 2008).



(a): Single Pane U-Factor = 1.04	(b): Double Pane U-Factor = 0.50	(c): Triple Pane U-Factor = 0.15

Figure 4.15: Different types of windows with different U-values
Source: (Light House Sustainable Building Centre & Wimmers, 2008)

Table 4.4: Thermal quality of several types of window frame
Source: (Light House Sustainable Building Centre & Wimmers, 2008)

Common wood or vinyl frame	Generally has a U-value between 2.0 - 2.5 W/m²K. These are the most commonly used.
Metal or aluminium frames	Though strong, these materials have high heat conductivity. Aluminum can decrease the insulating value of a window by 20 to 30%. These frames, combined with triple-pane windows, would reach a maximum U-value of 1.6-2.0 W/m²K.
Timber frames	Good insulator but requires more maintenance than aluminium. Wood used in their manufacture should be sourced from a sustainable forest.
Composite frames	Aluminum outer sections with either a timber or u PVC inner section.
Super-insulated frames	May consist of wood or a wood/metal composite window frame which is hollowed out and filled in with foam or other insulations. These types of frame may reach U-values of under 0.8 W/m²K.

In fact, a precondition for glass to deliver the desired thermal performance is to provide an insulated frame as well. For example, installing high performance triple-pane glass into a common frame would be inefficient. This is further detailed in Table (4.3).

According to Light House Sustainable Building Centre & Wimmers (2008), the following recommendations are useful to reduce heat gain/loss through windows (as illustrated in Fig 4.16):

- Usage of a super high performance window and frame to mitigate the quantity of energy lost through windows.
- Selection of window style with durable seals.
- Keeping in mind that improving thermal performance of windows is important, as nearly half of the energy loss of a home is associated with windows.

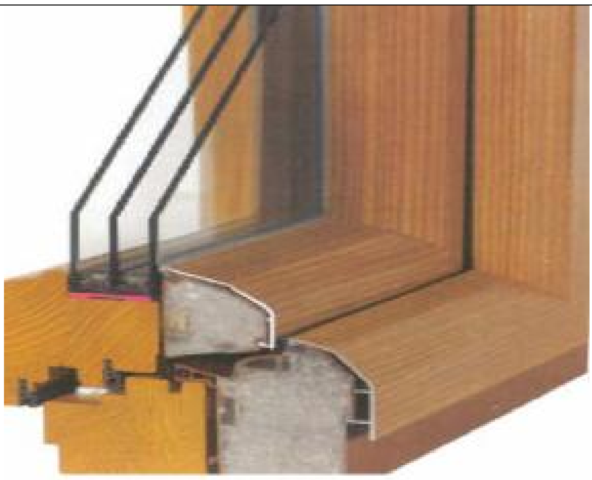


Figure 4.16: Super high performance windows used in cooperation with super-insulated frame

Source: (Light House Sustainable Building Centre & Wimmers, 2008)

For a complete discussion of appropriate locations for windows, see Section (3.4.2) in this study. As a general rule of thumb, windows should not exceed (2/3) of the envelope. In fact, due to the nature of thermal bridges, number of individual windows should, also be kept to a minimum. Slightly larger window is more efficient than two, even if they provide the same area of window (Ministry of Local Government, 2004).

In addition to that, appropriate use of shading could prevent too much heat from entering a building by shading the glass from direct sun light. This is particularly important for the south elevation during the warm summer season months.

4.5.3 Roofs

The roof might be the largest surface area of a building, and is exposed to the sun all day. As a result, choosing the right insulation for it is essential. Insulating surfaces could be performed using thermal insulations and waterproofs. The techniques that are usually used in roof insulation are explained below (The Engineer Site for Construction and Decoration, 2009):

A. Installation of heat insulating boards:

After the completion of the structure construction and ensuring that roof surface is clean, it should be firstly painted with a base layer of bitumen (primer). This aims to facilitate installing the thermal insulation (polystyrene boards). Thermal insulation boards should be tightly installed in a way that links between boards would be overlapped and placed an adhesive tape made of aluminum (7.5cm) in width. Then, these boards should be covered with a plastic layer to protect the thermal insulation before pouring a layer of foamed concrete (see Fig. 4.17).

Figure 4.17: The process of installing insulation boards over the roof
Source: (The Engineer Site for Construction and Decoration, 2009)

B. Pouring a layer of foamed concrete:

This layer protects the insulating boards from excessive heat. It is usually poured with a minimum thickness (3 cm). The thickness should be increased by (1 cm) per meter to ensure appropriate slope towards water drainage points (see Fig. 4.18).

Figure 4.18: The process of pouring a layer of foamed concrete on the roof
Source: (The Engineer Site for Construction and Decoration, 2009)

C. Installation of waterproof rolls:

The foamed concrete should then be painted by a bitumen protection layer. This layer should also facilitate the installation of the waterproof rolls (Polystyrene). These rolls are installed on the surface by overlapping welding using burner flame. The waterproof rolls should be extended to cover the base of the roof edge walls, where they are fixed using metal strips. Extra care must be taken not to overheat the waterproof rolls to avoid losing their elasticity as shown in Figure (4.19).

Figure 4.19: The process of fixing waterproof rolls over the foam concrete
Source: (The Engineer Site for Construction and Decoration, 2009)

D. Waterproof checking:

After finishing the installation of waterproof, it must be tested with the submersion test, in which the roof is filled with water and gutters are sealed off. Care must be taken to maintain a constant water minimum level of (5 cm) for (48) hours, or until the appearance of some signs of water leak. Upon passing the waterproof test, a (2 cm) protective cement layer should be made above the waterproof (see Fig. 4.20).

Figure 4.20: The process of inspecting waterproof with submersion method
Source: (The Engineer Site for Construction and Decoration, 2009)

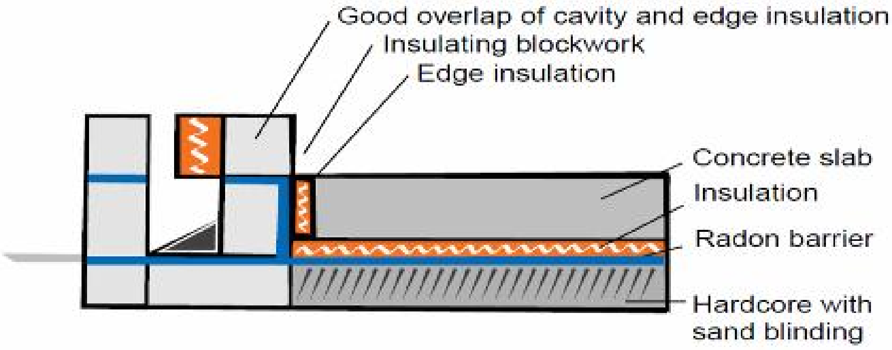
E. Tile installation:

Tiles are installed over the cement layer to ensure further protection of the insulation layers. This is done by spreading out a layer of sand and fixing the tiles using cement mortar, while maintaining the slopes as shown in figure (4.21).

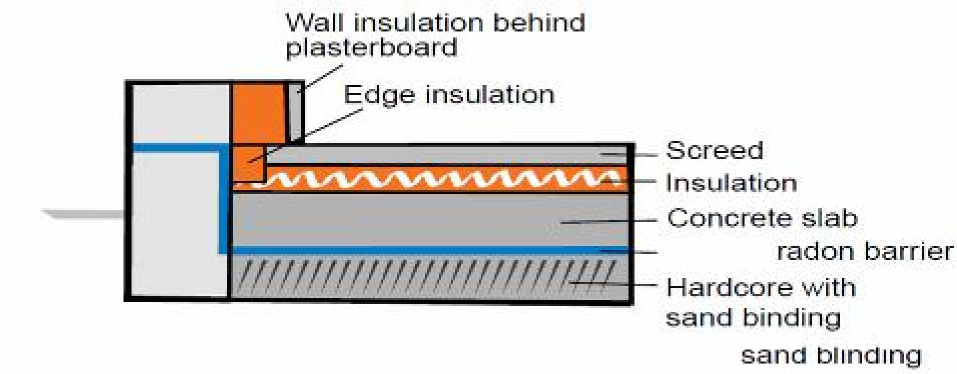
Figure 4.21: The process of installing tiles over the protective concrete layer
Source: (The Engineer Site for Construction and Decoration, 2009)

4.5.4 Floors

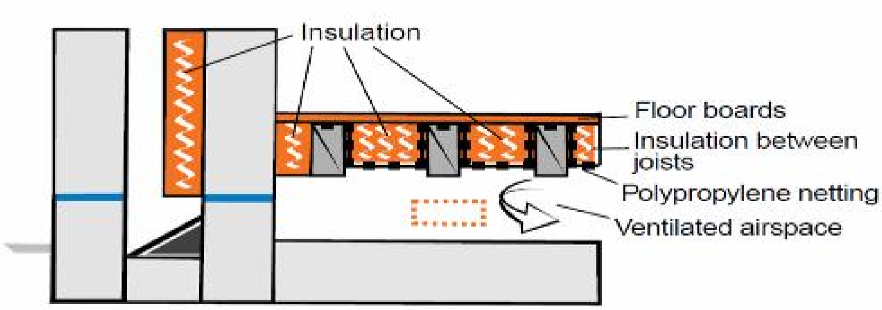
It is estimated that heat loss through the ground floor of a two-storey building typically accounts for approximately (10%) of the total heat loss. As for a single-storey building, the figure is about (15%). The quantity of ground floor heat loss depends on the type of soil. Buildings which built on wet soils tend to lose more heat through the ground than those on dry ones. Also, detached buildings tend to lose more heat through the ground floor than terraced buildings, because their ground floors are exposed on all sides. Figure (4.22) illustrates different examples of floor insulating. However, in all cases, the designer should try to minimize penetration of the insulation by pipe works and wiring (SEI, 2006).



(a): Concrete Floor with Insulation Under Slab, Cavity Walls



(b): Concrete Floor with Floating Screed, Hollow Block or Solid Walls



(c): Suspended Timber Floor

Figure 4.22: Different examples on thermal insulation of floor.
Source: (SEI, 2006)

4.6 Conclusion

This chapter discussed the aims and benefits of thermal insulation as a passive design strategy. Thermal insulation has a variety of types that protect building envelope from excessive outdoor climatic conditions, where undesired heat currents or air leakage may occur from or to the building. This includes the elements of walls, floors, roofs, and windows. However, proper selection of thermal insulation materials should be done based on their thermal properties, like U-Value and Thermal Lag, and economic feasibility to avoid inefficient options.

This chapter leads to conclude the importance of thermal insulation in reducing energy consumption of buildings. It is possible through using well-designed thermal insulation to reduce the required heating and cooling loads at no running cost, and without compromising the issue of thermal comfort. To achieve this, external walls should be thermally insulated, windows should be well-designed and sealed, and roofs should be insulated against moisture and solar radiation.

Chapter 5 : Case Studies of Low Energy Housing Projects

5.1 Introduction

In the previous chapters, the study discussed the issues of energy problem, at the local and global levels, the importance and means of passive design, and a review on thermal insulation. This showed the good role of passive design and thermal insulation in saving energy by reducing loads from heating and cooling, in addition to raising the level of thermal comfort within buildings.

This chapter constitutes a beginning of the practical study, where a systematic analytic methodology will be implemented to analyze some buildings and housing projects that focus on the issue of energy savings. This is aimed to show how to apply energy efficient design strategies passively and actively, and internally and externally. This includes the issues of good thermal insulation, good ventilation and orientation, the usage of energy-efficient systems in electricity generation, such as, photovoltaic cells, and water heating using solar energy in order to get higher energy efficiency at low costs.

5.2 The Lindas Passive House Project, Goteborg, Sweden

5.2.1 Project Description

This project is located in the natural environment of Lindas and Sweden, (20) km south of Goteborg. The goal of constructed that project, was to show that if it is possible to build houses at normal costs with low heating demand, which even being in a cold climate, in which no conventional heating system is required. The terrace houses were designed by (EFEM), as the result of a research project in cooperation with Chalmers University of Technology (see Fig. 5.1) (Hastings & Wall, 2007).

Figure 5.1: Some housing units in the Lindas Passive House Project showing solar collectors on the roof (above), and ground and top plans (bottom).
Source: (Hastings & Wall, 2007)

5.2.2 Relevance of the Case

Actually, this project was selected, because it contains many strategies of passive design. In fact, as buildings were designed to provide a thermally comfortable indoor environment, with a minimum energy use. The courtyard facade towards the south has large windows to make full usage of solar heat.

Balconies and roof overhangs, usually provide protection against extreme solar radiation during the summer season. Because of the common walls of the 11 m deep row houses, there is only a minimal external wall surface, and this is highly insulated and air tight. The roof window above the stair, usually, allows daylight to penetrate into the middle of the house, and also, provides a strong stack effect for effective ventilation in summer time.

5.2.3 Strategies of Energy Efficiency in Lindas Passive House Project

Several strategies of energy efficiency have been implemented in this project. In summary, some strategies are (Hastings & Wall, 2007):

A. Design Concept:

Generally speaking, the aim of building housing that requires no conventional heating system in this climate, was achieved by the following steps:

- A highly insulated, air - tight building envelope with:
    a. A mean U-value of a building envelope of 0.16 W/m^{2}K;
    b. An air tightness measured at 0.3 l/sm^2 at 50 Pa;
- Minimized thermal bridges;
- Energy-efficient windows with a mean U-value of 0.85 W/m^{2}K;
- Efficient ventilation with heat recovery (about 80%), and;
- 5 m^2 of solar collectors for domestic hot water (DHW) per housing unit.

Figure (5.2) illustrates energy supply for domestic hot water, space heating and ventilation for the 20 units.

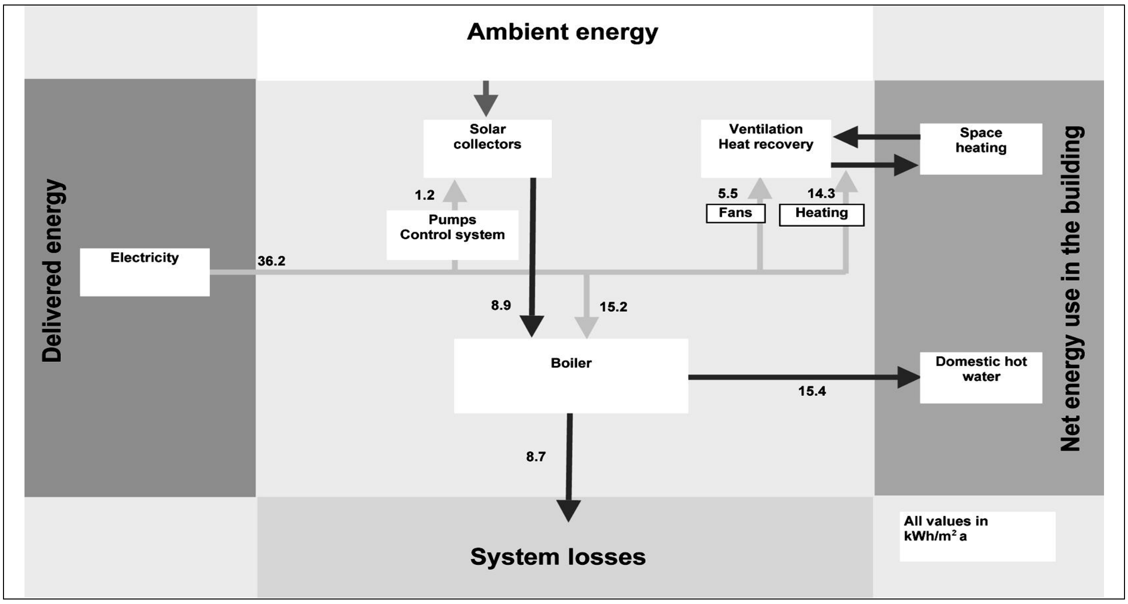


Figure 5.2: Energy supply for domestic hot water (DHW), space heating and ventilation for the 20 units, based on monitoring.
Source: (Hastings & Wall, 2007).

B. Building Envelope:

The materials that were used in opaque building envelope (walls, roofs and floors), are made from lightweight materials, that act as good insulators (see Table 5.1).

Table 5.1: Material constructions of building envelope in the Lindas Passive House Project

Source: (Hastings & Wall, 2007).

Material	Thickness
Roof (roof tiles of clay)	
Counter and tiling batten	6.0 cm
Expanded polystyrene	3.0 cm
Underlay felt Timber	2.2 cm
Ventilated air space / rafters	5.0 cm
Masonite rafters and mineral wool	45.0 cm
Double polyethylene sheets Rafters and mineral wool	4.5 cm
Gypsum board	1.3 cm
Total	**67.0 cm**
Exterior walls (from inside to outside)	
Gypsum board	1.3 cm
Studs and mineral wool	4.5 cm
Expanded polystyrene	12.0 cm
Polyethylene sheet Studs with mineral wool	17.0 cm
Gypsum board	0.9 cm
Expanded polystyrene	10.0 cm
Battens / ventilated air space	3.4 cm
Wood panel	2.2 cm
Total	**51.3 cm**
Floor (from inside)	
Parquet	2.5 cm
Foamed polyethylene	0.5 cm
Concrete	10.0 cm
Expanded polystyrene	10.0 cm
Polyethylene sheet Expanded polystyrene	15.0 cm
Drainage layer macadam	30.0 cm
Total	**68.0 cm**

C. Windows:

In fact, there are two types of treble-glazed windows. The first type is operable in which two low-emissivity coatings are used. One of the gaps between the panes is filled with argon, the other with air. The second type is fixed, where both gaps are filled with krypton gas. The energy transmittance is about (50%), and the mean U-value of the windows for a house unit is (0.85 W/m^2K) (see Fig. 5.3).

Figure 5.3: Windows at the end wall of Lindas Passive House Project
Source: (Hastings & Wall, 2007)

D. Ventilation:

As a matter of fact, buildings must have a good ventilation system. The ventilation system for a standard Scandinavian house is usually designed for a (0.5) air exchange per hour (Ach/h). In passive houses, the recommendation is to lower this rate to (0.3) (Ach/h) in order to reduce air infiltration and save in energy required for heating. Moreover, a heat recovery system is used where a heat exchanger is used. All ventilation ducts are well-insulated.

E. Hot Water Supply:

Generally, approximately (60-70%) of the hot water required for a house can be gained from the solar collectors installed on the roof of buildings or houses. This is only possible when one half of the roof is oriented to south. A large accumulation tank of about (500) liters with a built in electrical heater is also required (see Fig. 5.4).

Figure 5.4: Solar collectors and roof windows at Lindas Passive House Project
Source: (Hastings & Wall, 2007)

5.2.4 Energy Consumption

Table (5.2) shows that the project needs more energy than was expected and planned. This is due to that residents usually heat the houses to higher indoor temperatures and use more electrical appliances than was assumed during the planning stage. The variation in energy usage among the households is significant varying between (45) and (97) kWh/m^2a.

Table 5.2: Monitored average energy use for Lindas Passive House Project
Source: (Hastings & Wall, 2007).

Consumption by	kWh/m2a
Heating of space and ventilation air (electricity)	14.3
Domestic hot water (electricity)	15.2
Fans and pumps	6.7
Lighting and household appliances	31.8
Delivered energy demand	68.0
Domestic hot water (solar energy)	8.9
Total monitored energy demand	**76.9**

There is no strong correlation between total energy usage and the number of residents per household, nor whether the house is an end unit or middle one. Nevertheless, these houses, on average rate, consume approximately (50%) to (75%) less energy than equivalent houses, which had been built according to the normal building system. Fig. (5.5) compares between the energy consumption in existing houses, and the terrace houses in Lindas, which shows a significant difference in consumption, especially in domestic water heating and space heating due to the usage of passive design strategies in those buildings.

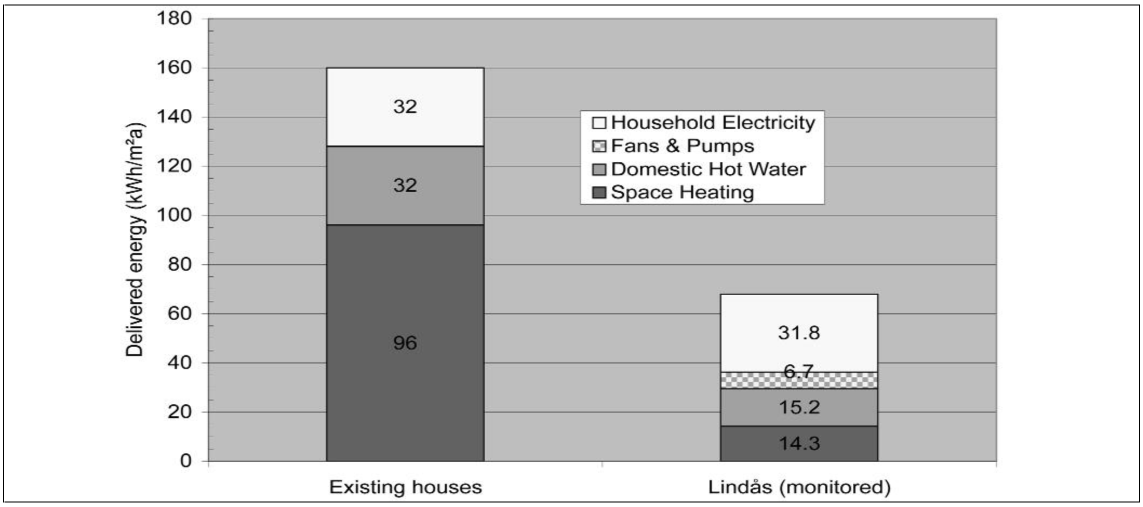


Figure 5.5: Delivered energy in the Swedish existing building compared with the terrace houses in Lindas Passive House Project
Source: (Hastings & Wall, 2007).

5.3 Bed ZED Housing Group, London, UK

5.3.1 Project Description

The accumulated project of housing (Bed ZED) in the province of Sutton in England was constructed in 2002 as a model sample for friendly–environmental buildings. It has been built with a high energy efficiency, which uses active and passive design techniques. This project is a part of a long term program to build (3.8) million building apartments by the end of (2021) on an area of (58000) hectares (40 apartment per one hectare). (Bed ZED) project contains grouping of (82) homes, with different models of apartments, consisting of one floor, and others, consisting of two floors. Green spaces between the units have been provided, with some service buildings, such as municipality building and a community center (Lazarus, 2009).

Figure 5.6: An arial view of Pool Houses (Bed ZED), showing the residential buildings, services and green areas.
Source: (Lazarus, 2009)

5.3.2 Relevance of the Case

The project has designed to meet a high standard to enhance the environmental awareness, with an emphasis on roof gardens, sunlight, solar energy, reduction of energy consumption and waste water recycling. It applies (SAP) British Standards, which aims to reduce energy demand. It uses high–quality thermal insulation for roofs, walls and floors, and utilizes the recovered heat from solar radiation and human beings activity, lighting, appliances and water heating (Lazarus, 2009).

5.3.3 Strategies of Energy Efficiency

Several strategies of energy efficiency were implemented in this project. In summary, some strategies are (Lazarus, 2009):

A. Design Concept:

The design concept depended on providing energy efficient residential buildings with a high thermal efficiency without threatening the environment. To achieve this, several active and passive strategies and techniques have been used, such as the high efficient insulation, tight construction, natural ventilation, passive solar storage (passive heat gain) by using high thermal mass, and green roofs. This was evident in the resulting design patterns which give several options:

1. Terrace with work space and garage.
2. Southern interface with a terrace and front garden.
3. Annexed space with apartment for social activity.

This diversity in composition of buildings gave the highest benefit from the sun for solar lighting and natural ventilation, which, led to the reduction in energy consumption, as it will be cleared in the following sections.

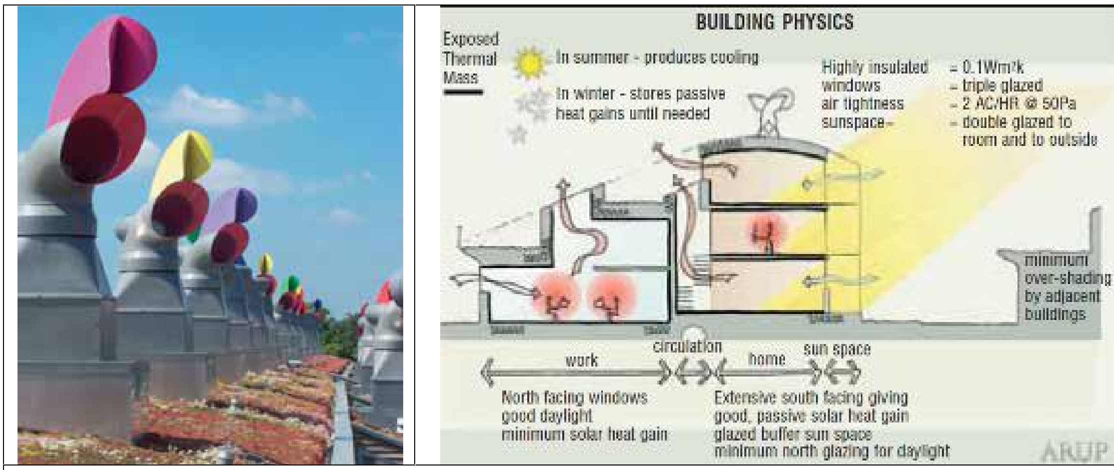
B. Super Insulation:

The isolator has been put outside the construction in order to avoid leaking heat transfer through the concrete ceilings, walls and floors, to avoid excess heat in the summer season, and the appropriate heat storage in the winter season. Triple- glazing windows filled with Argon gas and surrounded by wooden frame have been used to reduce heat loss (see Fig. 5.7).

Figure 5.7: The Use of Wall Insulation in the Bed ZED Project
Source: (Lazarus, 2009)

C. Natural Ventilation:

In order to reduce the energy demand needed to ventilate the buildings, wind cowls located on the roof of buildings have been provided. They draw cool air down into the space and react to changing wind directions. As illustrated in Fig. (5.8), they are highlighted as colorful elements on the roofs.



(a): Wind Cowls Provide Passive Ventilation with Heat Recovery.

(b): Multifunction Glass Areas (Solar Gain, Natural Lighting, and Ventilation).

Figure 5.8: Several ventilation strategies have been used in Bed ZED Project

Source: (Lazarus, 2009)

D. Reduction of space heating demand:

The houses are arranged as south facing terraces with triple storey conservatories harnessing passive solar heat gain. The result is that the internal temperature of buildings stays within the range of (18-21^{o}C) during the year, reducing the need of central heating to the minimum.

The southern elevation consists of two skins of double-glazing. Glazing on all other elevations is kept to a minimum level, and is triple-glazed. In this way, buildings fabric heat losses are reduced to such an extent that they can be compensated for by internal heat gains. Every day activities, such as cooking and usage of electric appliances and people’s own body heat, are usually sufficient to keep these super-insulated buildings at a comfortable temperature.

In addition, dense concrete block and concrete floor slabs provide thermal mass that absorbs heat during warm periods of time, and releases heat at cooler periods of time.

E. Rainwater Collection:

Rainwater that is gathered from roofs is harvested and stored in (1.2 m) diameter storage tanks that run along the length of the foundations of each block. The rainwater passes through a fine self-cleaning filter in the down pipe before entering the tank. It is then, delivered by submersible pumps and used for toilet flushing, irrigation and garden watering points, as illustrated in Figure (5.9).

In addition, water consumption in Bed ZED houses has been reduced by (33%) by installing some techniques and modern equipments of water saving, such as low flush toilets, spray taps and water recycling and reusing.

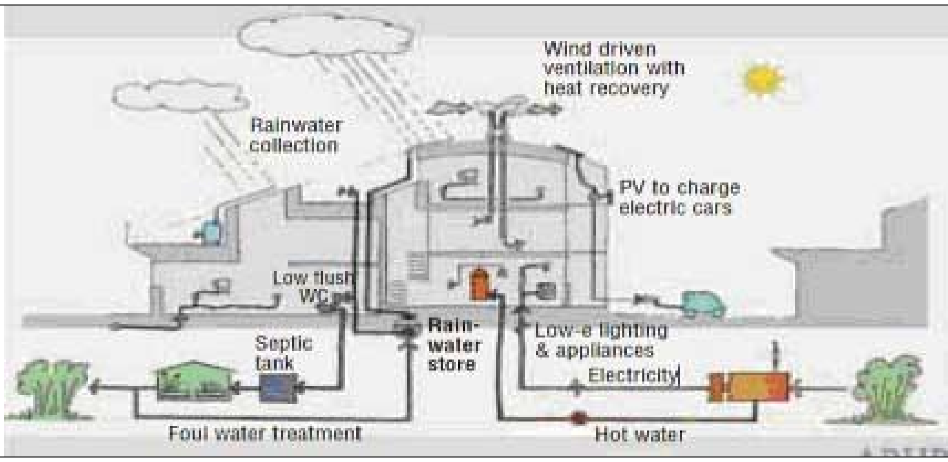


Figure 5.9: Rainwater collection in the Bed ZED Project
Source: (Lazarus, 2009)

F. Wood-Fuelled Combined Heat & Power (CHP):

By using the passive energy sources listed above, the energy demands of a Bed ZED development have been dramatically reduced compared to equivalent conventional developments. Space heating is reduced to (12%), water heating to (43%) and electricity to (75%) of UK average.

A combined heat and power plant (CHP) has been used in the project. (CHP) generates electricity like any normal power plant. However, it harnesses the heat energy generated by the primary fuel conversion to electricity. The heat energy is captured in hot water and distributed to the community through a system of super insulated pipes. The primary fuel for the (CHP) is wood chips from tree surgery waste that would, otherwise, be sent to the landfill (see Fig. 5.10).

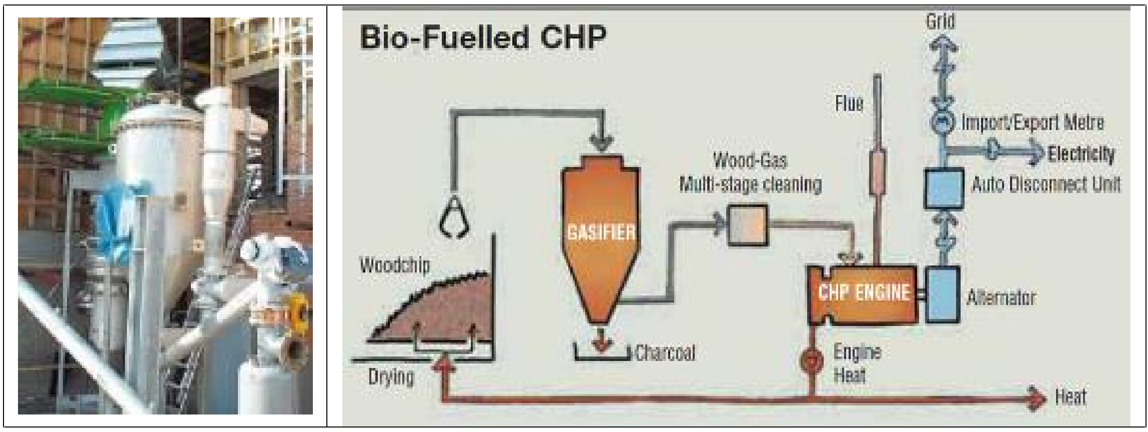


Figure 5.3: Biomass CHP plant to generate electricity and heat.
Source: (Lazarus, 2009)

5.3.4 Energy Consumption

Buildings in the (ZED) project costs a predicted extra of ($1267,485) compared to the conventional developments built according to the (2000) Building Regulations. However, for each building, the (ZED) planning allows a developer to generate an extra ($384,800) in extra profit. Moreover, the added value of the light, spacious dwellings with sky gardens and on-site services combined with the attraction of significant bill savings have the potential to bring about the developer a further of ($888,000). Developers can, therefore, choose to design for very considerable environmental savings and still recover their costs.

As mentioned above, the use of CHP and other renewable resources have been used in the generation of electrical power. This includes Photovoltaic cells, with an installed area of (777 m^2) that is integrated on the roofs of houses. Other methods include improving the efficiency of systems and home applications, the heat recovery system, and the use of high efficiency artificial lighting. To encourage residents to save energy, the electricity meter has been placed in a visible place in the kitchen (see Fig. 5.11).

(a): The Use of Photovoltaic Cells on Roofs

(b): The Use of Energy-efficient Lighting, and Placing the Electricity Meter in a Visible Place.

Figure 5.4: Several methods have been used to save energy in the Bed ZED Project
Source: (Lazarus, 2009)

Generally speaking, Bed ZED project has performed very much as planned and predicted previously. The monitoring results, summarized in Table (5.3), show the average reduced consumption of energy and resources across the development compared with the national average. Numbers in brackets, show a reduction of consumption, compared with the UK (2000) Building Regulations.

Table 5.3: Average reduced consumption of resources in the Bed ZED Project
Source: (Lazarus, 2009).

	Monitored Reduction	Target Reduction
Space Heating	88% (73%)	90%
Hot Water	57% (44%)	33%
Electricity	25%	33%
Main Water	50%	33%
Fossil Fuel Car Mileage	65%	33%

Table (5.4), shows a comparison between energy consumption in Bed ZED building and the average residential buildings.

Table 5.4: Comparison between Bed ZED building and existing buildings.
Source: (Lazarus, 2009).

	Bed ZED Building (Monitored)	**Existing Building**
Space Heating	59 Kwh/m2/year	140 Kwh/m2/year
Hot Water	3900 Kwh/household/year	3900 Kwh/household/year
Electricity Consumption (Lighting – Cooking - Appliance)	3.0 Kwh/person/day	4.0 Kwh/person/day
Water Consumption	76 liter/ person/day	150 liter/ person/day
Average Annual Bill Saving	6272.85 $	1880.36 $

5.4 Meir House, Negev Desert, Palestine

5.4.1 Project Description

The Meir House is located in the first solar neighborhood in Negev Desert. It was designed as a prototype towards creating an energy-conserving urban building code. It combines external insulation and internal thermal mass with open plan. Through quick simulation prior to construction and monitoring post-construction, the Meir House proves the success of an integrative approach to the design of a bioclimatic desert house (see Fig. 5.12), (Roaf *et al.*, 2007)**.**

Figure 5.5: General view of Meir House, Negev Desert
Source: (Roaf *et al.*, 2007)

5.4.2 Site and Climate

The site is located at latitude (30) north, and an altitude of (470 m) above sea level. The climate of the region is defined as arid, with hot and dry summers times, and cold winter times. Summer season daily average temperatures range between (32^{o}C and 17.3^{o}C), in July and August, but the maximum temperature of (42^{o}C to 43^{o}C) occurs in

May and June. Humidity during those months might drop as low as (24%), whereas, at night and early morning it may reach (65-90%). Winter time temperatures range between (15°C and 3.5°C). Average maximum wind speed ranges between (40 km/h) in winter season, and (30 km/h) in summer season (see Fig. 5.13), (Roaf *et al.*, 2007)**.**

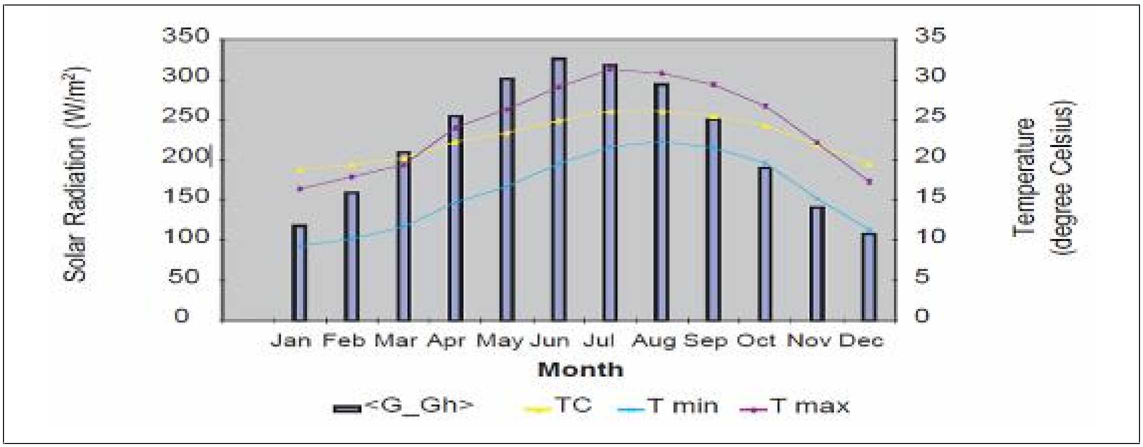


Figure 5.6: Solar radiation and temperature in Negev Desert through the year

Source: (Roaf *et al.*, 2007)**.**

5.4.3 Passive Design Strategies

Several passive design strategies have been implemented in this house, as follows (Roaf *et al.*, 2007)**:**

A. Orientation and Plan:

In general, considering the site's geometry and climatic constraints, the long axis of the house has been oriented towards east-west, with four bedrooms and one living room. The kitchen, bathrooms and laundry room are located at the northern part of the plan, and the garage serves as a western buffer. The house, also, includes a number of verandas and balconies to protect internal space from undesired and unexpected climate conditions (see Fig. 5.14).

Main openings are placed to the south, with smaller openings to the north for cross ventilation. However, all rooms have openings in two directions, to ensure appropriate ventilation throughout the house.

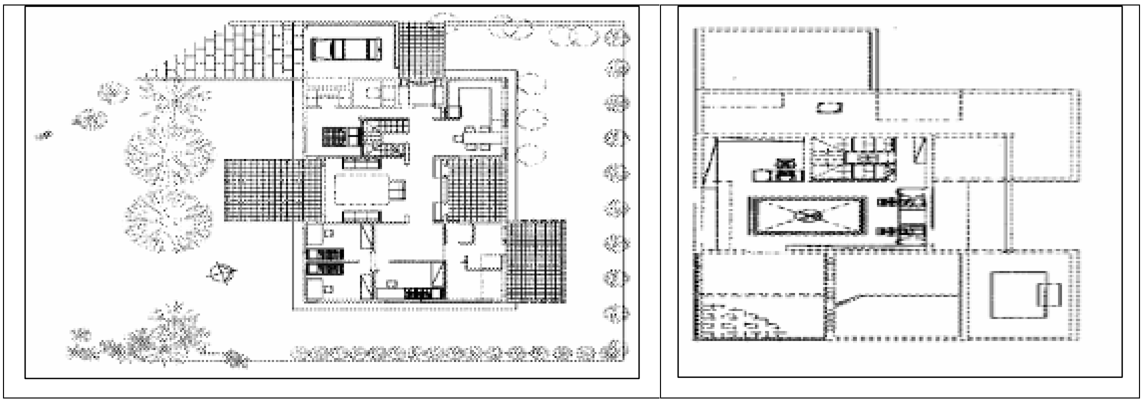


Figure 5.7: Meir House plans: ground floor (left), and first floor (right)
Source: (Roaf *et al.*, 2007)**.**

Another advantage of the Meir House project is form integration, which makes the surrounding open spaces weather-protected. These spaces are shaded by overhangs, deciduous plants, and pergolas with agricultural shading fabric.

B. Thermal Mass and Insulation:

Generally speaking, the wide diurnal temperature fluctuations characteristic of the Negev Desert climate facilitate the usage of thermal mass for internal temperature damping and for energy storage. This process and mechanism has been achieved by using medium-weight external walls, and heavy-weight internal vertical and horizontal partitions (see Fig. 5.15).

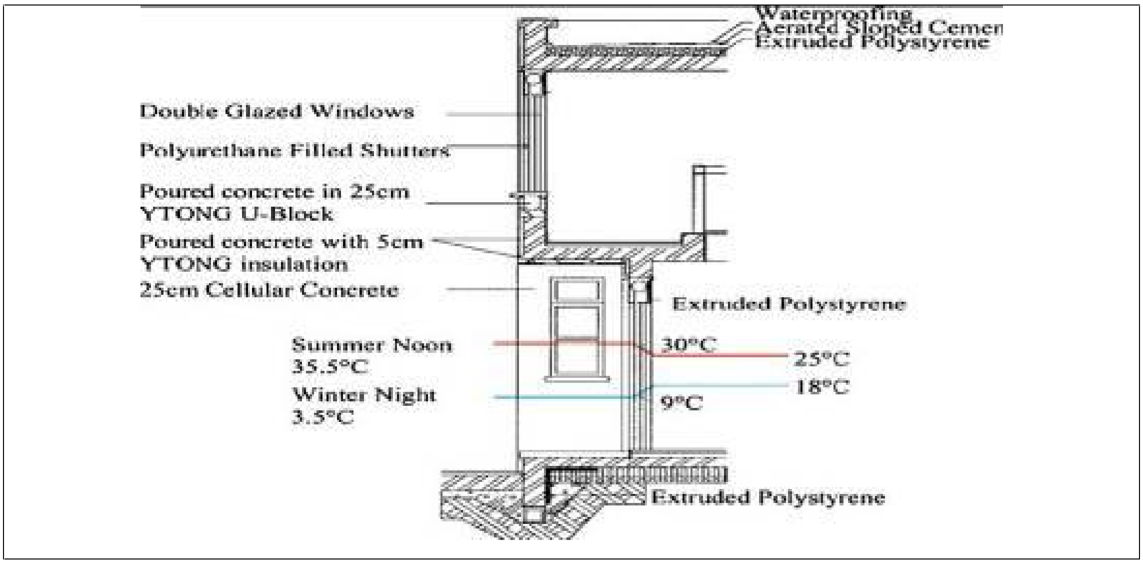


Figure 5.8: Section illustrating insulation and glazing system in the Meir House
Source: (Roaf, 2007)

The external walls are made of (250 mm) cellular concrete blocks, painted with a high reflectivity ochre-colored paint. The low U value (0.2 $W/m^2.C$) of the blocks eliminates the need for traditional sandwich wall sections, or external insulation that demands precise construction. Roof is made of cast of reinforced concretes, covered by extruded polystyrene and waterproofing.

As a matter of fact, aluminum frames encase double glazing for acoustical considerations and are fitted with mosquito frames. To further reduction of solar gains in the summer season, external aluminum rolling shutters filled with insulation (expanded polyurethane), and internal venetian horizontal and vertical blinds are fitted (see Fig. 5.16).

Figure 5.9: The shutters lowered in Meir House
Source: (Roaf, 2007)

C. Cooling and Heating:

North and south facing windows enable cross ventilation during summer season nights, where air currents are used to cool down building fabric (night-time ventilation). Mesh screens (in both inlet and outlet openings), play a definitive role here by reducing wind speed down to about (20 to 25%) of external wind speeds, depending on wind incidence angles. As illustrated in Fig. (5.17), The existence of windows on different levels in the same space, enhance ventilation by enabling different operation modes (cross, stack, and suction).

Figure 5.10: Windows on upper levels enable ventilation (cross, stack, and suction) during summer season nights
Source: (Roaf, 2007)

An overall area of (24 m^2) of south glazing (approximately 30% of the south facade), approximately (14.5%) of the floor area, and (8 m^2) of the east facade are made of glass. This is intended to help achieving a passive approach to heating the house. The openable greenhouse (2.25 m^2) on the balcony provides additional heating.

5.4.4 Monitoring

Monitoring was undertaken during the summer and winter of 1995. Climatic data were received from the Ben-Gurion National Solar Energy Center. Through passive designs, orientation, thermal mass and the collapsible greenhouse, savings of almost (90%) on electric backup bought from the utility company were realized. Table (5.5) shows a comparison between Meir House and a typical heated house in the Negev Desert in terms of electricity consumption and cost.

Table 5.5: Electricity consumption and cost in Meir House compared with a typical house in the Negev Desert
Source: (Roaf, 2007).

Type	Heat only, Excluding Bathrooms (kWh/m2)	Unit Cost (NIS)	Cost of Electricity (NIS)
Meir House	5.5	0.25 kWh	250.00
Typical House	72.2	0.25 kWh	3250.00
Savings	66.7	0.25 kWh	3000.00

5.5 Conclusion

In this chapter, several case studies have been presented. These cases represent projects and buildings with a focus on energy-efficient design. Several passive and active strategies of saving energy while maintaining human thermal comfort in buildings have been implemented in these projects. This includes good thermal insulation, natural ventilation, and harvesting solar energy for heating and electricity generation considering the local climatic conditions.

It has been concluded that implementing energy-efficient design strategies in buildings is a viable option. This is true in the case of passive strategies or active ones. However, passive strategies are preferable as they are obviously cheaper. Also, it is essential prior to proposing any energy-efficient project to review the experience gained in similar projects as the issue of energy-efficiency is based on innovation and ongoing development.

Chapter 6 : Investigating the Effect of Buildings Thermal Insulation Using Computer Simulation

6.1 Introduction

It has been concluded from the previous chapter that buildings have a great potential in the field of energy savings. This has been demonstrated through the analysis of some relevant case studies. The purpose of this chapter is to carry out a numerical simulation in order to assess this potential considering the local climatic conditions of Gaza. In order to achieve this aim, a prototype residential building has been three-dimensionally simulated using Ecotect 5.5 program.

Thermal behavior of this building has been assessed before and after using thermal insulation in the building envelope in order to numerically demonstrate the effect of this design strategy. Moreover, some other passive design strategies like the use of night-time ventilation strategy have been demonstrated as well. Following this improvement process of building environmental design, the amount of energy that would be saved has been estimated. Also, the pay back period of the thermal insulation design strategy has been estimated. The following sections explain in details this modeling study.

6.2 Description of the Building

The prototype building that has been chosen is a five-storey residential building that represents a residential building type in Gaza. Each floor accommodates four flats with a different orientation. The building was assumed located in an open area on all sides. Simplicity in the building design has been observed, and a sufficient area of 160m^2 has been provided to accommodate a family of seven members. Each flat consists of three bedrooms, a living room, a dining room, two toilets and a kitchen. The apartments are vertically linked with common staircase as shown in Fig. (6.1).

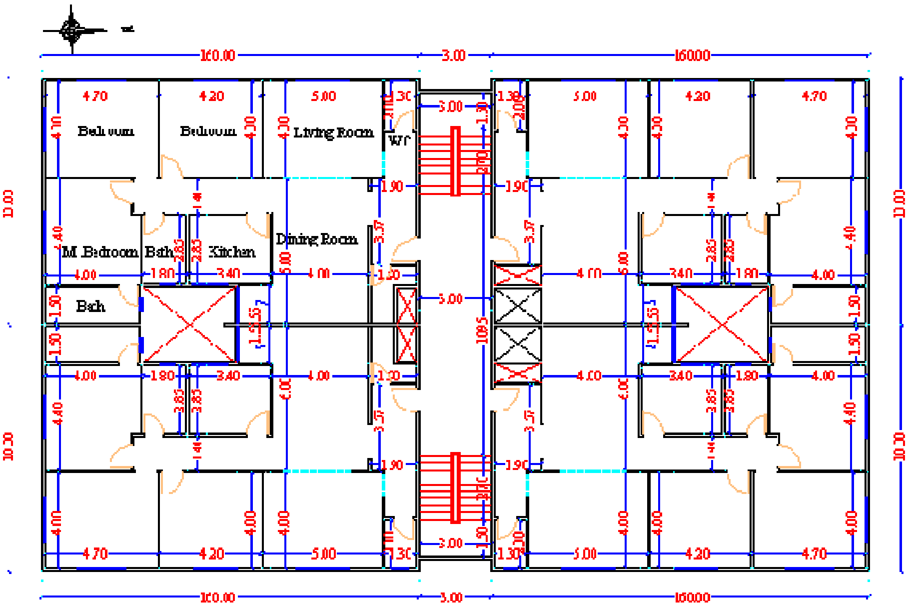


Figure 6.1: Plan of the building modelled in the study

6.3 The Modelling Tool

Ecotect 5.5 program has been used as a thermal simulation tool in this study. It is user-friendly software that has been originally developed at the Welsh School of Architecture at Cardiff University. Ecotect enjoys a CAD interface and several thermal analysis tools that allow assessing buildings thermal performance during the design stage. This includes:

- Calculation of the monthly heat loads and thermal comfort.
- Calculation of hourly temperature profiles, and hourly heat gain and losses in buildings.
- Displaying shadows and interactive sun-path diagrams.
- Calculation of the incident solar radiation on surfaces.

6.4 Modelling Setup

Before carrying out the thermal analysis, it is essential to carry out the following steps:

6.4.1 Drawing the Model

The building has been three-dimensionally modelled using Ecotect program. Its long axis has been oriented north-south, which reduces its exposure to the southern sun.

Ecotect reads any building as several thermal (or non-thermal) zones, which should be observed in the modelling process.

Thus, each flat of the twenty flats in the building has been assumed as a single thermal zone, where the internal partitions are assumed to have low thermal mass and thus are neglected (Fig. 6.2). This has resulted in twenty thermal zones, which are named according to their height. For example, the ground floor includes four flats as follows: GF-a, GF-b, GF-c, and GF-d, and so on.

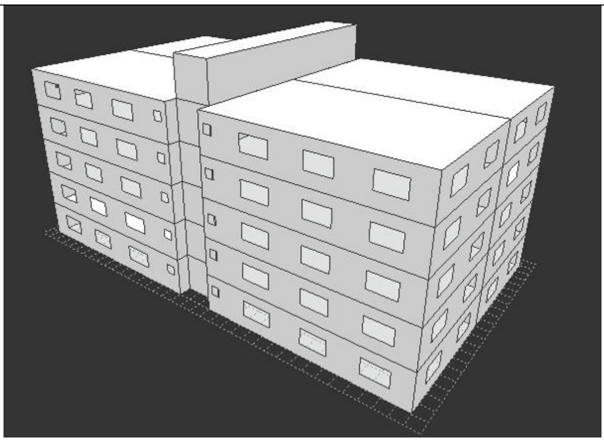


Figure 6.2: Three dimensional view of the building

6.4.2 Defining the Building Materials

Ecotect classifies building elements into several types. This includes floors, walls, roofs, ceilings, windows, etc. For each element several options related to building materials are available. These materials, along with their thermal properties, are available in the program material library. This includes:

- U-value, which indicates heat transmittance of a building material.
- Solar Absorption, which refers to the portion of incident solar radiation that is absorbed by the surface.
- Thermal Lag, which is the time taken for heat to pass from one side to the other.
- Admittance, which represents its ability to absorb and release heat energy and defines its dynamic response to cyclic fluctuations in temperature conditions.

The most common construction system in residential buildings in Gaza Strip is the structural system (reinforced concrete foundations, columns, and ceilings). In this study, building materials are defined to match the most common ones in Gaza. This is intended to explore the reference building thermal performance and decide whether it needs some improvement or not. As mentioned above, Ecotect material library offers a wide range of building materials. However, additional materials have been created in this study to meet the common building materials in Gaza. Thermal properties of these additional materials have been obtained using the thermal properties calculator integrated in Ecotect, and the Palestinian Code of Energy Efficient Buildings (Ministry of Local Government, 2004).

The following is a description of the several materials used in the reference modelling case:

A. External Walls:

Most commonly, walls in Gaza are made of hollow concrete blocks and thin layers of cement plastering applied to the internal and external walls. A typical section of external walls shows 20 cm hollow concrete blocks, with 2 cm of internal plaster and 3 cm of external plaster (Fig. 6.3).

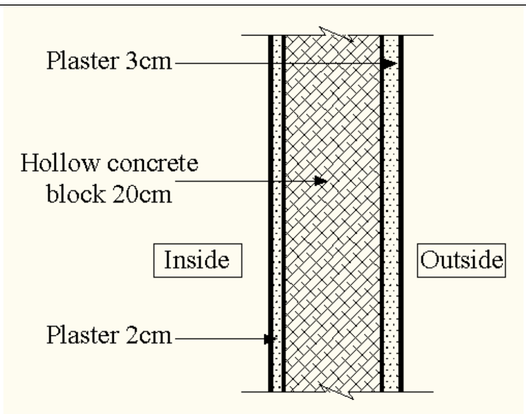


Figure 6.3: Section through a typical external wall in Gaza buildings

The thermal properties of this element are as follows: U-value: 2.3 W/m^2K, admittance: 4.4 W/m^2K, decrement factor: 0.3, time lag: 7.4 hrs, solar absorption (0-1): 0.7. (Ministry of Local Government, 2004).

B. Ceilings:

The typical ceiling section shows three parts: 8 cm layer of reinforce concrete, 17cm layer of hollow concrete blocks, and 1 cm layer of plastering (Fig. 6.4). In

Ecotect, the internal floors between flats are assumed the same but with these layers in reversed manner.

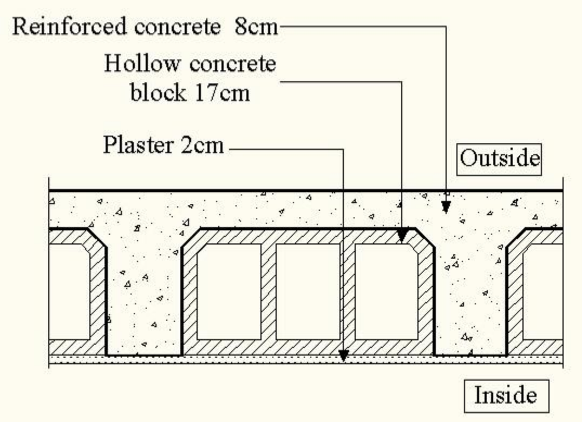


Figure 6.4: Section through a typical reinforced concrete ceiling in Gaza

The thermal properties of this element are as follows: U-value: 2.6 W/m^{2}K, admittance: 4.9 W/m^{2}K, decrement factor: 0.4, time lag: 6.8 hrs (Ministry of Local Government, 2004).

C. Glazing:

Windows are important parts of the building envelope since they provide both lighting and ventilation. Figure (6.5) shows a section of a typical single-glazed window with aluminum frame. The thermal properties of this element are as follows: U-value: 5.5 W/m^{2}K, admittance: 5.5 W/m^{2}K, solar heat gain coefficient: 0.9, transparency (0-1): 0.42 (Ministry of Local Government, 2004).

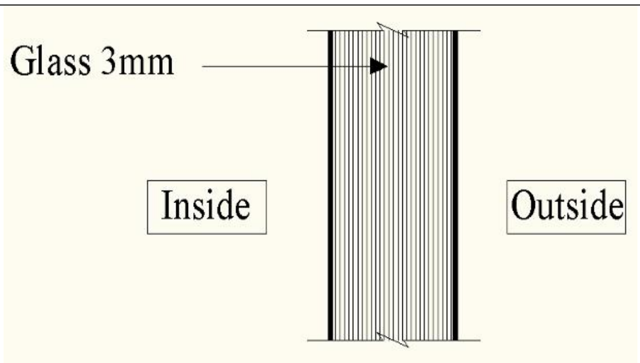


Figure 6.5: Section through a typical single-glazed window in Gaza

D. Floor:

Definition of the floor building materials is particularly important in predicting thermal performance of the ground floor. Despite that fact that ground floor is very important in the process of thermal performance prediction, we did not refer to it in detail due to the limited size of the study.

6.4.3 Defining Zone Thermal Settings

The second step after defining the building materials is to define the thermal settings of each thermal zone. This includes the following:

A. Estimation of Internal Heat Gains:

Internal heat gains in the thermal zone settings may be a result of the building occupants, lighting or appliances. Heat gains due to lighting and appliances are called the Sensible and Latent Gains.

As for occupants, Table (6.1) illustrates the several levels of heat production according to occupant's activity:

Table 6.1: Heat emission due to occupants

Source: (CIBSE, 1988).

Activity	Watts
Sedentary	70
Walking	80
Exercising	100
Strenuous	150

In each zone seven occupants are assumed in "sedentary" mode. Thus, the total heat gain due to occupants is = 70 W * 7 person = 490 W. It is important to note that it is only required in Ecotect to specify the number of occupants, which helps the software to calculate the resulting heat gain.

To specify the Sensible Gains, heat gains due to lighting and appliances should be estimated. As for lighting, it is estimated in residential buildings that heat gains due to energy efficient lighting is about 11W/m^2 (CIBSE, 1998). As for appliances, Table (6.2) shows an assumption of the appliances that are usually used in residential buildings in addition to their operation times. The total heat gains due to these electric equipment is 550 W. Given that each thermal zone (or apartment) floor area is 160m^2, heat gain due to equipment is assumed 3.5W/m^2.

Table 6.2: Heat emission due to equipments
Source: (CIBSE, 1988), adapted by author.

Equipment	Number	Watts	Operation period	Total (W)
Refrigerator	1	50	50%	25
Washing machine	1	1000	10%	100
Oven	1	2000	5%	100
Microwave	1	2000	5%	100
Kettle	1	2000	2.5%	50
TV.	1	150	50%	75
P.C.	1	200	50%	100
Total				**550**

Thus, Sensible Heat Gains in the thermal zone settings should be defined as: heat gains due to lighting + heat gains due to appliances = 11 + 3.5 = 14.5 W/m^2.

B. Estimation of Ventilation Rate:

According to CIBSE Guide (1988), a ventilation rate of 18 litres of fresh air every second is required for every person in the case of residential buildings. As number of persons in every zone is 7, this means that the volumetric air change rate is 126 l/sec, which equals 126*103*3600 cm^3/h = $45.36*10^7$ cm^3/h, i.e. 453.6 m^3/h.

Given that volume of the zone is $160m^2 * 3m = 480\ m^3$, the required air change per hour is = 453.6/480 = 0.94 Ach/h. In Ecotect program, this value (1 Ach/h approximately) represents the average uncontrolled air leakage (infiltration) in typical constructions. This can provide sufficient ventilation rate in winter when windows are closed. In summer, where openings are opened, a higher ventilation rate is required. Air change rate in residential buildings can be assumed 10 Ach/h (CIBSE, 1988). This variation between summer and winter ventilation can be secured through using a ventilation schedule, as explained in the following section.

The following figure shows the Zone Management panel including the above-explained settings.

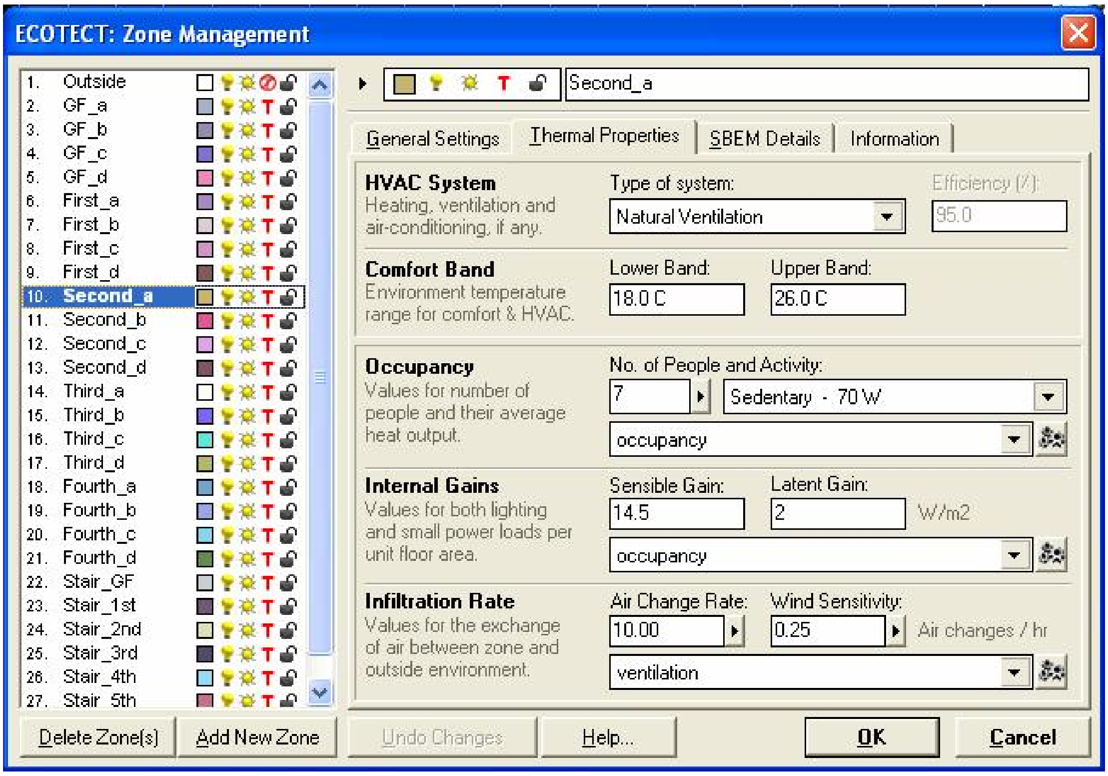


Figure 6.6: The Zone Management panel showing the typical settings implemented in the reference modelling case

C. Schedules Management:

Schedules feature is used in Ecotect to control some variables in the thermal settings of zones. For example, it can be used to switch off the lights overnight in office buildings, which reduces the resulting sensible heat. In this study, two schedules have been used.

The first one is the Occupancy Schedule. This assumes 100% building occupancy (7 persons) from 12 am to 8 am, 30% from 8 am to 2 pm, and 70% from 2 pm to 12 am. This assumption is true in weekdays. In weekends, a full occupancy over the whole day is assumed. The same schedule is implemented to the sensible heat, which is proportional to occupancy. The second schedule is the Ventilation Schedule. This assumes 70% ventilation rate (7 Ach/h) during the relatively hot months (April to September), and 10% ventilation rate (1 Ach/h) during the relatively cold months (October to March). (see Fig.6.7).

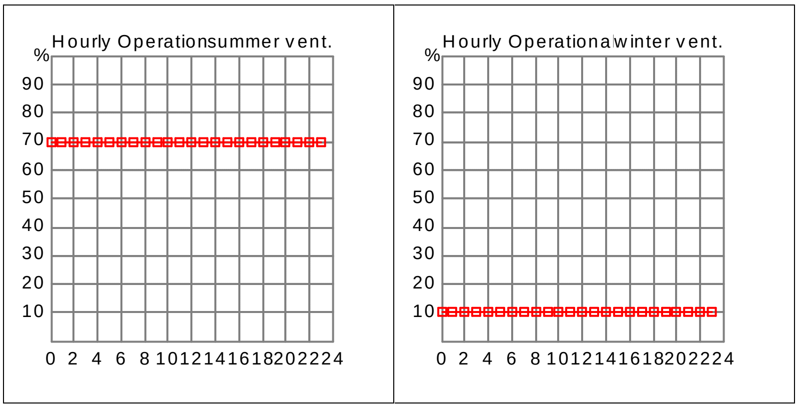


Figure 6.7: Ventilation Schedule assumes 70% ventilation rate in the relatively hot months "lift" 10% ventilation rate in and the relatively cold ones "right"

6.5 Thermal Modelling of the Reference Case

To carry out any thermal analysis using Ecotect, it is essential to specify the city in which the building is located. To do so, the climatic data file of this city should be downloaded from the program directory. In fact, there are limited climate data files to download while using the program.

As there is no climatic data file for Gaza, it is possible to rely on Al-Arish climatic data file due to the similarity between these two cities. Al-Arish is a coastal city in Egypt that is close to Gaza. Both cities are located on latitude 31 N. Table (6.3) compares temperature averages for both cities:

Table 6.3: Average monthly temperature in Al-Arish, Egypt, and Gaza, Palestine
Source: (weatherbase.com, 2010)

Average Temperature (Al-Arish)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°C	13	14	16	18	21	24	25	26	25	22	20	16
Average Temperature (Gaza)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
°C	13	14	15	18	20	23	25	26	25	22	19	15

It is possible now to start the thermal analysis of the building, giving that thermal insulation is not used yet. Due to the limited size of the study, thermal analysis will be limited to two zones (flats): zone Second-a (i.e. flat "a" in the second floor), and zone Fourth-a (i.e. flat "a" in the top floor). Both zones are south-westerly, which represents high exposure to sun, where thermal insulation may be required. Moreover, zone Fourth-a is located in the top floor and receives additional solar radiation through the roof, where thermal insulation may be required as well.

Ecotect offers several thermal performance analysis features and indicators. This includes:

- The hourly temperature profile.
- The hourly heat gain & losses.
- The monthly loads/ discomfort.

Based on this, the following analysis illustrates the thermal performance of the building (zones Second-a, and Forth-a) initially and before using thermal insulation:

6.5.1 The Hourly Temperature Profile

This displays internal and external temperature profiles together for a selected day and thermal zone. This facilitates comparing both profiles and understanding building thermal behavior. For example, temperature peaks, swing, and relation to thermal comfort limits can be observed.

The graph also displays other environmental information such as the outside wind speed and the beam and diffuse solar radiation This graph includes a temperature scale on the left edge, and a solar radiation scale on the right one.

Temperature values have been obtained for the average hottest day (30th April) to represent summer conditions, and for the average coldest day (12th January) to represent winter conditions. Fig. (6.8) shows the average summer temperature profiles for zones Second-a and Fourth-a.

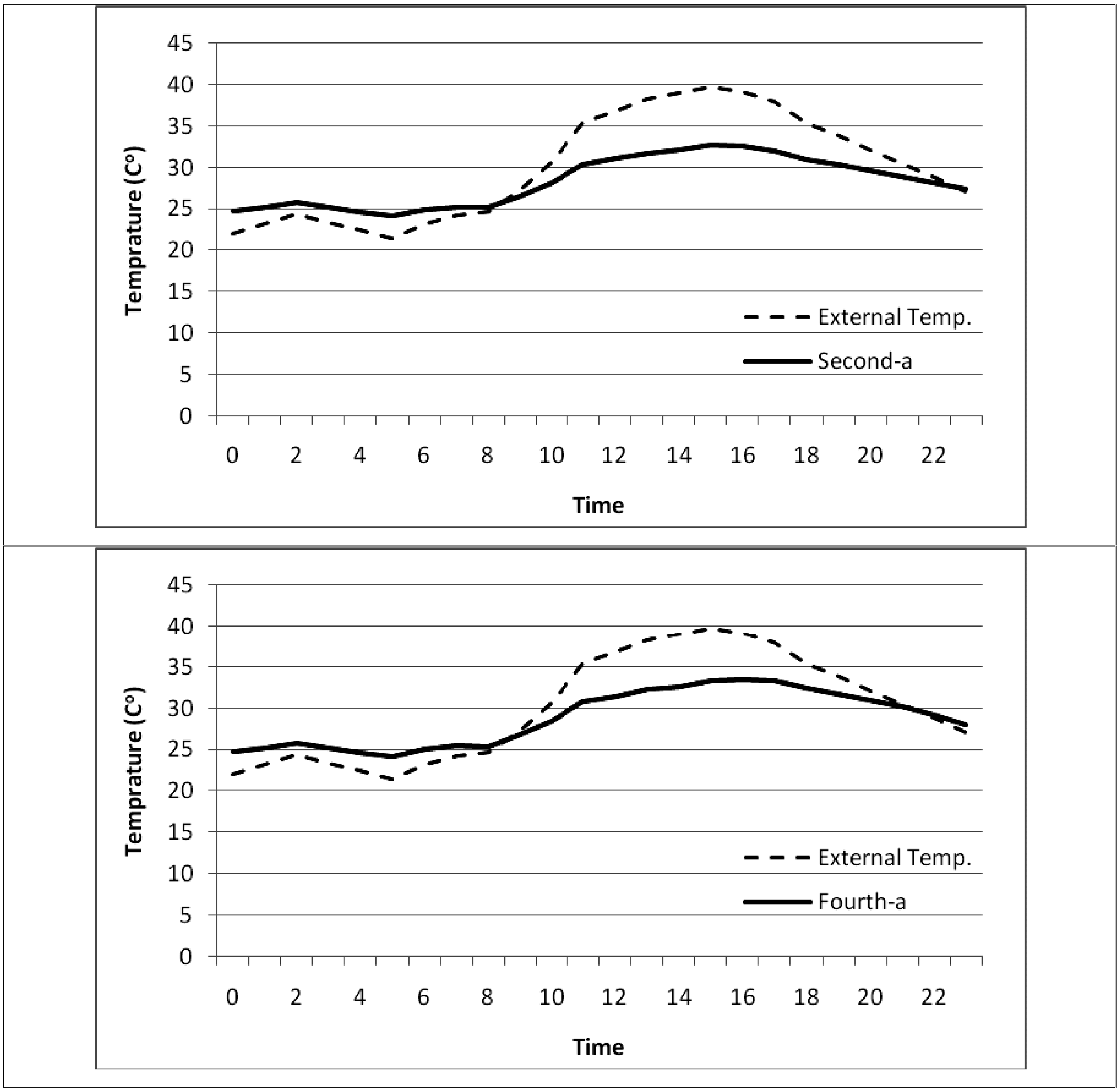


Figure 6.8: Hourly temperature profiles for zones Second-a and Fourth-a in the average hottest day

This figure shows that zone Fourth-a has a slightly higher internal temperature compared to zone Second-a mainly in the afternoon period. This can be a result of the solar radiation acting on the roof of zone Fourth-a. Another observation is that internal temperature in both zones has less swing compared to the external one, which presents the effect of building envelope in modifying the external temperature passively.

Thermal comfort limits have been defined in Ecotect from 18 to 26^{o}C. As shown in Table (6.4), it is clear that both zones are above the lower limit, but exceeds the upper one mainly afternoon as external temperature reaches 36.8^{o}C.

Table 6.4: Hourly temperature values for zones Second-a and Fourth-a in the average hottest day

Hr.	External Temp. (°C)	Internal Temp. (°C)		Hr.	External Temp. (°C)	Internal Temp. (°C)	
		Second-a	Fourth-a			Second-a	Fourth-a
0	22	24.7	24.7	**12**	36.8	31	31.4
1	23.2	25.2	25.2	**13**	38.3	31.7	32.2
2	24.3	25.7	25.7	**14**	39	32.1	32.5
3	23.3	25.1	25.1	**15**	39.8	32.7	33.2
4	22.4	24.6	24.6	**16**	39.2	32.5	33.4
5	21.4	24.1	24.1	**17**	38	32	33.3
6	23.2	24.9	25	**18**	35.3	30.9	32.3
7	24.2	25.2	25.4	**19**	33.8	30.3	31.7
8	24.6	25.1	25.3	**20**	32.1	29.6	30.9
9	27.3	26.4	26.7	**21**	30.5	28.9	30.1
10	30.8	28.1	28.4	**22**	28.8	28.1	29.1
11	35.5	30.4	30.8	**23**	27.1	27.3	28

Fig. (6.9) and Table (6.5) show the average winter temperature profiles for zones Second-a and Fourth-a.

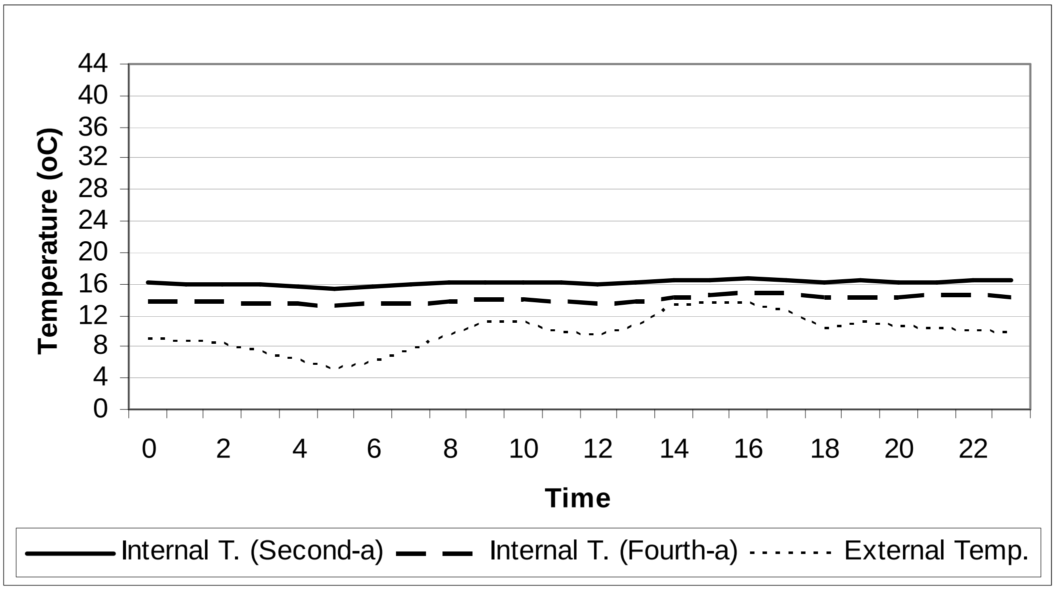


Figure 6.9: Hourly temperature profiles for zones Second-a and Fourth-a in the average coldest day

It is clear that both zones are outside the comfort area (18-26°C) with no significant swing. However, zone Fourth-a has lower internal temperature compared to zone

Second-a during the whole day. This can be a result of heat loss through the roof of zone Fourth-a.

Table 6.5: Hourly temperature values for zones Second-a and Fourth-a in the average coldest day

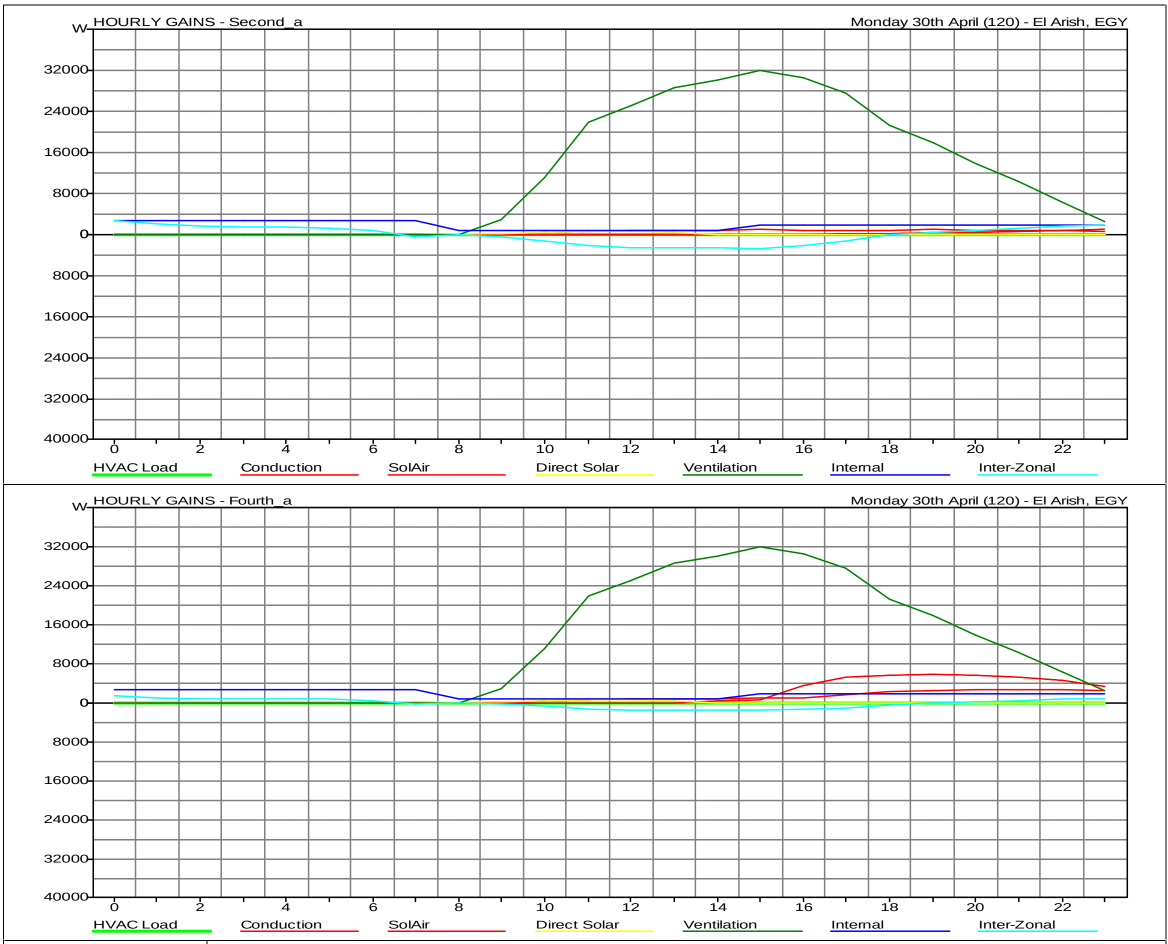
Hr.	External Temp. (°C)	Internal Temp. (oC)		Hr.	External Temp. (°C)	Internal Temp. (°C)	
		Second-a	Fourth-a			Second-a	Fourth-a
0	8.9	16.1	13.9	**12**	9.5	16	13.6
1	8.6	16	13.9	**13**	10.5	16.1	13.8
2	8.4	16	13.8	**14**	13.2	16.5	14.3
3	7.3	15.8	13.6	**15**	13.6	16.6	14.5
4	6.1	15.7	13.5	**16**	13.5	16.7	14.8
5	5	15.5	13.3	**17**	12.4	16.6	14.8
6	5.9	15.7	13.4	**18**	10.3	16.3	14.2
7	7.5	15.8	13.6	**19**	11.2	16.4	14.2
8	9.4	16.1	13.8	**20**	10.6	16.3	14.2
9	11.2	16.3	14.1	**21**	10.3	16.3	14.5
10	11.2	16.3	14	**22**	9.9	16.4	14.5
11	9.6	16.1	13.7	**23**	9.6	16.4	14.4

6.5.2 The Hourly Heat Gain and Losses

This graph displays magnitudes of the several heat flow paths acting on the examined thermal zone in the specified day. This is displayed in Watts (or kW), and includes several heat flow paths like fabric, zonal, and solar heat gains or losses. This graph is useful to understand what is going on inside the building as a result of changing its building materials, ventilation system, or windows orientation for example.

Fig. (6.10) shows the hourly heat gains and losses for zones Second-a and Fourth-a in the average hottest day. It is clear from the graph that zone Fourth-a gains more heat through building fabric as it has more exposed surface area (238m^2 compared to 78m^2 in zone Second-a). Fabric heat gains in zone Fourth-a (63253Wh) are higher by about three times when compared to zone Second-a (15501Wh).

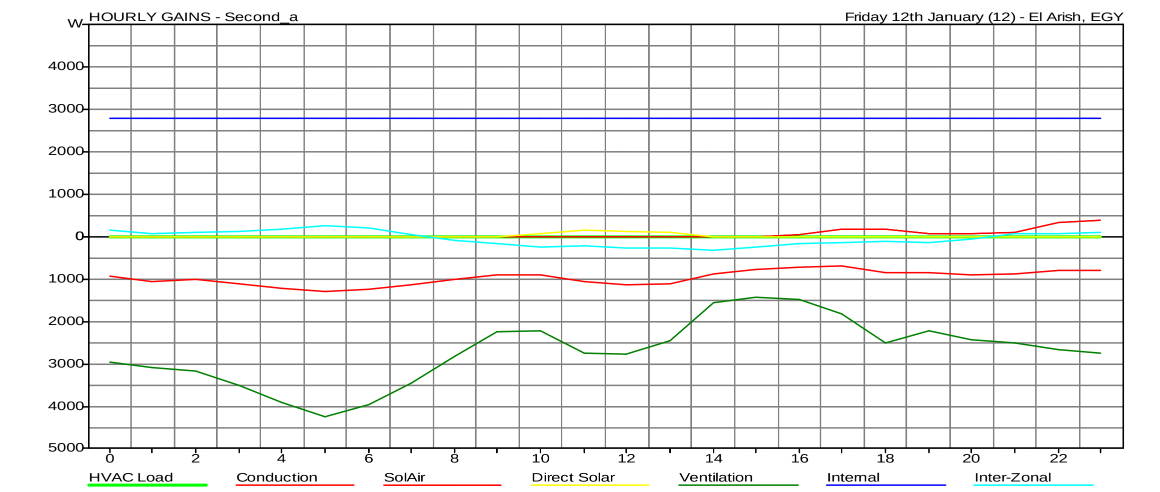
Solar heat gains are the same as there is no difference between both zones in terms of windows area and orientation. Ventilation gains are the most significant. It is useful to note that ventilation gains profile is similar to the external temperature profile presented in Fig. (6.8). This means that ventilation gains occur as a result of the hot air admittance to the space. The zonal gains or losses depend on the internal temperature of the adjacent zones. Heat should move the hotter zones to the colder ones. It is clear from the graph that zone Fourth-a loses more heat to the zones below it as it gets hotter.

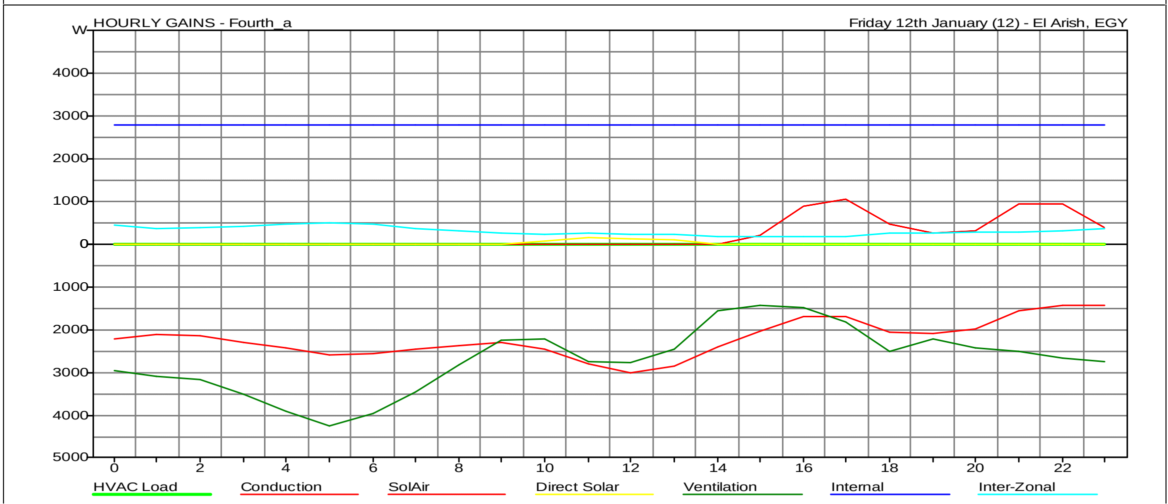


	Zone: Second-a					
Heat Path	HVAC	Fabric	Solar	Vent.	Internal	Zonal
Total (Wh)	0	15501	2821	283074	46084	-123
	Zone: Fourth-a					
Heat Path	HVAC	Fabric	Solar	Vent.	Internal	Zonal
Total (Wh)	0	63253	2821	283074	46084	-2108

Figure 6.10: Hourly gains for zones Second-a and Fourth-a in the average hottest day

Similar observations can be noticed in the winter, as presented in Fig. (6.11), but in a reversed manner. However, internal gains are higher and constant over time as the presented day is a weekend day in which full occupancy is assumed. Also, zone Fourth-a gains some heat from the underneath zones as it is colder than them.





	Zone: Second-a					
Heat Path	HVAC	Fabric	Solar	Vent.	Internal	Zonal
Total (Wh)	0	-21745	504	-64874	67440	-874
	Zone: Fourth-a					
Heat Path	HVAC	Fabric	Solar	Vent.	Internal	Zonal
Total (Wh)	0	-47372	504	-64874	67440	7498

Figure 6.11: Hourly gains for zones Second-a and Fourth-a in the average coldest day

6.5.3 The Monthly Discomfort Degree Hours

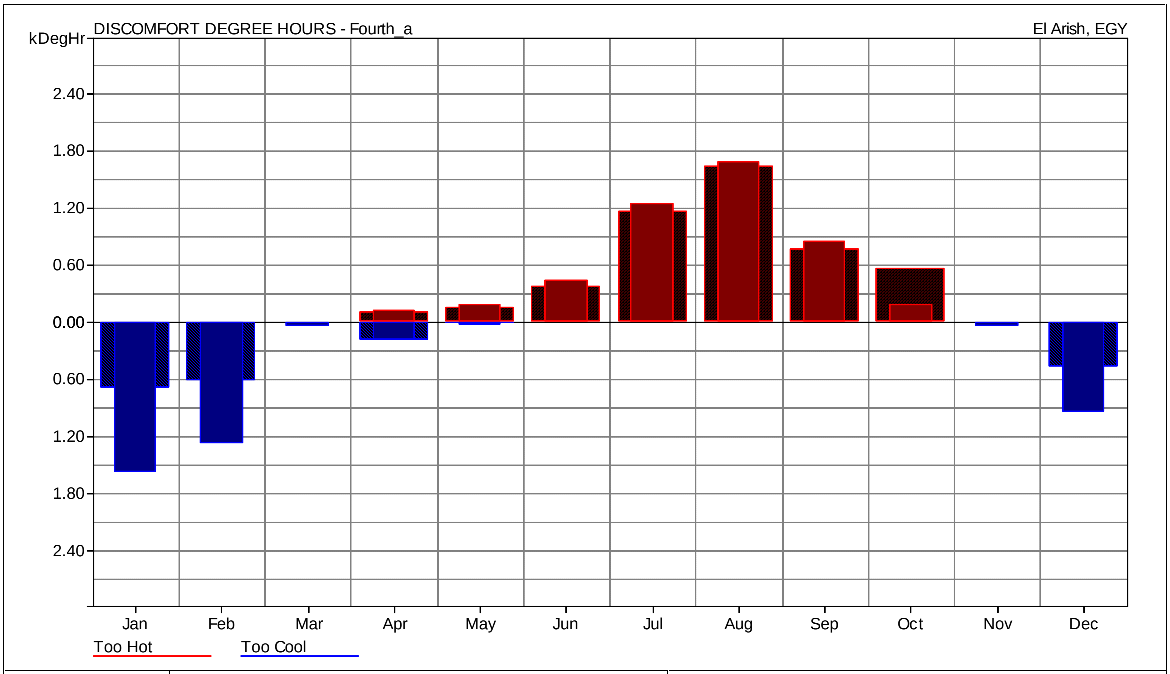
If a thermal zone is naturally ventilated, Ecotect can perform a thermal comfort assessment with reference to the occupants inside the space. This considers the amount of time the internal temperature of this zone spends outside the specified comfort conditions. Thermal discomfort in Ecotect can be estimated using three values:

- Degree Hours: This method is the most sensitive one as it measures thermal discomfort by the number of degrees spent outside the comfort band. For example, 10 degree hours mean that a thermal zone has spent 1 hour at 10 degrees above or below the defined comfort level, which makes building occupants feel too hot or too cool, respectively.

- Percentage of Time: this simply counts the number of hours a thermal zone spent outside the comfort band as a percentage of each month.
- Total Hours: this simply counts the actual number of hours a thermal zone spent outside the comfort band.

As indicated above, the first method is the most sensitive one, and thus will be mainly used here.

Fig. (6.12) shows the discomfort intervals measured in degree-hour for each month in the year. This is given for zones Second-a (the hatched bars) and Fourth-a (the solid ones), given that comfort lower limit is 18^{o}C and comfort upper limit is 26^{o}C.



	Zone: Second-a			Zone: Fourth-a		
	Too Hot	**Too Cool**	**Total**	**Too Hot**	**Too Cool**	**Total**
Deg. Hrs.	4811	1991.9	6802.9	4750.4	4123.6	8874

Figure 6.12: Monthly discomfort degree hours for zones Second-a (the hatched bars) and Fourth-a (the solid ones)

It is clear that there is a significant amount of discomfort recorded for both zones, especially in summer and winter. However, the problem is more significant in summer, and more significant as well for the upper zone "Fourth-a". Table (6.6) presents the monthly discomfort levels as a percentage of time for each month, which shows the need for heating in the cold months, especially in the months of Jan. and Feb., and the need for cooling in the hot months, especially in the months Jul. to Sep.

Table 6.6: Monthly discomfort presented as percentage of time for each month for zones Second-a and Fourth-a

	Zone: Second-a			Zone: Fourth-a		
	Too Hot	**Too Cool**	**Total**	**Too Hot**	**Too Cool**	**Total**
Month	%	%	%	%	%	%
Jan	0	81.45	81.45	0	98.12	98.12
Feb	0	70.98	70.98	0	91.07	91.07
Mar	0	1.21	1.21	0	11.29	11.29
Apr	5.14	18.89	24.03	5.42	19.03	24.44
May	10.22	5.11	15.32	11.56	5.38	16.94
Jun	36.25	0	36.25	39.86	0	39.86
Jul	71.24	0	71.24	71.91	0	71.91
Aug	89.52	0	89.52	88.17	0	88.17
Sep	60	0	60	60.69	0	60.69
Oct	67.2	0	67.2	32.53	0	32.53
Nov	0	0.42	0.42	0	10	10
Dec	0	38.31	38.31	0	63.04	63.04

The previous analysis shows that the proposed building requires some improvements to improve its thermal performance. One option is to examine the effect of thermal insulation, which is the main passive design strategy discussed in this study. This is because thermal insulation protects the building from the undesired climatic conditions, and reduces its need for heating and cooling. This will be done for the external walls of zone Second-a, and for the external walls and the roof of zone Fourth-a as discussed below.

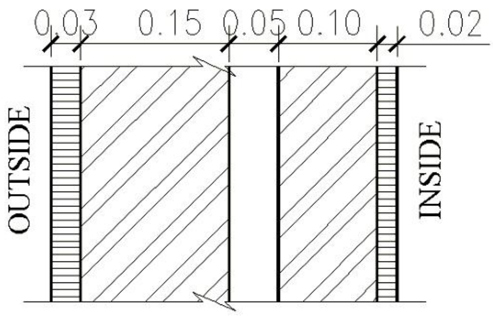
6.6 Thermal Modeling of the Improved Case

In this section, the effect of using thermal insulation on the examined building's thermal performance will be examined. Several thermal insulators are available for use in buildings, as explained in Chapter 5. Two options recommended by the Palestinian Code of Energy Efficient Buildings (Ministry of Local Government, 2004) will be examined here:

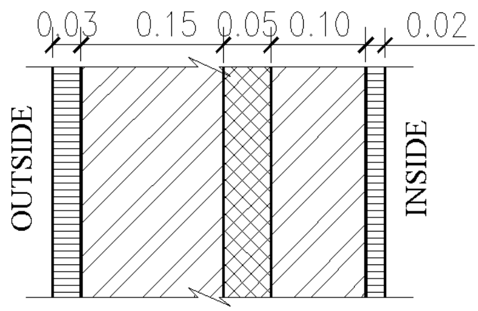
- Wall Insulation-A: This is a 35cm double wall with a middle air cavity and cement plastering at both sides. Thermal properties of this insulated wall are: U-value: 1.5 W/m^{2}K, admittance: 5.6 W/m^{2}K, decrement factor: 0.13, time lag: 7.4hrs (see Fig. 6.13 -a).

- Wall Insulation-B: Similar to the above one but polystyrene insulation in the middle instead of the air gap. Thermal properties of this insulated wall are: U-value: 0.4 W/m^{2}K, admittance: 5.6W/m^{2}K, decrement factor: 0.2, time lag: 12hrs (see Fig. 6.13 -b).

The following figure illustrates the above-explained two wall sections:



(a): Wall Insulation-A: 5 cm air cavity in a 35cm double wall



(b): Wall Insulation-B: 5 cm polystyrene in a 35cm double wall

Figure 6.13: Two proposed external wall sections with two thermal insulation options

The following sections illustrate the thermal performance of the building (zones Second-a and Forth-a) after using thermal insulation:

6.6.1 Zone "Second-a"

The use of both Insulation-A and Insulation-B will be examined for zone Second-a here. Building material of the external walls in the whole building has been changed to these two insulated walls. The Hourly Heat Gain and Losses graph could be a useful tool to demonstrate the effect of thermal insulation as it displays heat movement through building fabric. Table (6.7) shows the resulting heat gains or losses through building fabric.

Table 6.7: Heat gains or losses through building fabric in zone Second-a for the average hottest day and the average coldest day before and after the use of thermal insulation

	Wall Insulation-A			Wall Insulation-B		
	Before Insulation	**After Insulation**	**Diff.**	**Before Insulation**	**After Insulation**	**Diff.**
Heat Gain in Summer (Wh)	15501	10411	-33%	15501	9692	-38%
Heat Loss in Winter (Wh)	-21745	-16542	-24%	-21745	-15408	-29%

Results obtained showed that the use of thermal insulation has successfully reduced heat gains or losses through building fabric. However, Wall Insulation-B (polystyrene in a 35cm double wall) seems to be more effective when compared to Wall Insulation-A (air cavity in a 35cm double wall).

However, a look at the resulting thermal comfort conditions in table (6.8). It show that these conditions have improved in the cold months but not in the hot ones. As for the "Too Cool" case, thermal discomfort has been reduced by 9% and 43% as a result of using Wall Insulation-A and Wall Insulation-B, respectively.

As for the "Too Hot" case, thermal discomfort has increased by 2% and 11% as a result of using Wall Insulation-A and Wall Insulation-B, respectively. This indicates that despite the positive effect of thermal insulation in protecting the building from the undesired hot weather in summer, it seems that it prevented internal gains from leaving the space which increases thermal discomfort.

Table 6.8: Thermal discomfort degree hours in zone Second-a before and after the use of thermal insulation

	Wall Insulation-A			**Wall Insulation-B**		
	Before Insulation	After Insulation	Diff.	Before Insulation	After Insulation	Diff.
Too Hot (Deg. Hrs.)	4811	4913.8	+2%	4811	5319	+11%
(Deg. Hrs.)	1991.9	1820.2	-9%	1991.9	1130.2	-43%

Thus, thermal insulation has worked effectively in the cold months but not in the hot ones. This confirms the need of adopting a comprehensive passive design strategy in which several passive techniques are integrated. One strategy will be examined here, which is the use of night-time ventilation in the relatively hot months. As mentioned at the beginning of this study, these months are assumed to span from April to September. This strategy has been discussed in Chapter 4. It aims to cool the building fabric over night by increasing ventilation rate during night-time.

Thus, the building becomes able to absorb more internal heat gain during the day time. To do so, the ventilation schedule explained in Section 6.4.3 (C) will be modified.

That schedule assumed a constant ventilation rate of 70% (7 Ach/hr) during the hot months. This will be modified to allow for 100% ventilation rate from 6pm to 8am when air temperature is low, and 30% ventilation rate from 8am to 6pm when air temperature is high. This is illustrated in the following figure:

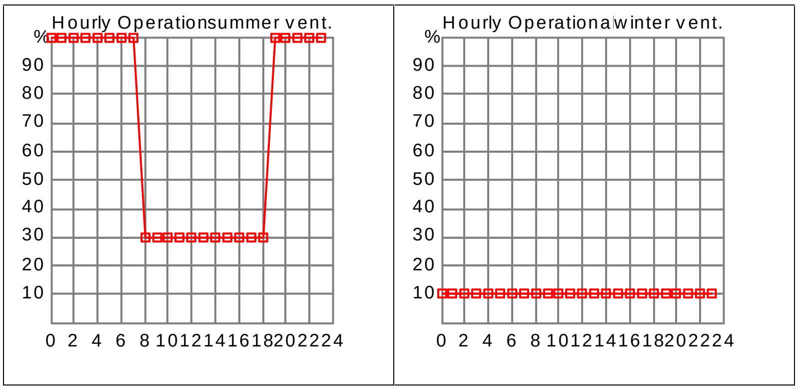


Figure 6.14: The modified Ventilation Schedule showing the use of night-time ventilation strategy in the hot months "lift". No change has been made to the cold months "right"

The effect of night-time ventilation on thermal discomfort is presented in Table (6.9). It shows that night-time strategy, along with thermal insulation, helped reducing the degree hours of the "Too Hot" category by 27% for Wall Insulation-A, and by 18% for Wall Insulation-B. As for the "Too Cool" category, there is no improvement in the case of using Wall Insulation-A along with night-time ventilation. However, Wall Insulation-B seems to be more effective as a reduction of 34% in discomfort is observed.

Table 6.9: Monthly discomfort degree hours for zone Second-a before the use of night-time ventilation in summer along with thermal insulation (the hatched bars) and after the use of it (the solid ones)

	Wall Insulation-A			**Wall Insulation-B**		
	Before Insulation & Nigh-time Vent.	**After Insulation & Nigh-time Vent.**	**Diff.**	**Before Insulation & Nigh-time Vent.**	**After Insulation & Nigh-time Vent.**	**Diff.**
Too Hot (Deg. Hrs.)	4811	3528.7	-27%	4811	3927.9	-18%
Too Cool (Deg. Hrs.)	1991.9	2005.3	+1%	1991.9	1313.7	-34%
Total	6803	5534	19%	6803	5242	23%

In total, Wall Insulation-A has reduced the thermal discomfort by about 19%, compared to 23% in the case of Wall Insulation-B. However, the first insulator seems to be more effective in the hot months while the second one seems to be more effective in the cold ones.

6.6.2 Zone "Fourth-a"

Thermal insulation in this zone is similar to zone Second-a but with additional thermal insulation implemented to the top roof. An insulated roof section recommended by the Palestinian Code of Energy Efficient Buildings (Ministry of Local Government, 2004) will be examined here. This roof is a 25cm ribbed concrete roof covered with 5cm of thermal insulation (polystyrene), 5cm of foam concrete, 2cm of moisture insulation, 2.5cm of sand, and 1cm of tiles, respectively from bottom to top.

Thermal properties of this insulated roof are: U-value: 0.73 W/m^{2}K, admittance: 5.3 W/m^{2}K, decrement factor: 0.1, time lag: 11hrs. It is useful to remember that thermal properties of the roof in the reference case were as follows: U-value: 2.6 W/m^{2}K, admittance: 4.9 W/m^{2}K, decrement factor: 0.4, time lag: 6.8 hrs.

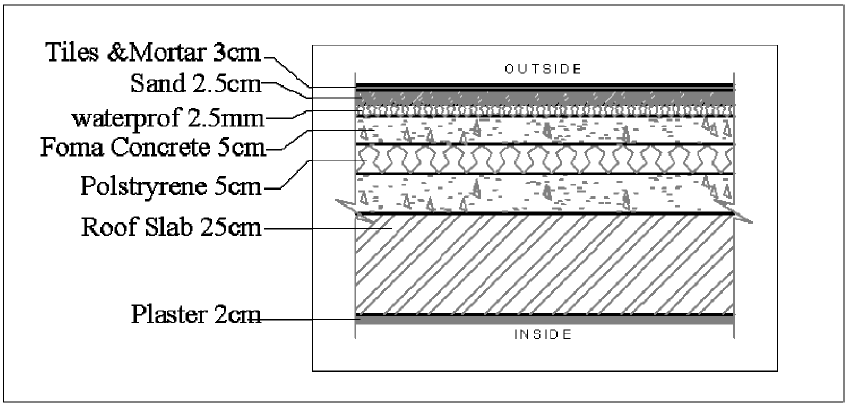
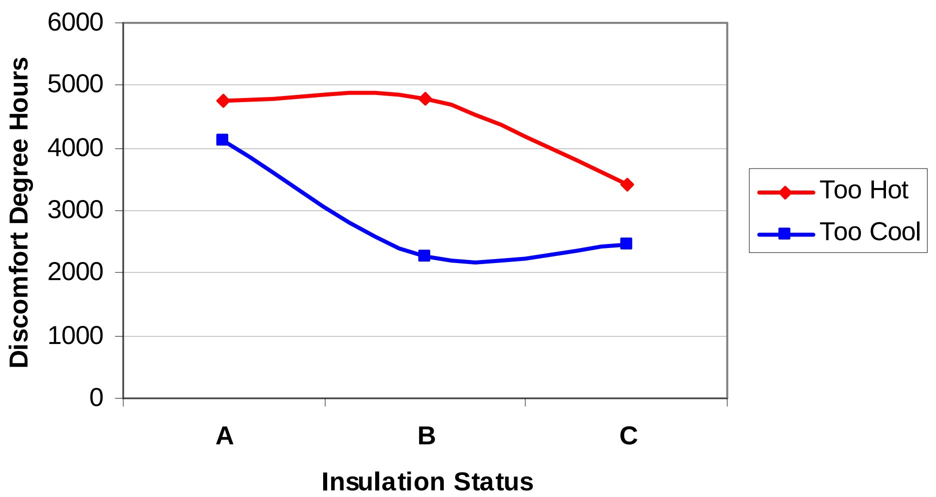


Figure 6.15: The insulated roof section

The previous analysis revealed that thermal insulation works more effectively when integrated with the night-time ventilation. It also revealed that Wall Insulation-B offers better insulation in general. Thus, these two considerations will be implemented here.

Figure (6.16) shows the discomfort periods measured in degree-hour for each month in the year for zone Fourth-a. This is shown in three stages:

- Before using the wall and roof insulation
- After using the wall and roof insulation (Wall Insulation-B).
- After using thermal insulation along with night-time ventilation.



	A. No Insulation	B. Wall & Roof Insulation	Diff. (A & B)	C. Insulation & Night-time Vent.	Diff. (B & C)
Too Hot (Deg. Hrs.)	4750.4	4781	+1%	3417.5	-29%
Too Cool (Deg. Hrs.)	4123.6	2267	-45%	2455	+8%
Total	8874	7048	-20%	5872.5	-17%

Figure 6.16: Annual discomfort degree hours for zone Fourth-a before insulating the walls and roof and after it

It seems that findings here are consistent with ones obtained in the case of zone Second-a. The positive effect of using thermal insulation is significant as it could reduce thermal discomfort by about 17%. However, this is more significant in the cold months where occupants feel too cool. It can be noticed from the above-listed results that the use of thermal insulation was not enough to relief the "Too Hot" discomfort.

However, after using night-time ventilation the "Too Hot" discomfort has been reduced by 29%. However, this occurred on the account of the "Too Cool" thermal discomfort. This is because the weather may be too cold for some days in the relatively hot months where night-time ventilation is implemented. In conclusion, these interesting findings show that the use of wall and roof thermal insulation together is essential in the case of upper residential flats to ensure better comfort conditions in both summer and winter.

6.7 Expected Energy Savings and Payback Period

To estimate the amount of energy that would be saved as a result of using thermal insulation, the monthly space load graph in Ecotect can be used as an approximation method. This graph displays the total heating and cooling loads required to maintain thermal comfort in a specified thermal zone. To do so, the building is assumed air conditioned when the internal temperature is higher or lower the thermal comfort limits (18-26^{o}C). The fact that the building is air conditioned implies two changes in the zonal thermal settings:

- Natural ventilation rate will be set to the minimum, assumed 1.5 Ach/hr of air infiltration, as windows are closed.
- Night-time ventilation will not be used as windows are closed to allow for air conditioning.

Table (6.10) shows the expected energy savings as a result of using thermal insulation for zones Second-a and Fourth-a. Both wall insulation types assumed in this study (Wall Insulation-A, and Wall Insulation-B) have been considered, in addition to the roof insulation in the case of zone Fourth-a. Heating and cooling loads are estimated in kWh. Each kWh is assumed to cost 0.5 NIS according to the local price.

Results obtained show that it is possible to save an annual amount of 180 NIS for zone Second-a, and an annual amount of 1847 NIS for zone Fourth-a when comparing the total heating and cooling loads before and after using thermal insulation, given that Wall Insulation-A is used. In the case of using Wall Insulation-B, it is possible to save an annual amount of 180 NIS for zone Second-a, and an annual amount of 1793 NIS for zone Fourth-a. There is no significant difference between Wall Insulation-A and Wall-Insulation-B as a total in terms of heating and cooling loads. However, it can be noticed that Wall Insulation-B saves more money in heating on the account of cooling, while Wall Insulation-A offers more balanced savings. Also, it can also be noticed that the effect of roof insulation is more significant as more money can be saved in zone Fourth-a.

Table 6.10: Annual heating and cooling loads and money saving for zones Second-a and Fourth-a before using thermal insulation and after it

A. Wall Insulation-A, and roof insulation						
	Loads for zone Second-a (kWh)			Loads for zone Fourth-a (kWh)		
	Heating	Cooling	Total	Heating	Cooling	Total
Before Insulation	1779	12900	14678	3645	14538	18184
After Insulation	1506	12813	14319	2217	12274	14490
Diff. (kWh)	273	86	360	1428	2265	3693
Money Saved	137	43	180	714	1132	1847
B. Wall Insulation-B, and roof insulation						
	Loads for zone Second-a (kWh)			Loads for zone Fourth-a (kWh)		
	Heating	Cooling	Total	Heating	Cooling	Total
Before Insulation	1779	12900	14678	3645	14538	18184
After Insulation	874	13444	14318	1861	12737	14597
Diff. (kWh)	905	-545	360	1785	1802	3586
Money Saved	452	-272	180	892	901	1793

In order to estimate the payback period, construction costs of the external walls and top roof have been estimated before and after using thermal insulation. This is explained in details in the Appendix. The following sections summarize the findings:

6.7.1 Wall Insulation-A

Given that the additional cost of using Wall Insulation-A (35cm double wall with a middle air cavity) in zone "Second-a" is $390 (NIS 1480 approximately), and that the annual saving in heating and cooling as a result of using thermal insulation is NIS 180, it is possible to get back insulation cost in zone "Second-a" in 8.2 years.

As for zone "Fourth-a", the additional cost of insulation includes both walls ($390) and the roof ($5520). This equals $5910 (NIS 22,460 approximately). Given that the annual saving in heating and cooling as a result of using thermal insulation is NIS 1847, it is possible to get back insulation cost in zone "Fourth-a" in 12.2 years.

6.7.2 Wall Insulation-B

Given that the additional cost of using Wall Insulation-B (35cm double wall with polystyrene in the middle) in zone "Second-a" is $813 (NIS 3090 approximately), and that the annual saving in heating and cooling as a result of using thermal insulation is NIS 180, it is possible to get back insulation cost in zone "Second-a" in 17.2 years.

As for zone "Fourth-a", the additional cost of insulation includes both walls ($813) and the roof ($5520). This equals $6333 (NIS 24,065 approximately). Given that the annual saving in heating and cooling as a result of using thermal insulation is NIS 1793, it is possible to get back insulation cost in zone "Fourth-a" in 13.4 years.

6.8 Conclusion

Buildings thermal behavior modeling is a complicated process in which several aspects interact, and several assumptions should be reasonably treated. Thus, the use of computer simulation significantly facilitates this process. This chapter shows the great potential of passive design techniques to save energy without technical complications. With the focus of thermal insulation, it is possible to significantly reduce thermal discomfort by about 20% over the year by using thermal insulation in walls and top roofs. The additional cost of using this thermal insulation depends on the type of insulation used. The use of air cavity in a double wall has been found more feasible when compared to the use of polystyrene in the same double wall.

However, the positive effect of thermal insulation in summer can only be invested when it is coupled with night-time ventilation to reduce the adverse effect of the internal gains. Despite the fact that thermal insulation has been explored in this chapter, the potential of other passive design techniques, like shading, the use of double glazed windows, and the use of landscaping, can not be neglected in order to achieve a comprehensive perspective of energy efficient design strategies.

Chapter 7 : Conclusions and Recommendations

7.1 Introduction

This study has been carried out with the aim to explore the potential of passive design techniques in saving energy and improving thermal conditions in buildings. Thermal insulation has been given more attention as one of the most effective energy-efficient design strategies. Through implementing the stated methodology in Section (1.5) of Chapter one, several conclusions and recommendations have been achieved. These are presented in the following sections.

7.2 Energy Problem and Solutions

Through the study of the global energy status, with more attention given to Gaza case, the following conclusions have been realized:

- Energy is considered an essential component of the contemporary life that cannot be dispensed. However, Rising standards of life have increased the reliance on traditional energy supplies (coal, oil, and natural gas). This growing demand faces the fact that conventional energy reserves are non-renewable and limited.
- Also, the increasing rates of energy consumption are associated with several negative environmental impacts as a result of the harmful Carbon emissions, which threaten all aspects of modern life.
- This energy shortage calls to turn to the alternative sources of energy, which are sustainable and environmentally friendly.
- As construction is responsible for 50% of the total energy consumption in the world (Edwards & Hyett, 2002), buildings can be considered as a field of high priority to implement energy saving strategies.
- This is more important in Gaza Strip, which suffers from severe shortage in conventional energies due to several factors including the political instability.

7.3 The Importance of Passive Design

As mentioned above, the sector of buildings is a significant one in terms of energy consumption. Thus, it is necessary to reduce this consumption while maintaining acceptable levels of services and thermal comfort inside buildings. Through the study of passive design principles including thermal insulation, in addition to some relevant case studies, the following findings can be confirmed:

- It is essential in building construction to secure a state of thermal comfort for building users. This is effectively achievable through the implementation of the principles of passive design, including the use of thermal insulation, thermal mass, natural ventilation, and natural lighting.
- Passive building design relies on the natural sources of energy and includes no mechanical installations. Thus, it gives the opportunity to save energy while improving thermal comfort.
- Heat flow from the external environment to the building, or vice versa, could be effectively controlled using thermal insulation. This is directly reflected in the reduction of heat gains or losses through the building fabric, which reduces the energy required for heating or cooling.
- In this regard, it is necessity to select the appropriate thermal insulation materials, and to make good choice of the type of windows.
- Sustainability is commonly implemented in buildings nowadays, with the fact that the increasing public awareness has inspired these projects.
- These projects aim to reduce the amount of energy required for buildings, and promote the use of renewable energy technologies. They are based on innovative solutions, and can be continually developed and improved.
- Despite the high initial cost of these projects, the reduced running cost in terms of energy means that the capital cost could be retrieved in some period of time. This is in addition to the positive environmental return.

7.4 Thermal of Performance Modeling

The final part of the study aimed to numerically assess the thermal performance of a residential building prototype located in Gaza. This has been carried out through computer simulation using Ecotect program. It has been concluded that:

- Computer simulation is a powerful research tool that effectively examines buildings thermal performance.
- Numerical assessment of buildings thermal performance gives more value to any recommended energy-efficient design strategy.

- The current common building materials in Gaza Strip are ineffective in terms of providing thermal insulation (U-value of external walls is 2.3 W/m^2K, and 2.6 W/m^2K for roofs), and do not comply with the Palestinian standard.
- The use of thermal insulation has been found to be effective as it improves thermal comfort conditions by about 20% over the year. This is true for the middle and top floors of the examined multi-storey building.
- The improvement observed in the hot months is conditioned by the use of night-time ventilation in order to reduce the negative effect of the internal heat gains.
- The use of air cavity wall (U-value = 1.5 W/m^2K) has been found to improve thermal comfort more effectively in summer time on the account of winter time, while the opposite has been observed in the case of using polystyrene insulation (U-value = 0.4 W/m^2K).
- The use of air cavity in a double wall has been found more feasible when compared to the use of polystyrene in the same double wall. It is possible to get back insulation cost in 8.2 years in the middle floor (compared to 17.2 years in the case of using polystyrene insulation), and in 12.2 years in the top floor (compared to 13.4 years in the case of using polystyrene insulation). However, the observed payback period in both cases may be reduced by optimizing the thickness of the invested thermal insulation.

7.5 Recommendations

The above-mentioned conclusions lead to the following recommendations:

- The shortage of conventional energy sources in Gaza necessitates effectively investing the available renewable energy sources, especially solar energy.
- Technical and financial support must be provided for the development of renewable energy projects.
- It is required from all parties involved in the construction sector to adopt effective strategies for energy-efficiency that integrate both passive and active means into building design, taking into account the economic and environmental benefits of that.
- This requires that the concerned official bodies take an action to legalize the issue through appropriate building norms and policies that put energy-efficiency of buildings in action.

- This includes taking the necessary measures to reduce the emission of greenhouse gases in accordance with the global trend, and reduce building energy consumption through using building materials with acceptable U-Value.
- It also includes encouraging the relevant research efforts, especially those who tackle the Palestinian case, and integrating the issue of building sustainability in the curriculums of students in schools and universities.
- It is recommended to extend the work carried out in this study in order to give more value to the results obtained. This can be achieved by validating these results through implementing other research tools, like experiments. It is also possible to examine other design aspects like the use of single-family building, wall types and windows, and other climatic conditions like the West Bank case.

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Appendix: Thermal Insulation Cost Estimation

The following section estimates the cost of thermal insulation that has been used in the building envelope in the thermal modeling study. For zone (Second-a), this includes south and west external walls. For zone (Fourth-a), this includes south and west external walls in addition to the roof.

1. Cost of Wall Insulation

Table 1: Area of the External Walls (Western and Southern Walls)

Wall area				
Wall	No.	Length (m)	Height (m)	Area (m^2)
Western	1	16	3	48
Southern	1	10	3	30
Total area of the walls				78
Windows area				
West window	2	1.2	2	5
West window	1	1.2	2.2	2.65
West window	1	0.7	0.7	0.5
South window	2	1.2	2	5
Total area of the windows				13
Net area of the walls				**65**

Table 2: Cost of Wall Construction without Thermal Insulation

Wall	**Area (m^2)**	**Cost ($/$m^2$)**	**Total Cost ($)**
Hollow Block 20cm	65	12	780
Total			**780**

Table 3: Cost of the Wall with Wall Insulation-A (Air Cavity)

Type	**Area (m^2)**	**Cost ($/$m^2$)**	**Total Cost ($)**
Hollow Block 15cm	65	10	650
Air Cavity	65	0	0
Hollow Block 15cm	65	8	520
Total			**1170**

Table 4: Cost of wall with Wall Insulation-B (Polystyrene)

Type	**Area (m^2)**	**Cost ($/$m^2$)**	**Total Cost ($)**
Hollow Block 15cm	65	10	650
Thermal Insulation 5cm	65	6.5	422.5
Hollow Block 15cm	65	8	520
Total			**1592.5**

2. Cost of Roof Insulation

Table 5: Area of the Roof

Type	Length(m)	Width(m)	Area(m2)
Concrete ceiling	16	10	160
Net area			**160**

Table 6: Cost of the Roof Construction without Thermal Insulation

Type	Area (m^2)	Cost ($\$/m^2$)	Total Cost ($)
Concrete ceiling 25cm	160	35	5600
Total			**5600**

Table 6: Cost of the Roof with Thermal Insulation

Type	Area (m^2)	Cost ($\$/m^2$)	Total Cost ($)
Ceramic Floor Tiles	160	12	1920
Water proof (Bitumen)	160	6	960
Foamed Concrete 3-7cm	160	10	1600
thermal insulation (Polystyrenes)	160	6.5	1040
Concrete ceiling 25cm	160	35	5600
Total			**11120**