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Economic and Environmental Impact of Thermal Insulation in Residential Building in Bahrain

By

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Submitted in Partial Fulfillment for the Degree of Master in Environment and Sustainable Development

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May, 2006

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DECLARATION

I declare that this work is the result of my own investigation and that it has not already been accepted in substance for any degree, nor is it being currently submitted for any degree.

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ABSTRACT

The main objective of this study is to estimate the electrical energy saving due to using thermal insulation in residential building in Bahrain and studying the effect of this conservation on the consumer, the national economy as well as the environment.

The study investigation includes the use of different insulation materials, widths and different walls and roof construction commonly used in Bahrain. This investigation was done by using the computer simulation technique "Energy-10 Software".

The simulation results show the energy use, cooling load and life cycle cost for the insulated standard houses and the best condition standard houses. These results are then, compared to the result of the actual standard houses.

From this comparison the energy and cost saving were calculated for the different walls and roof construction and the use of different insulation materials and thicknesses.

The analysis of the results obtained from the simulation showed that, the energy performance of the polyurethane insulation was the best and the optimum thicknesses for wall and roof were 50mm and 100mm respectively. The result also, showed that the energy performance of the best condition house (insulated cast insite reinforced slab roof and insulated double block wall constructions) were better than the actual standard houses. It reduces the electricity consumption and the cooling load by about 34%, 30% and 32%, 28% for types E and 3A houses. It also reduces the life cycle cost by BD 3878.36 and BD 4117.8 for types E and 3A houses. In addition it reduces the Carbon dioxide (CO_2) by about 26%, 29.8% for type E and type 3A respectively

The study also, emphasized the importance of the use of insulation in building, due to its high energy saving, economical and environmental benefits.

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NOMENCLATURE AND ABBREVIATIONS

C°	Degree centigrade
C	Thermal Conductance
ft	Foot
ft^2	Square foot
F	Fahrenheit
hr	Hour
in	Inch
k	Kelvin
K	Thermal Conductivity
m	Meter
m^2	Square meter
r	Thermal Resistivity
R	Thermal Resistance
W	Watt

Btu	British Thermal Unite
E	Emissivity (It is a measure of ability of material to emit energy)
HVAC	Heating, Ventilating, and Air- Conditioning Equipment
LCCA	Life Cycle Cost Analysis
NPV	Net Present Value
U-value	Heat Transfer Coefficient (a measurement of the heat flow rate through a substance)
R-value	Thermal Resisting (a measure of the heat flow resistance of a substance)

CHAPTER ONE

1. INTRODUCTION

1.1 General Introduction

The Kingdom of Bahrain is located on the southern shore of the Arabian Gulf between latitude 25 32 and 26 20 North and longitude 50 20 and 50 50 East. The Kingdom is an archipelago formed of 36 low- lying Islands; with a total land area of about 706 square km., large areas of the coastal zone have been reclaimed in recent years. Bahrain is close to tropic of cancer, located in the desert zone having significant aspects of general climate are cool winters with sparse rainfall, and hot summers with high humidity. The winter season from December to February is influenced by low-pressure systems from the Mediterranean, which travel east into the Gulf and cause periods of disturbed weather. These disturbances accompanied by rainfall, which averages approximately 74 mm per annum. January is usually the coolest month, when extreme low temperatures are experienced and prevailing wind of Northwesterly. Between March and May and between October and November the weather is normally warm and dry, with pleasant breezes and many hours of sunshine. The summer season from June to September is generally hot with a noticeable increase in humidity. Temperatures average 38 to 42 Centigrade and average Relative Humidity range from 67 to 82%.

Initially the region influenced by low pressure over Pakistan. These causes dry Northwesterly wind, known locally as "Al Barah" they persist for long periods and create more pleasant condition. After this period, the low pressure system decline allowing the formation of Southeasterly winds known locally as the "Kaus", which cause a steady rise in both temperature and humidity.

The total population of Bahrain was estimated to be 677,886 in 2004. About 93 percent of the population resides in urban areas, primarily in Manama, its suburbs, and the nearby city of Al Muharraq. Manama serves as the country's governmental and commercial center, while Al Muharraq is the site of Bahrain International Airport. The country has a high population growth rate 1.56 percent (2004 estimate). The high growth rate results primarily from a continues relatively high birth rate.

Bahrain is the oldest oil producing in the Arabian Gulf. All of Bahrain's 125 million barrels of onshore proven oil reserves are located in the Awali field, the first oil field to be developed in the Arabian Gulf. Discovered in 1932, Awalis crude oil production peaked at more than 75,000 barrels per day (bbl/d) in the 1970s, but has declined since then. As of late 2004, Awali is producing around 35,000 bbl/d of crude oil. In addition, Bahrain receives oil via sub sea pipeline from Saudi Arabia, some of this oil comes from the Abu safa offshore field. which lies in Saudi Arabia waters.

Unlike other Gulf States, Bahrain exports refined petroleum products rather than crude oil. The country's refinery, Sitra is located south of Manama and has a current capacity of 248,900 bbl/d. Bahrain exports most of the Sitra refinery's product to India and the Far East.

Bahrain has natural gas reserves of about 3.25 trillion cubic feet (Tcf), much of it associated gas from the Awali oil field. The country produced 327 billion cubic feet (Bcf) of natural gas in 2002, all of which was consumed locally. The largest domestic consumer was Aluminum Bahrain (Alba), which uses it in its power plant. Bahrain's growing demand for electric power generation is likely to cause it to become a net natural gas importer in coming years.

In order to implement the Kingdom's policy of providing an alternative source of income for the country and avoid dependency on oil, the government of Bahrain has given much more attention to the industry in the last two decades. Besides oil refining industry and to utilize the availability of natural gas, the government of Bahrain has established petrochemical industry in December 1979 for production of basic petrochemical products, ammonia and methanol. This industry has been successfully developed and operated above the design production capacity during the year 1985-2003, when the total quantity of ammonia exported reached 69998 metric tones in 2003 against 104,921 metric tones in 1985, and total quantity of methanol exported increased from 126,054 metric tones in 1985 to 360,154 metric tones in 2003.

Bahrain has the first major aluminum in the region established in 1971. Since the operation of full capacity for the smelter by the end of 1973, this industry has matured considerably. As the flagship of Bahrain industrial development program, aluminum industry continually looked to the future, improving efficiency and increasing output. Total aluminum products were increased from 72.243 in 1980 to 798.382 metric tones in 2003.

The percentage share of manufacturing in gross domestic product continually increased. It reached 11.2% in 2003 compared to 10.1% in 1985. while the percentage share of crude oil and gas went down from 28.0% in 1985 to 24.9% in 2003.

Electricity production and distribution in Bahrain is the responsibility of the Ministry of Electricity and Water. In 2002, Bahrain had an estimated electric generating capacity of 1.4 gigawatts (GW), and produced 6.9 billion kilowatt-hours (bkwh). Installed capacity is barely able to meet current consumption, with the country's population growth and economic development leading to rapid power demand increases. At present, Bahrain gets its power from two combined water and power production complexes and three smaller electricity-only plants. The recent focus has been on the modern Hidd complex. Phase one, which was completed in 1999, added 280 megawatts (MW). Phase two added another 600 MW when it was completed in 2004.

Kingdom of Bahrain provides electricity as a commodity for its users at an average price of 10 files/kWh. The electrical energy, which is most costly to generate, is most extensively used. The government subsidizes a substantial part of the electrical energy cost sold to the public. The subsidy is estimated to reach as high as 72% of the generation cost price (Al-Rgom, Fatoon, 2003).Thus, the increase of consumption of electricity means the increase of the money spent by the government in subsidy. The electrical energy consumption has increased from 4,611.92 Million kWh in 1995 to about 8,267.30 Million kWh in 2004 (Central Statistics Organization, 2004).

The electrical consumption is distributed in to four sectors; domestic, commercial, industrial and agricultural. Most of the produced electricity is being consumed domestically. Almost 53% is being used in this sector the rest is utilized by the commercial, industrial and agricultural at 27%, 20%, and 0.6% respectively. A pie Chart that illustrated in Figure 1.1.

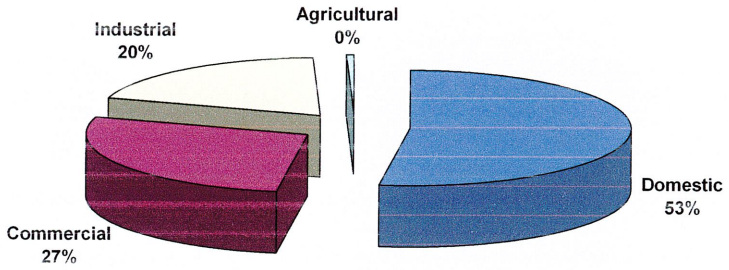


Fig.1.1 Consumed electrical energy by sector in 2004

Increasing energy consumption trends can be attributed to domestic habits. The consumption is at lowest level when ambient temperature are low and it is at its highest levels when ambient temperature is high and this indicates that most of the energy is being used for air conditioning during summer time.

1.2Problem Definition

Buildings are large consumers of energy in most countries. In harsh climatic conditions such as Bahrain, a substantial share of energy goes to the air-conditioning of buildings. This air-conditioning load can be reduced through many means; notable among them is the proper design and selection of building envelope and its components.

Most of electric energy generated in Bahrain is consumed in building. The maximum power demanded is experienced during summer, with a bout 80% of the demand due to air conditioning in buildings. The construction of thousand of modern building in last two decades with very little consideration to energy consumption is one of the principle causes of the high electric energy consumption. This will results in building new power plants, which are extremely costly, and the demand on such is continuing with the rapid growth in population.

The use of thermal insulation in building walls and roof does not only contribute in reducing the required air-conditioning system size but also

in reducing the annual energy cost. Additionally, it helps in extending the periods of thermal comfort without reliance on mechanical air-conditioning especially during summer periods.

Therefore, proper use of thermal insulation in buildings enhances thermal comfort at less operating cost and it is long-term investment for homeowners, occupants and for the country's energy sector.

1.3Objective Of The Study

The main objectives of this study are as follows:

- Selecting the best insulation material and the optimum roof and wall insulation thickness for residential buildings in Bahrain.
- Selecting the best roof and wall constructions. which could be used in Bahrain.
- Estimate the saving in electrical energy due to using best insulation material and optimum thickness of insulation in residential buildings.
- Estimate the saving in electrical energy due to using the best insulation material and optimum roof and walls thickness. and the best wall and roof construction.
- Study the economic effect of this saving on consumer.
- Study the effect of this saving on the environment.

Thermal Insulation History

From caves to superinsulated houses, human beings have demonstrated the need for protection from the elements. The true origins of the science of thermal insulation, however, are difficult to identify.

Organic materials have served as the polar bear or feathers on a bird, cotton, wool, straw, and even hair. Similarly, prehistoric human beings clothed themselves with wool and skins from animals and built homes of wood, stone, earth and other materials for protection from the cold winter and the heat of summer. For thousands of years, house structures were designed to best suit the climate of their location. For example, using the earth as insulator, the Egyptians retired to the coolness of subterranean chambers and grottoes on hot days (Albert Farwell, 1933).

Historians believe that the ancient Greeks and Romans discovered Asbestos and found many uses for it because of its resistance to heat and fire. The Romans even used Cork for insulation in shoes in order to keep their feet warm. Pliny, in the first century, referred to use of cork as an insulating material for roofs. Early inhabitants of Spain lined their stone houses with Cork bark, and North African natives used Cork mixed with Clay for the wall of their dwellings (Paul Dunham, 1947).

As technology developed, so did innovations to improve the comfort of human beings. Introduction of the fireplace and chimney by the Norwegians and people of Iceland during the twelfth and thirteenth centuries provided controlled, artificial heat (Albert Farwell, 1933). It was evident that the task soon not only how to keep heat out but also how to keep heat in.

The thatched huts of northern Europe were built with roof, up to 2ft thick, of woven Straw and walls of Clay and Straw. Similarly, the indigenous peoples of the South Seas built huts of the dried sea grass. The hollow fiber of the dried sea grass provided a good degree of thermal resistance (Paul Dunham, 1947).

The industrial revolution of the late nineteenth century deliberate commercial application of thermal insulations. For example, blanket type insulations were being developed throughout the 1890s. Mineral wool was first commercially produced as a pipe insulator in Wales in 1840 and in the United States for the first time in 1875 (Henry S. Harrison, 1998).

Fiberglass had its beginnings in ancient Egypt, when people discovered that they could draw hot glass into threads, which were placed around vessels for decoration. The modern technique of making fiberglass insulation, developed in 1931, involves jetting of molten glass through tiny heated holes in to high speed air streams; where in the resulting fibers are drawn very thin and to great length (T. Neil Davis, 1981).

Wood shavings were very popular insulation product due to the wide availability of raw materials and their low cost at the turn of the century.

Reflective insulation materials, using bright metallic surfaces, were first patented in 1804. Aluminum eventually become the predominant reflective material, but it did not achieve commercial popularity until the 1930s (Paul. Dunham, 1947).

Thermal insulation was not as necessary prior to the 1920s as it now because of the construction materials and methods used at that time. Materials were heavier, including windows and door sashes, which provided adequate weather resistance. The growing popularity and use of lighter building materials increased the need for insulation products (Henry S. Harrison, 1998). The gradual introduction of air-conditioning systems into home design also contributed to a greater need for thermal insulation.

During World War II, the use of building insulation was made mandatory to conserve metal required for heating and air –conditioning equipment and to save Fuel (Tyler. Stewart Rogers, 1964). This probably contributed to a greater awareness by the general population of the sensible applications of insulation in residences as well.

The 1970s saw a dramatic shift in public awareness and sensibility toward energy conservation. Many researchers point to the Arab oil embargo of 1973 and 1974 as the catalyst for energy. A second sharp rise in oil prices occurred in 1979 following the Iranian revolution, further contributing to public discussion as well as new energy programs.

As the result of the energy crisis, heavy demand for insulation induced many new products to enter insulation industry. The rising energy costs, especially heating oil, have begun to affect homeowner in their purses, "spend a dollar on insulation, save $12 in energy costs" (Richard T. Bynum, JR, 2001).

Over the last few decades, the world has experienced a growing realization of the limited availability of conventional forms of energy, particularly fossil fuels. This was sparked by the rapid increase in the demand for energy was doubling once every 10-15 years in response to the growth in industrialization and affluence in advanced and developing nation. The increase in the price for energy over the past 20 years or so changed the relative economic benefit in favor of minimizing the consumption of energy and introducing Cost-effective energy conservation measures wherever possible(Bahrain University,1995).

As with other energy-efficiency policies, interest in energy standards was fueled by the oil shocks of the 1970s. Prior to that time, only a few countries had regulations affecting the energy use of buildings. These were simple, prescriptive insulation requirements that bear little resemblance to the multi-faceted performance standards used in many countries today. Over the last two decades, improvements in calculation methods, computer modeling, and building energy research have provided the means for many countries to revise their original standards and develop more comprehensive versions. Currently, at least 40 countries have some form of existing voluntary or mandatory standard for energy use in new buildings, and six more countries have standards on their legislative drawing boards. As environmental and economic concerns about energy use and electricity generation grow, energy standards are likely to play an even larger part in national and international energy-efficiency agendas (Kathryn. Janda and John F. Busch. 1994).

Thermal Insulation in Building

Buildings have a substantial share of the energy consumption all over the world. In locations with prevailing hot climatic conditions, the bulk of this energy is usually used by building air-conditioning and ventilation systems. The amount of energy used in the air-conditioning process is directly related to the building thermal load. Heat transfer by conduction through walls and roofs represents a major component of the total thermal load of buildings. Using thermal insulation effectively could lead to a significant reduction in thermal loads and consequently reduction in the overall building energy needs.

In a 1996 study of the energy and environmental benefit of fiber glass, rock wool and slag wool insulation materials prepared for the North American Insulation Manufacturers Association (NAIMA), researchers compared the energy used to make insulation with the energy currently being saved by insulation products installed in the building envelope of residential and commercial structures. The study looked specifically at the energy saving benefits of the insulation currently in place in the United States in residential and commercial buildings as well as in industrial applications. The findings of the study are startling. The authors reported that "because of home insulation, drastically less energy is needed to heat and cool homes in the United States today when compared to the same homes without insulation. The difference results in energy savings of 51% or 10.4 quadrillion Btu nationwide. "That 10.4 quadrillion Btu is equivalent to a 255 day supply of gasoline for the entire United States or to 51% of the total annual industrial energy consumption in the United States. In the commercial building sector, the study found that insulation currently in place saves 1.51 quadrillion Btu annually, or 37 day supply of gasoline for the entire United States. According to the study, if level of insulation in all U.S residential building were improved to meet the Model Energy Code, an additional 249.2 billion pounds or 125 million tones per year of carbon dioxide emissions could be avoided. This would, in turn, reduce total carbon dioxide emissions in the U.S. by nearly 30%. Additionally, improved insulation in the commercial building sector would reduce carbon dioxide emissions-36.12 billion pounds less or 18 million tons or another 4% reduction in total annual U.S. carbon dioxide emissions.(NAIMA,1996).

The European Insulation Manufactures Association (EURIMA), representing over 30 mineral fiber manufacturers in 16 European countries, has conducted a study of the European insulation industry's contribution to the solution of global warming. The report, entitled " Thermal Insulation Means Environmental Protection, found that:

- The EURIMA member countries account for approximately 3 billion of the 20 billion tons of CO_2 emitted in the world's atmosphere per year.
- Households and small businesses alone accounted for a quarter (737 million tons) of the 1987 CO_2 emissions in the countries under review.
- Depending on the climatic conditions in the individual countries, heating accounted for 60 to 80% of these emissions.
- As a result, there is an annual reduction potential of approximately 600 million tons of heating-related CO_2 emissions which could be

cut dramatically by the application of improved thermal insulation in the EURIMA countries (EURIMA, 1990).

Similarly, a report from Australia analyzed the potential impact on greenhouse gases from the use of more effective insulation of new and existing residential buildings. According to the Fiberglass and Rock wool Insulation Manufacturers Association of Australia (FARIMA), which represents all Australian mineral fiber manufacturers, the findings are significant. FARIMA found that a home insulation thermal performance standard would reduce energy lost through the wall by 20-30% and through the ceiling by 30-40%. In terms of pollution reduction potential, FARIMA states that, "the carbon dioxide emission savings from these homes would total 3.2 million tones a year within five years". It is important to keep in mind that this study looked only at residential homes in Australia. (FARIMA, 1996).

A study on the residential sector air conditioning load and electricity use in Hong Kong was done to estimate the energy saving from using two energy efficient measures, the use of tined glass to reduce solar heat and the application of Thermal Insulation to external walls to lower heat conduction. The building energy computer program DOE-2 was used to predict the electricity saving for the eleven year period from 1997 to 2007. It has been found that the electricity savings are small during the initial years, about 0.2% of the electricity use in the residential sector in 1997. However, as older buildings are replaced by newer ones with more energy efficient design features, the energy saving in subsequent year will have a bigger impact on the overall electricity use situation in the residential sector. (Lam, J.C, 2000)

Another study was done in Egypt on thermal insulation and computer simulation for housing energy analysis. Four types of apartment building housing units was analyzed using an energy computer program in hot-arid and hot-humid climate. The four apartments are constructed with the same building materials. These apartments are investigated as follows: without thermal insulation, with an insulated roof and then with insulated walls and compare the efficiencies of the four design alternatives. The study shows that the insulated hollow concrete blocks save about 70% of the total energy consumed in cooling and about 60% in heating than uninsulated ones. (Hanna, G.B., Horigome, T, Kimura, K, Takakur, Nishino, 1990).

Most buildings in the Gulf countries are not well insulated due to the absence of enforcement of such regulations and other standards from the regulating authorities side as well as the lack of appreciation of the attained energy saving and economic gains from the user side. Consequently buildings use more energy than necessary for their operation (Mohammed Al Homud, 2003).

Many studies have been conducted on energy conservation in buildings. For example, the University of Bahrain study was devoted to studying the potentials of energy conservation in building in Bahrain. It is covering; the potential saving of building's wall and roof insulation, reducing infiltration rate, glass type, and other measures related to building envelop. It has been conducted by using DOE-2.1 building energy simulation program. The study showed that, the energy conservation in building in Bahrain can save 1590 GWh/year (46%) of electric energy. Insulating external walls and roofs of 50% of the building in the country will save up to 380 GWh/year (30%) of total electric energy generated.

Another study, assess the energy conservation potentials and cost benefits was done by a master student for a range of different design strategies for Bahrain housing. The design strategies include use of different locally available building materials, use of insulation materials and variation of building orientation. The strategies are investigated by using PC-DOE program. The study showed that the energy performance of sand lime brick and block is better than, that of the wood construction commonly used in Bahrain and suggest the building main façade orientation to be in the north direction for the studied Standard house. Also, it emphasized the importance of the use of insulation materials in buildings and show that the pay pack period of the extruded polystyrene insulation is less than two years. (Al-Asfoor, Habib, 1987)

A parametric energy analysis on a detached single family house in hot-humid climate of Dahran, Saudi Arabia has been conducted also using DOE-2.1 building energy simulation program. The study showed potentials for reducing energy consumption in residential building if properly designed and operated. Parameters with the greatest impact are the glazing area, infiltration level, walls, and roof construction in addition to the behavioral parameter of thermostat settings. A reduction of as mush as 38% of the total annual energy use was reported from the study, considering the combined effect of the analyzed parameters (Said, S.A. and Abdurrahman, M.A.1989).

Other studies on envelope optimum thermal design of residential and office building in the hot and hot-humid climates of Saudi Arabia have been conducted. Annual energy saving of as much as 37 and 28% were achieved through the optimization of a small two-story residential building in the two climates of Riyadh and Jeddah, respectively. Various annual energy saving were achieved through envelope thermal design optimization of large, medium and small office building in the two climates. As much as 15,19, and 40 % of energy saving were achieved for the three office sizes in Riyadh, respectively, compared to 8, 12, and 24% for the same type of office in Jeddah (Al-Momoud, M.S. 1997).

Another study investigate the thermal performance of external insulation by evaluating both effect of mass and the effect of the type and thickness of insulation on the cooling and heating due to heat transmitted by the building envelope in the hot and arid climate. The study showed that, all rigid exterior insulation far better than the more flexible insulation and among the rigid insulation tested, the Extruded Polystyrene exhibited better impact resistance and the optimum thickness of the insulation is one inch (Al-Nafeez Ibrahim and Rogers Julie S, 1990).

A study was done to investigate the thermal insulation economic for Saudi residential buildings in different Saudi cities (Dahran, Riyadh, Jeddah and Khamis Mushait). It has been conducted by using DOE-2.1 building simulation program. The study showed the following:

1. In Saudi Arabia. walls require either same thickness or thicker insulation materials than roofs.
2. Riyadh city has the most economic benefits from using insulation materials, than Jeddah, Dhahran, and Khamis Mushait, respectively.
3. For walls, locating the insulation material on the interior has no economic or thermal difference from locating it on the exterior.
4. For roofs, locating the insulation material on the exterior is better from the economic point of view than locating it on the interior.
5. The change of discount rate has no effect on the relative performance of the insulation materials.
6. When insulating buildings, customers get significant annual savings ranging from SR 1000 to SR 1100.
7. The government will get higher savings ranging from SR 2500 to SR 1700. (Ahamed, Hadeel Noman, 1991)

Recently, a parametric energy analysis on single zone buildings with different internal load and different climatic locations in hot-arid climate (Riyadh) and hot-humid climate (Dahran), Saudi Arabia has been conducted using energy simulation analysis. The study was on the performance of building thermal insulation as a function of building type and location. It's showed that, the reduction in building annual energy due to the use of wall and roof thermal insulation ranges from 16.53-45.1% and reduction are less significant ranging from 19.6-37.65%. Building envelope thermal insulation has more significance in reducing the annual energy use and the peak cooling load for the hot-humid climate of Dhahran more than the hot-dry climate of Riyadh with increased level of thermal resistance (Al-Momoud, M.S. 2003).

To sum up, the proper use of building envelop thermal insulation not only reduce annual energy requirements but also produces lower peak loads and reduce HVAC equipment cost. In addition to that, positive environmental; impacts would also result from less reliance on the artificial heating and air-conditioning systems.

Finally, this study estimate the electrical energy saving due to using different thermal insulation material and thickness in Standard residential building in Bahrain and studying the effect of this conservation on the consumer, the national economy as well as the environment. Also it investigates the optimum thermal insulation thickness and best construction condition for roof and walls of the standard houses in Bahrain.

1.5 Research Methodology

I. Thermal Insulation Survey.

This involves the studying the different types of thermal insulation, which are used in Bahrain and studying the different methods of adding these types of insulation with roofs and walls in accordance with weather condition in Bahrain.

II. Computer Applications

The study was carried with the aid of computer simulation program named Energy10 to study the effect of using roof, wall insulation or both

in reducing the building cooling load and analyzing the simulation result to study the economic criteria of different types of insulation.

The Energy-10, building's energy simulation program is used to simulate the chosen buildings thermal behavior and energy consumption. The methodology of this program is well documented and is based on accepted ASHRAE method and formulated for thermal response analysis and fundamental principle of heat transfer. Energy-10 is the Windows based software. The software is designed to use on commercial, institutional and residential building with one or two thermal zones and of approximately 3,000 square meters (10,000 square feet) and under. It relies on a "whole building approach" and integrates daylighting, passive solar heating, and low energy cooling strategies with energy-efficient shell design and mechanical equipment.

Data Collection and Analysis

For each type of the building sample, we selected a base-case building. The overall description of each building is entered in to the simulation program. This involves the following:

1. Description of building geometry and details (i.e. wall and roof characters, orientation, etc).
2. Description of composition of wall, roof, (i.e. layers of various building materials and corresponding characteristic, wall color, etc).
3. Description of cooling/heating zone
4. Air-conditioning system specification.

Basic Meteorological data including Temperature, Rainfall, Daily Sunshine hours, Relative Humidity and Wind speed for Bahrain was selected from the Civil Defense Directorate Station at Bahrain Airport and was formatted according to the requirements of the energy simulation program.

Each base-case building with it description and operation condition will be analyzed by using Energy-10 simulation program. Also cost /benefit analysis will be used to analyzed the data based on market as well as electric energy price. An economical analyze will be done for different type of insulation materials and for optimum conservation measure (insulation both wall and roof).

1.6 Organization of Thesis.

The presentation of this Thesis is organized into the following main chapters:

Chapter Two
This chapter describes the building construction types in Bahrain, the natural features of Bahrain traditional houses, the present situation of the housing and the construction practices.

Chapter Three
This chapter discusses the important issues of the different types of thermal insulation materials and their thermal properties, fundamental and principle, selecting criteria, its application , insulation cost, effect of it on environment , the building code and insulation standard and regulation.

Chapter Four
This chapter describes the energy 10 software, its mission and vision, graphic output and its simulation results.

Chapter Five
This chapter describes the studied standard residential building (Zayed Town) and the reasons of choosing them.

Chapter Six
This chapter discusses the results of the simulation studies, analysis, comparative assessments of application of the thermal insulation to the standard houses and its effect on the cost and environmental saving.

Chapter Seven
This chapter presents the conclusion and the recommendation of the study.

A list of references and Appendices are also included.

CHAPTER TWO

2. Building Construction Types in Bahrain

Introduction.

Building have many purposes, it provides security for people and possessions against a potentially hostile outside world. The primary function of building is to shelter their inhabitants, to modify the outdoor weather and create an acceptable internal environment for living.

In the past, building modified climate principally through their sitting and external envelope against, rain wind and sun. Sometimes the traditional response to climate was a passive one. Shelter was sought from the adverse elements, whether cold or hot temperatures, or strong winds.

Every region all over the world, which can be said to have its own local architectural characteristics and historical background, contributed to the attainment of indoor comfort condition. However, human efforts have always been consistent towards establishing new designs aiming for better conditions in the future.

2.1 Traditional Old Houses

The oldest houses in Bahrain date only from the early nineteenth century, but their style of construction is thought to have developed three to four hundred years earlier. The style has certain general affinities with the architecture of the rest of Arabian Gulf area, but it is essentially unique to Bahrain.

Almost all houses found in traditional neighborhood are courtyard houses. The courtyard house was inherited from the pre-Islamic era and spread widely in throughout the Middle East and Mediterranean regions, becoming a self-contained entity in several different societies and cultures (Al-Hashimi, Khalid, 1996).

The courtyard is generally the central element of the house and provides an in ward oriented open space that offer security privacy and spiritual contact with the sky. The courtyard house, foremost, is an architectural concept that controls the environment by creating a domestic microclimate space within the house. The courtyard void serves as a light well and air well into which the cool dense night air sinks. In addition, it

has passive cooling capabilities that make them appropriate for the climate in this region.

Bahrain, located in a hot arid region, with high humidity, and little diurnal range has very hard and aggressive climate. The main purpose of the courtyard was to protect the inhabitant from the climate. Though it is humid, the clear sky condition at night helps to release part of the stored heat by radiation to the sky and by providing internal shade during the day to activate airflow in the house.

2.1.1 Construction Materials

Rubble and rough pieces of local stone, often combined with coral rock obtained from the sea, were the main building materials employed in early house construction. The latter is porous and does not hold the heat to the same extent as a denser material. The coral rock was quarried in thin slabs for use as partition wall. Wood was used to strengthen the structure whilst gypsum plaster was applied to bind and coat the wall. Typically, the houses were constructed around a central courtyard with rooms facing inwards.

The traditional houses were designed to create cool living condition. The type of construction seen in Bahrain is sometimes called "pier and panel" or frame and panel. It consists of solid rubble pillars strengthened by poles with horizontal tie beams providing further support to prevent the pillars deflecting. The intervals between the pillars provided space for shuttered windows, storage recesses or shelves. An alternative was to enclose these intervals with paneling.

The piers and tie beams formed a chquer-board of recesses, which were in filled according to taste. This took several characteristic forms. Frequently the lower level of apertures in the reception room was enclosed with unglazed windows, which were either barred on the exterior or screened by ornamental stucco or wood carving. Not only did this feature provide a decorative façade to the house but it also allowed the passage of light and air, but not direct sunlight.

2.1.2 Construction Methods

Originally, their were two types of residential construction methods. The first type of construction, the more common one, is a masonry-structured house. The size of the house is determined by the wealth and economical capabilities of the occupants. The walls of the house are usually thick, constructed from cut coral stone, plates of sediment stone and coral slabs from the sea (Froosh). Palm trunks and imported hard wood joists (Danchal) are used as roofing, and as structural reinforcement in the building. The first floor walls are constructed from thick piers with openable wooden panels in between.

The second type of construction is a lightweight structure built with available natural resources, using from palm leaves and ropes, without any nails. This type of structure is carried out by poor people, and often families are grouped around a courtyard. Different types of dwelling using this method, called "Barashti", "Areash" or "Kubar" are very primitive but are very efficient for the climate.

2.1.3 Roof Construction

Flat roofs are fairly conventional throughout the Arabian Gulf. However, the method of their construction incorporates some distinctive local variations. Wooden poles of tamarisk or mangrove, often treated with bitumen, were laid from wall to wall to provide a basic frame, which was covered with palm leaf matting. This was subsequently sealed externally with a larger of mud and pebbles. Internally ceilings were painted in decorative patterns with strong bright colours. Because of the absence of rain for most of the year, flat roofs were used for outdoor living during the night in summer, when the air temperature used to drop to within the comfort zone. see below Figure 2.1.3

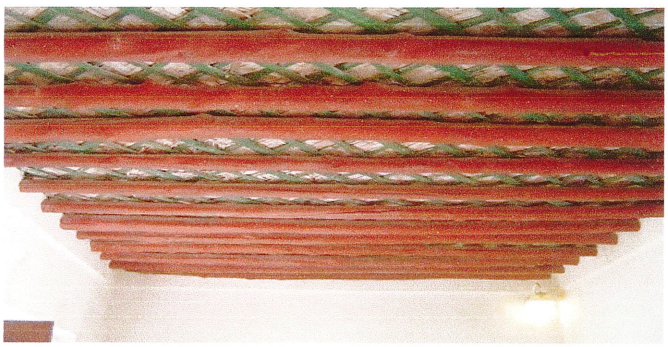


Fig.2.1.3 The bottom part of the roof.

Roof were constructed of 10 to 15 cm diameter wood poles called *dnachal*, a grid of bamboo sections called *basjiel*, a grass mat called *barie,* a layer of mud mixed with straw 15 to 20 cm thick, a layer of compact ash and a second layer of mud mixed with straw 15 to 20 cm thick.

2.1.4 Wall Construction

The houses were in general attached to each other to minimize the wall surface area exposed to the direct solar radiation rays. They were also protected from the street by thick windowless wall, which excluded solar radiation, unfavorable hot wind and dust from the insulated cooler interior. Light was admitted only through small windows, which mainly were openable on the courtyard, and the dark rooms that remained were meant for sleeping.

The old house wall were traditionally about 500mm thick, partly because the dried mud used in construction did not have a high strength and also because the thick walls gave better insulation against the summer heat. In order to provide outdoor facilities for inhabitants while ensuring the privacy which purdah dictated houses were built with a central courtyard. This gives the family a cool refuge when the heat of the day penetrated the fabric of the house.

2.1.5 Ventilation

The typical ventilation elements found in Bahraini traditional houses are wind tower, wall wind-catcher, wooden louver panels, perforated latticework and distributed openings.

During the old days, the wind towers and wind catchers were doing the job of today's air-conditioner in Bahrain. The parts of the Moslem world where wind towers and wind catchers were built fell within the hot dry humid tropics exposed either to land winds, which are light, dry and hot; or to sea breeze which are humid and strong.

2.1.5.1 Wind Tower

A wind tower is called "Badgir or Badger" they were designed to catch the breeze and funnel it into the spaces below.

The wind towers in Bahrain were built of thin coral slabs and plastered with gypsum. The plastered walls have the ability to absorb the humidity during the night, and to cool when in contact with wind during the day. The cool air becomes heavier and slides through the shaft, and the wind pressure differential of air movement create a pleasant breeze inside the house. This mechanism, which can also reverse, accelerates the air speed inside the room and helps to achieve heat exchange by the structure and by the people who use the space.
A cool chimney has an opposite effect, the hot air escape from the tower and allows the cool air to enter the house via door and windows. The wind tower efficiency varies according to the climate conditions during different times of the year.

A wind tower is provided with an openable-hinged panel, at the ground floor, to control its operation. Figure 2.1.5.1



Fig.2.1.5.1 Wind Tower.

2.1.5.2 Wall Wind –Catchers

Wall wind-catchers are another adequate method of achieving air movement in the warm humid climate. If the wind tower is considered a multi-directional ventilation device, the wind-catcher is a directional ventilation device. It supplies another source of ventilation, besides the ordinary windows.

Two types of wall wind-catchers were found in traditional house; the first applied in the rooms and the second applied on the parapet walls of the roof. Both construction methods are similar; they are made by filling the spaces between the structural pies with two parallel walls, with a gap in between. The gap left open in the case of parapet thin walls, whereas the gap is controlled by an openable wooden shutter in the case of a room.

2.1.5.3 Balcony Screens

A similar method is used with the wooden louver screens on the roof or balconies. The upward direction of the louvers allows the air to penetrate through the screen to the inside, but prevents the visual, exposure of the occupants. Decorative lattices work and perforated panels cover wind-escape outlets that take advantage of the stake effect phenomena, which generates air movement by convection inside the room if heat rises.

2.1.5.4 Windows

Windows sizes and location in the traditional wall elevation were not arbitrary, but thoughtfully chosen to allow convection cooling in the living space. Windows generally are not glazed and are provided with a double layer of wooden shutters set between the thick wall piers. Most of the rooms had adjustable shutters in the lower level as well in the higher level of windows facing the courtyard. Smaller windows facing outside and full size panel window are facing the courtyard full size panel window also normally found on the first floor.

2.2 The Present Housing Situation in Bahrain

House designs have moved away from the traditional thick-walled structure with small windows, built round a courtyard. The new houses and flats constructed of hollow concrete blocks with a more compact layout. Such dwellings are virtually untenable in summer without cooling.

2.2.1 Construction Methods

Most building in Bahrain, including residential, have been built with hollow concrete block with about 12mm thick sand/cement plaster on either side. The roof consists of either reinforced concrete slab (in-situ or pre-cast) or hard wood timber joist (with 75 mm thick concrete) water proofing material, covered with sand/cement screed and recently foamed concrete has been used to provide slopes of about 1% to shed rain water.

2.2.2 Roof Construction

Most of the old Bahraini houses and some of the lower income houses use wooden beam roofing called *Murabaa* due to its relatively low cost (Figure 2.2.2 (a)).

Modern buildings use either cast in site-reinforced slab or precasted type slab, hollow casted slab as well as insulated roof are being used in houses built by the Ministry of Houses and also recently in private villa. Figure 2.2.2 (b, c &d)

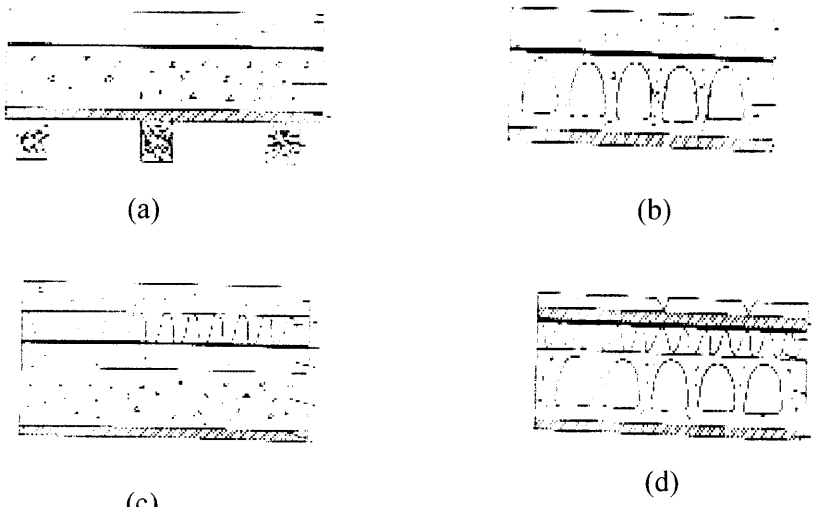


Fig.2.2.2 types of roof construction

2.2.3 Wall Construction

Most of the private residential buildings are constructed using the load bearing wall method. In the wall bearing technique, outside walls are commonly constructed from hollow concrete blocks, usually with 200mm thickness, covered on both sides with sand-cement plasters. (Figure 2.2.3 (a))

Some of the houses built by the Ministry of Housing are sandwich type precasted wall with 50mm polystyrene insulation.(Figure 2.2.3 (b,c &d).

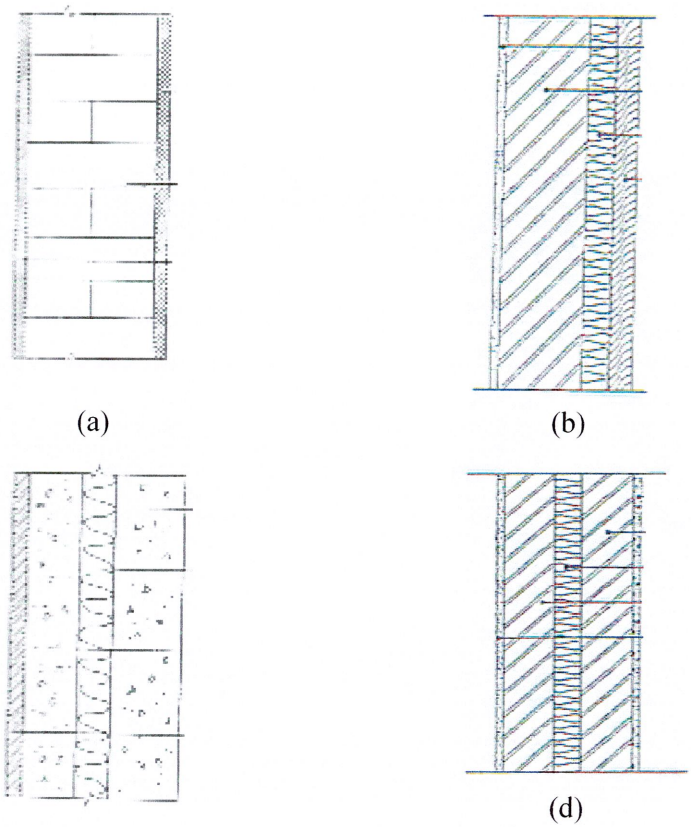


Fig.2.2.3 types of wall construction

2.2.4 Construction Materials

Concrete masonry blocks are manufactured locally by several Bahraini firms. They are manufactured in different sizes ranging from 4 inches to 10 inches (10-25 cm) thick. The produced blocks are either solid or hollow with different shapes for different applications. The materials used in the brick productions, are Portland cement, washed marine sand and local aggregate or Ras Al Khimah aggregate. Slotted blocks with polystyrene insulation imbedded in the slots are being manufactured by few firms as insulating brick.

2.3 Development of Modern Housing Projects

2.3.1 Isa Town

Official housing programs in Bahrain started decades ago. The main intent of the government at the beginning was to develop the existing residential settlements that were scattered around the country and adjacent to the main cities.

In 1963, the foundation for the first new housing town,"Isa Town" was laid on the middle of Bahrain Island toward the northeast. Isa Town contains 5650 housing units built on 498 hectares. The construction of the houses at that time was simple and the design were based on concepts of local traditional housing needs.

In 1975, the Ministry of Housing was established the new Ministry commenced immense construction programs in different rural and urban sites around the country. New imported building technologies and planning standard were applied mainly through international consultants and companies who were not very familiar with the site and society of the island. Some of them are:

2.3.2 Hamed Town

The rapid increase in housing demands and the scarcity of the existing urban land, led the Ministry of Housing to launch a second new town as a major housing project on the island in 1980, occupation of the first houses was in 1984.

Hamed Town is located in the middle of main Island facing the west coast. The town is designed around a longitudinal axis 9 km long with an average width of 2.5 km. It site about 12000 dewelling units and accommodate a population of approximately 60000 people.

2.3.3 Zayed Town

Zayed Town was directly managed by the office of the Crown Prince; it is a unique project in many ways. The objective of the Zayed Town project was to meet the growing demand for public housing in Bahrain. But from the very start, back in 1997, it was conceived that there was an opportunity to do something different and unique, so

rather than provide more standard public housing, at Zayed Town to create a showcase site for future public housing projects in Bahrain and the Gulf.

Phase one of this project was complete in July 2000 and it nearly 19 hectares and with a development budget of over BD 10 million (US 27 million), and its provide 273 two-storey semi-detached family town houses.

There are two different styles and sizes and all based on the (fareej concept) traditional Bahraini houses clustered round a common courtyard with a sitting, play area and linked to neighboring clusters.

The specification of these dewellings is also well above the normal for public housing.

The outside wall are commonly constructed with 200mm (8") thick hollow concrete blocks, covered from both sides with sand-cement plaster. The roof is flat and consists of a 150mm (6") thick pre-cast concrete slab covered with a water proofing membrane and 50mm (2") thick polystyrene foam insulation.

Window sizes are almost uniform regardless of the orientation and only the front faced are shade with protection to control the light.

In these modern units, an air-conditioning system is the only way to retain comfort in the hot summer season.

CHAPTER THREE

3. THERMAL INSULATION

3.1 Introduction

Thermal insulation is defined by ASHRAE 1989 as a material or assembly of materials used primarily to provide resistance to heat flow, thermal insulation is broadly classified as capacitive, resistive and reflective.

Thermal insulation reduces heat loss from buildings. It can be used in both new building and for retrofit in existing buildings, and is usually a low cost solution.
Adding insulation can have several benefits:

1. **Economy and energy conservation**

- Reduce the consumption of electrical energy during cooling periods inside the building and therefore reduces the environmental pollution
- Reduce the size of power plant required and the level of energy consumption, which helps to minimize the problems caused by excessive loads of generators and the distribution networks and reduce its initial cost.
- Help to reduce the cost of power consumption and electromechanical item's cost.
- Protects the building materials from the constant fluctuations in temperature.

2. **Health, aesthetics and safety**

- Reduce the environment pollution and the heat transmitted into the buildings.
- Thermally insulated buildings have less noise pollution from Airconditioners and chiller rooms as also from the noise penetrating from outside.

3. **Thermal comfort**

- Reduce the time to cool a room up.
- Protects furniture inside the buildings.

3.2 Insulation Fundamental and Principle

3.2.1 Heat-transfer Mechanisms

It is no secrete that a house will lose heat in winter and gain heat during the summer. Heat, or thermal energy, flow continuously through materials and space, taking the path of least resistance and flowing from the warmer surface to the colder surface (Richard, T.2001). Insulation attempts to keep thermal heat where it is wanted. To understand how thermal insulation work, it help to understand the three mechanisms of heat energy transfer; convection, conduction, and radiation.

Convection

Is the transfer of heat by physically moving the molecules from one place to another. Convection takes place when a fluid, such as gas or a liquid, is heated and moved from one place to another, when warm air in a room rises and forces the cooler air down, convection is taking place. For example, air, when heated, expands and rise. If this air movement is created mechanically by a floor register, fan, or the wind, it is called forced convection. When the sun heats the warm air and it rises, causing the cold air to settle free convection. Free convection also occurs when the sun shining through a window, heats the air inside a building.

Conduction

Is the process by which heat transfer take place in solid matter, such as the direct flow of heat through a material within a single or two different bodies in direct contact. Scientifically, it is the molecule- to –molecule transfer of kinetic energy. For example, it occurs when a person touches a sun-warmed window or when the handle of a poker gets warm after the other end has been placed in a fire for a few minutes.
Convection and conduction are functions of the roughness of surfaces, air movement, and the temperature difference between the air and surface. Mass insulations, because of their low densities, are designed to suppress conduction and convection across their sections by the entrapment of air molecules within their structure.

Radiation

Is the transference of heat from one body by radiant energy through space to another. This is evident the way the sun warms the surface of the earth, which involves the transfer of heat through electromagnetic waves and absorption of that energy by other surfaces. Inside home, surfaces may exchange heat with each other through radiation, which can have some impact on indoor ambient temperature. Heat energy from radiation is most relevant to home comfort in the summertime, however, when the roof and exterior wall absorb heat from the sun. This process is more critical in hot climates.

Radiant heat transfer between objects operates independently of air currents and is controlled by the character of the surface (emissivity) and the temperature difference between warm objects emitting radiation and cooler objects absorbing radiation.

Emittance (or emissivity) refers to the ability of a material's surface to emit radiant energy. All materials have emissivities ranging from zero to one. The lower the emittance of a material, the lower is the heat radiated from its surface (Richard, T.2001).

Reflectivity and emissivity are related, and a low emittance is indicative of a highly reflective surface.

3.3 Basic Forms of Thermal Insulation

3.3.1 Loose-Fill Insulation

Loose-fill insulation materials are distinguished from other insulation types by the size of the individual unit of material. Produced as shreds, granules, or nodules, loose-fill insulation products can either be poured or blown into place depending on the material or the construction application.

Loose-fill insulation material for paring application are most commonly sold in bags, where larger applications, such as attic installations, may require mechanical blowing equipment available from professional insulation installers.

Loose-fill insulation are well suited for places where it is difficult to install other types of insulation, such as irregularly shaped areas, around obstructions, and in hard to reach places.

Loose-fill insulation products can be installed in either enclosed cavities such as concrete block wall, wood frame walls when an additional barrier is installed, or unenclosed spaces such as attics. Blown-in loose-fill insulation is particularly useful for renovation and retrofit installation because it can be installed with minimal disturbance of existing interior or exterior finishes. Loose-file insulation materials that are modified with water-activated binders or adhesives and installed by pneumatic methods. The loose-fill materials such as cellulose, fiberglass, mineral wool (rock wool and slag wool), vermiculite, perlite, wood shavings and expanded polystyrene.

Some loose-fill insulations installed in attic cavities will lose some of their installed R-value over time because of setting, "Researchers say that it is possible, however, to install loose-fill insulation in wall cavities without settling if the cavity is completely filled with insulation at the proper density"

All loose-fill insulations are permeable to water vapor. Fiberglass and rock wool absorb less than 1 percent of their weight, whereas cellulose absorbs 5 to 20 percent of its weight. It is important to note that any insulation can absorb moisture if exposed to extremely high humidity.

While the debate continues as to the health effects of loose-fill insulations, it is important to be protected during any type of insulation

installation. A National Institute of Occupational safety and Health (NIOSH), approved respirator and protective eyewear and clothing such as goggles, gloves, long-sleeved shirts, and pants will minimize contact with the insulation. (Figure 3.3.1)

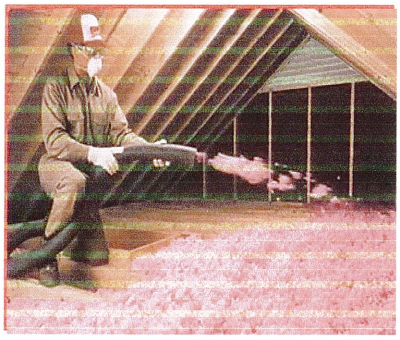




Fig.3.3.1Blowing loose fill insulation.

3.3.2 Blanket Insulation: Bats and Rolls

Blanket insulations are flexible, bound products made from mineral (glass, rock, and slag) or cotton fibers. They are available in widths suited to standard spacing of wall studs and attic or floor joists.

They come in rolls or bats in standard widths, usually to fit between framing on 16 or 24" centers. Continuous rolls can be hand-cut and trimmed to fit. Bats are available in a variety of precut lengths. Available with or without vapor retarder facings, the thickness and density of the insulation varies depending on the R-value desired.

Bats with a special flame-resistant facing are also available in various widths for applications such as basement walls where the insulation will be left exposed. Newer products on the market include plastic-wrapped bats and fiberglass bats encapsulated in non-woven fabric. (Figure 3.3.2)





Fig.3.3.2 Blanket insulation.

3.3.3 Sprayed-In-Place Insulation

Whether referred to as self-supported, wet-spray stabilized, spray-on,or dimensionally stable, sprayed-in-place insulations, are basically modified loose-fill product that are blown in to wall cavities or attics.

Cellulose, fiberglass, and rock wool are the most common materials used today. A special blowing machine that combines an adhesive, water, and the insulating materials sprays the mixture in to or over open wall and ceiling cavities. Sprayed-in-place insulation systems are especially advantageous when insulating irregular or out-of-square framed structures as well as walls with unusual interior geometry (such as cross-bracing, blocking).

Sprayed-in-place insulation adheres tightly to walls, framing members, and any other construction materials it may come in to contact with, when installed properly, sprayed–in-place insulation material to itself and to the application area. The adhesive is either a liquid that mixes with the insulation at the nozzle of the blowing machine or a power premixed in the insulation materials.

When applied correctly, this insulation resists settling and shifting and allows the cavity to be filled completely and by forming, a continuously uniform blanket throughout the wall cavity sprayed-in-place insulation allows no air gaps and provides very good resistance to air leakage, while not creating any inherent resistance to moisture transmission. Sprayed-in-place insulation is most practical for new construction or unfinished space such as basements with exposed studs.

Sprayed-in-place insulation in unfinished spaces needs time to dry before being enclosed or sheathed. The drying time for the insulation varies depending on the type of insulation material and its moisture content, the moisture content of framing members, and climate. Most products in use today require no more than 24 hours for drying.

R-value is important, but it is only one of the many factors that affect the actual performance of insulation as installed. Sprayed-in-place insulation of any form should not be relied on to prevent moisture movement within an insulated cavity. Generally, sprayed-in-place insulation systems including installation costs are usually more expensive than blanket insulation products. (Figure 3.3.3)



Fig.3.3.3 Sprayed-In-Place Insulation

3.3.4 Foamed-In-Place Insulation.

Foamed-in-place insulation materials have become popular in the commercial and residential building industry since the early 1970s (Richard, T.2001). Cost, thoroughness of installation, and air and vapor retarder properties all are to be considered when selecting a foamed-in-place insulation product.

Foams are classified as open-cell or closed-cell. In open-cell foams, the individual cell is interconnected. These insulation materials are of low density and flexible, with a rigidity similar to that of a sponge or sponge rubber.

In closed-cell foams, each cell is completely enclosed by a thin wall or membrane of plastic. These foams comprise the high-density, rigid foams like polyurethane foam. Closed–cell–foams also take longer to completely dry (cure).

Foamed-in-place materials require special equipment to meter, mix, and spray in to place. Installation of foamed-in-place insulation is always done by certified insulation installers. Foam system provides good air leakage control, moisture control, and sound control, in addition to providing thermal insulation. (Figure 3.3.4)



Fig.3.3.4 Foamed-In-Place Insulation

3.3.5 Rigid Board Insulation.

Rigid insulation is made from fibrous materials or cellular plastic foams and is pressed, extruded, or molded in to board like forms. Board products can provide both thermal and acoustical insulation, possess modest strength properties with low weight, and provide adequate coverage with few heat-loss paths when installed properly.

Rigid insulation boards also may be manufactured with various facers to enhance or protect certain physical properties. Even though rigid board products are typically more expensive than other types of insulating materials, they are used commonly in buildings where there are spaces limitations, where rigidity is critical to the application, or where higher R-values are necessary.

Rigid board insulation R-value can range from four to eight per inch of thickness depending on the composition and the method of aging. Board insulation products can be applied in a variety of locations, such as exterior sheathings applied over wall framing members, within wall cavities, in masonry veneer wall cavities, or behind an interior finish

material and a number of board insulation products are also used with low-slope construction, the most common types include cellular glass, glass fiber, mineral fiber, perlite, polyisocy-anurate, polystyrene (expanded and extruded), wood fiberboard, and composites.

Rigid insulation is also being used in innovative ways in new construction to create more energy-efficient homes. Many variables affect the installed thermal performance of rigid board insulation. These include the density of the foam. The blowing agent used to create the foam, the method of aging, the cellular structure, the durability of the material, the presence of dents and chips, the thickness and type of facer (if any) that is used, the thickness of the board, and conditions in which the foam is installed.

Rigid insulation can be used as an air infiltration retaeder when installed properly. With respect to moisture movement, special attention must be paid to the use of rigid board products on the exterior of a wall when a vapor retarder is already in places on the interior of the wall. Although rigid board insulation offers no food value to insects, it provides the potential for insects to easily tunnel from the ground to more desirable materials. (Figure 3.3.5)



Fig.3.3.5 Rigid Board Insulation

3.3.6 Radiant Barriers and Reflective Insulation.

Radiation, or more specifically, electromagnetic radiation, is energy that can be detected only when it interacts with matter. This is best exemplified by the warmth that is felt on a person's face when stepping out into the sun after standing under a shade tree. Although light is the name given to the type of electromagnetic radiation that can be seen, the

bulk of the earth's radiant electromagnetic spectrum. A barrier to limit the transfer of infrared radiation is commonly referred to as a *radiant barrier*.

In residential design applications, radiant barrier is a single sheet of reflective material positioned so that it faces an open space, such as an attic or wall cavity, generally more effective in hot climates than in cool climates, radiant barries often are used in buildings to reduce summer heat gain and winter heat loss. The radiant barrier itself provides no significant thermal resistance and must be installed in conjunction with airspace to be effective.

Reflective insulation is the use of radiant barriers in combination with other materials such as a system of reflective sheets and airspaces designed together to fill a cavity and act as insulation. Reflective insulation systems typically are fabricated from aluminum foils with a variety of backings such as Kraft paper, plastic film, polyethylene bubbles, or cardboard. The use of a reflective surface to intercept the flow of radiant energy is actually historical in origin.

The effectiveness of a radiant barrier is based on its ability to reflect the radiant that strikes it and at the same time not radiate energy. Radiant barrier materials must have high reflectivity (usually 0.9, or 90 percent, or more) and low emissivity (usually 0.1 or less) and must face an open airspace to perform properly. A radiant barrier by itself provides no thermal resistance; it must be installed in conjunction with an airspace.

The Department Of Energy (DOE) reported that, "radiant barriers tend to offer mush lower potential for energy saving in colder climates. Radiant barriers are more effective in blocking summer heat gain and saving air-conditioning costs" (Richard, T.2001).

Reflective insulation is a multilayer radiant barrier product with an intrinsic R-value. Comprised of layers of aluminum foil, paper, and/or polyethylene, the insulation creates reflective airspaces within the cavity, thereby reducing radiant heat transfer and heat flow by convection." The use of aluminum foil as a reflective insulation ensures a minimum 95 to 97 percent reflectance of long wave radiant heat" (Richard, T.2001).

Reflective insulation applications are similar to those of radiant barriers. Since most foil-faced reflective insulation products also retard vapor

transmission, special attention must be paid to vapor retarder placement in the wall, floor, or ceiling assembly. Trapping moisture between two vapor retarders can lead to condensation-related decay and damage. This can be problematic in attic floor insulation applications. (Figure 3.3.6)





Fig.3.3.6 Radiant Barriers and Reflective Insulation

3.4 Major Thermal Insulation Materials

The following is a survey of the characteristic and properties of major insulation material classified according to their origin.

3.4.1 Mineral Fiber

The term mineral fiber historically refers to rock wool and slag wool. These are also called Man-Made Vitreous Fibers (MMVFS). Mineral fibers are produced by extracting fibers from molten mineral substances such as rock, slag or glass.

Mineral fiber is available either in bats, blankets or granular loss fill. The best two examples, and the most commonly used ones, are fiberglass and rock wool.
Fiberglass is available either in loose-fill form, or in bat or blanket form, backed on one side, or faced on both sides by foil or paper. It is produced from molten glass spun in to fibers that are compressible and wool-like in appearance. The fibers, treated with oil and binders to suppress dust and maintain the material's shape. The fibers are sprayed with a binder, then cut into batts or blankets of various thickness.

The thermal resistance of mineral fiber is stable and has a relatively high R-value compared with other insulation materials. The thermal resistance (R-value) for fiberglass in batt form is about 3 to 3.5 ft^2 hr°F/Btu per inch thickness, its density is rather low being usually less than 1 lb/ft^3 while the R-value for fiberglass loose-fill insulation is 2.2 ft^2 hr°F/Btu per inch thickness at 75°F (24°C).

Both rock and slag wool are produced by similar manufacturing processes, the only difference lies in the raw material used, being natural rock in the former and steel, copper, or lead in the latter. The raw material is melted, when spun into fibers, the fibers are than sprayed with a phenolic resin, which acts as a binder, it is then compressed and cut to form batts. The fibers of rock and slag wool are not as resilient as those of glass, as a result of this, the product does not regain its designed thickness after being packaged, which results in a lower thermal resistance.

Rook wool batts and blowing wool are produced with densities in the range of 1.5 to 2.5 lb/ft^3 and reported unit thermal resistance (R-value) of 3.2 to 3.7ft^2 hr°F/Btu per inch thickness at 75°F for batts and 2.9 at 75°F for blowing wool.

Mineral fiber insulation looks, feels and performs much like fiberglass. It has the same benefits and drawbacks as fiberglass insulation. Since it does not melt or support combustion, it is a good material for insulating around chimneys.

3.4.2 Cellular Plastics

Cellular Plastics are usually foams with small closed cells containing entrapped gas. Four types of foams are commonly employed; Polythane, Polyisocanurate, and urea-based formaldehyde. The first three are available in board form, while the latter is usually foamed-in-place.

The thermal insulation property of cellular plastic depends on the nature of the enclosed gas, Fluorocarbon gas being the best available. "For cellular plastic foamed with Fluorocarbon gas, the thermal properties degrade after sometime because it is eventually replaced by air. All cellular plastic require fire protecting surfaces" (Richard, T.2001).

3.4.2.1 Polystyrene

Polystyrene a thermoplastic polymer is manufactured for building insulation by extrusion or molding. Polystyrene Foam is a polymer saturated with foam, which when heated becomes a compact, close-celled material, highly resistant to heat flow. Two methods are widely used for producing polystyrene foam, namely, extruded and expanded.

Expanded Polystyrene (EPs)

Formally called extruded expanded polystyrene (XEPs) foam board. It is created by the process of extrusion, which results in fine, closed cells that contain a mixture of air and refrigerant gas. The other manufacturing process is molding, which produces coarse, closed cells containing air. Molded expanded polystyrene (MEPs), can foam board, now called *expanded polystyrene (EPs)*, can be molded in to many everyday items such as coffee cups, coolers, protective cushioning for shipping materials, or insulation boards for construction applications.

EPs is used for a variety of building applications. These include cavity wall insulation, exterior insulation and finish systems, exterior sheathing, perimeter insulation, and under slab insulation. Low-slope roof application include flat or tapered roof insulation for built-up roof systems and ballasted, mechanically attached or fully adhered single-ply membrane roof systems. Specialty products also include cores for structural insulated panels and concrete masonry unit core insets.

EPs is a lightweight, strong, resilient, nun corrosive, dimensionally stable material that does not cause skin irritation. Typically expanded polystyrene has a lower R-value than extruded polystyrene because of its lower density and because it does not contain refrigent gas. EPs has a density of 0.8 lb/ft^3, the thermal conductivity lies within the range of 0.23 to 0.26 Btu/ ft^2 hr°F/per inch thickness. The R-value for expanded polystyrene is lower than for extruded polystyrene because of the mixture of air and fluorocarbon gas found in the cells of the latter, compared to the sole presence of air in the cells of the former.

EPs is water resistant, although the spaces between the foam beads can absorb water, when used as a sheathing, it is not considered a vapor barrier. Although EPs is affected by and possibly can deteriorate from contact with organic solvents, their vapors, and solvent-based adhesives, it can be used for specific low-slope roofing systems.

Most EPs products are actually 90% or more air, because it is only rigid foam of insulation that has never been made with CFCs, HCFCs, or hydro fluorocarbons (HFCs). During manufacture, polystyrene beads are expanded with pentane, a hydrocarbon that contributes to smog but is not implicated in ozone depletion or global warming. EPs is inert and nontoxic.

Extruded Polystyrene (XPs)

XPs is a homogeneous product consisting of fine, closed cells containing a mixture of air and an insulating gas also used in other industries as a refrigerant. Available brands of extruded polystyrene are easily recognized by their colors: blue, pink, green or yellow.

XPs is manufactured by pushing freshly expanded foam through an extrusion die. XPs is used for insulating foundations and concrete slabs, for residing underlayments, and for exterior wall sheathing, for protected membrane roof applications, and as the insulation for structural insulating panels and insulation concrete forms. XPs products can range in thickness from 1/2 to 3" and in board size of 2'*8'. 4'*8', and 4'*9' for a variety of sidewall, below-grade, and roofing applications.

Total R-values per board can range from 2.8 to 20 depending on board thickness. The R-value of XPs is R-5, regardless of density. XPs has a more consistent density, greater compressive and tensile strength than EPs polystyrene. Its density is in the range of 2 lb/ft^3 and its thermal conductivity is 0.12 Btu/ ft^2 hr°F/per inch thickness. Although XPs is more expensive than EPs, it has a higher R-value, lower water absorption levels, and a higher compressive strength than EPs.

XPs is also used for low-slope roofing system, XPs will deteriorate from contact with organic solvents and adhesives, and only low-temperature bitumens can be applied to the boards to protect the insulation.

XPs must be protected from sunlight because, overtime, ultraviolet (UV) light degrades it. The styrene used in polystyrene insulation is identified by the Environment Protection Agency (EPA) as possible carcinogen, mutagen, chronic toxin, and environmental toxin, the relatively small quantities as associated with building occupant exposure should not be a cause for concern.

Expanded and extruded polystyrene are available in sheets/boards varying in thickness from 1/2 to 19 inch, both products do not deteriorate with age. The foam board does not cause skin irritation, when board joints are properly sealed.

3.4.2.2 Polyurethane (PUR)

Is a foamy cellular plastic produced by a reaction between isocyanurates and polyols. During the reaction, the mixture expands, thus capturing fluorocarbon vapor, which is used as a blowing agent. Fluorocarbon gas is mainly responsible for the insulation properties of polyurethane foam as it has an extremely low value of thermal conductance.

The boards are usually double-faced with foil or sometimes come bonded with an interior or exterior finishing material. The boards must be protected from prolonged exposure to water and sunlight, and if used in an interior application, they must be covered with a fire-resistant thermal barrier material such as gypsum wallboard.

Rigid PUR foams will, when ignited, burn rapidly and produce intense heat and dense smokes and gases that are irritating, flammable, and/or toxic.

3.4.2.3 Polyisocyanurate (PIR)

Polyisocyanurate rigid insulation is actually a mixture of rigid PUR. Polyisocyanurate is basically made from isocyanates in the presence of a catalyst. PIR is a thermoset, closed-cell, rigid foam plastic insulation that is manufactured through a controlled chemical reaction. Liquid raw materials expand and are molded into boards, and facers are applied to the top and bottom surfaces. Facers provide strength, improve rigidity, enhance thermal performance, and help limit thermal drift.

PIR foam board rigid insulation has the highest R-vale of any common insulation material and not recommended for below-grade applications.

PIR board insulation is also a cost-effective roof insulation product because it is approved for installation directly to the steel roof deck without the need for a thermal barrier.

"Although not as critical to residential applications, PIR is stable over a large temperature rang (-100 to +250°F). PIR with glass fiber or organic felt facers will lose thermal resistance over time, which must be taken into account when designing the roofing system" (Richard, T.2001).

It is more expensive than most other types of insulation PIR boards must be protected from prolonged exposure to sunlight or water, and when they are used in an interior application, a fire-resistant covering generally is required. PIR foams have a density rang 2 to 4 lb/ft^3, and thermal conductivity of 0.11 to 0.15 Btu/ ft^2 hr°F/per inch thickness at 75°F and a thermal resistance of approximately 7 ft^2 hr°F/ Btu per inch thickness.

3.4.2.4 Urea-based Formaldehyde

Urea-based formaldehyde is available only as a spray-in-place material. It is manufactured on site by mixing a urea formaldehyde based resin with a solution of a foaming agent containing an acid catalyst together with compressed air. The density of urea-based formaldehyde is 0.7 to 0.8 lb/ft^3, and its R-value is 4.2 ft^2 hr°F/ Btu per inch thickness.

Urea-formaldehyde foam may produce strong odours if improperly mixed or applied. "It has also been reported that it shrinks linearly from 1 to 9 % " (Bahrain University, 1995).

3.4.3 Cellulose Insulation

The production of cellulose insulation is a relatively simple process, is made from finely shredded newsprint that is chemically treated to resist fire, corrosive, vermin and fungal growth. It contains at least 70 percent post-consumer paper waste.
Only available in loose-fill form, it is either poured in place or installed with a blower, because of the small size of particles, cellulose can flow around abstractions such as nails, electrical wires, trusses and braces to fill cavities uniformly.

The density of cellulose insulation is in range of 2.2 to 3 lb/ft^3, the R-value range is 3.7 to 3.2 ft^2 hr°F/ Btu per inch thickness.

One drawback of insulating with cellulose is that it can settle overtime if the insulation is not blown or poured to manufacture's recommended density.

3.4.3.1 Perlite

Perlite is a granular-type loose-fill insulation. It is a naturally occurring siliceous rock. Perlite is different from other volcanic glasses because when the crushed ore is heated to a suitable point in its softening range, it expands from 4 to 20 times its original volume. This expansion is attributed to the presence of water, between 2 and 6 percent, in the crude perlite rock. After expansion, an air blast separates and grades the particles a according to size.

This expansion process account for the lightweight quality of expanded perlite. Perlite is used widely as a loose-fill insulation in masonry construction. In this application, perlite is poured into the cavities of concrete block, where it completely fills all cores, crevices, mortar area, and ear holes.

Expanded perlite can be manufactured to weight as little as 2 lb/ft^3, making it adaptable for numerous application. In addition to providing thermal insulation, perlite is fire-resistant, has lower water absorption, reduces noise transmission, and is resistant to rot, vermin, and termites. Perlite loose-fill insulation is packaged in bags and must be poured into place. It is not suitable for blow-in installation methods. It is best used for attics and is reasonably well suited for wall.

3.4.3.2 Vermiculite

Vermiculite is a laminated mineral containing silica, magnesium dioxide, aluminum oxides, and other minerals. Vermiculite expands when heated to form lightweight material with insulating properties. There are two types of vermiculite: untreated and treated.

The treated materials are coated with asphalt to make it water-repellent for use in high-moisture area. Untreated vermiculite absorbs water and, once wet, dries very slowly. Untreated vermiculite has an R-value of 2.3 per inch, compared with an R-value of 2.5 per inch for treated material.

Vermiculite is usually hand-installed, is nonabrasive, pours easily into irregular spaces, and is suitable for both horizontal and vertical applications. It is noncombustible, odorless, resistant to vermin and nonirritating.

3.4.3.3 Low-Density Concretes

Low-density concrete are produced by mixing cement with water and a suitable aggregate. The aggregate material being either vermiculite or perlite to improve the thermal resistance properties of concrete. Anther method for producing low-density concrete is by foaming a Portland cement mixture. The foaming process required the addition of a foaming a Portland cement mixture. The foaming process requires the addition occurs evolving a gas, hence resulting in a close-celled porous material with superior thermal properties.

The density of insulating concrete covers a wide range from 12 to 88 lb/ft^3. The thermal resistance decrease sharply with increasing density. The thermal conductivity of insulating concrete increases with an increase in moisture content.

Low-density concrete is non-combustible and is highly resistant to water penetration and is mainly applied in roof systems and decks.

3.4.4 Reflective Surfaces

Reflective materials are different from other insulating materials in the method of reducing the flow of heat, which is accomplished mainly by reflecting the incident infrared radiation rather than by reducing the conduction of thermal energy as the other, conventional thermal insulation materials do. The most commonly used reflective insulation material is aluminum foil.

3.4.4.1 Aluminum Foil

The most common reflective insulation products are foil-faced polyethylene sheets, which consist of layers of aluminum foil separated by polyethylene bubbles. It can be employed either as a single sheet or as multiple of foil that can be used together with Kraft paper in combination with an air space.

These products are non-carcinogenic, water-resistant, fungus-resistant, lightweight, easy to install with staple gun and can be cut using a utility knife.

The sizes available vary based on specific products. Rolls are usually available in width of up to 6 ft and length up to 125 ft. the R-value of an aluminum foil varies greatly depending the material directly adjacent to it. See table 3.5

3.5 Selection Criteria of Thermal Insulation Materials

The selection of any type of thermal insulation material depends upon certain criteria, involving a compromise between the following:

1. Thermal conductivity and thickness.
2. Degree of combustibility.
3. Compressive strength.
4. Water absorptivity.
5. Vapor permeability.
6. Dimensional stability
7. Ease of handling.
8. Cost
9. Age predicted
10. Decay edibility (by fungus or termites)
11. Applicability.

3.6 Specifications of Thermal Insulation Materials

For a material to be totally effective as a thermal insulator, it should however have the following characteristics:

1. To be of homogeneous structure.
2. To be water, humidity and vapor proof.
3. To be of a durable high insulation efficiency.
4. To be of a good mechanical ability.
5. To be corrosion and prevailing environmental circumstance resistant.
6. To have fixed dimensions with low expansion and shrinkage ability.
7. To be thermal shock resistant and capable of bearing swift diversity of the temperature under which they exist without sustaining a physical drainage.
8. To be fire retardant in wall and to be fire resistant if installed in a manner that directly exposes it to fire.

9. To be fungi resistant and not suitable for bacteria, pest or insect growth.
10. To be resistant to chemical reactions or change.

3.7 Installation of Thermal Insulation Materials

The following terms and conditions shall be observed in the preparation and installation of the thermal insulation materials:

1. To cover the roof insulation materials from both sides and to place a barrier on the top side and a water proof barrier on the bottom side.
2. To store the insulation materials in dry covered places, and to preserve them from breakage.
3. To cover the external wall insulation materials with a vapor retardant.
4. To take due precaution in the storage of insulation materials in order to avoid breakage of the same during building work or installation.
5. To ensure that all the insulation material surfaces are dust and grease free before using them.
6. To install insulation materials with good thermal capacity in the internal side of walls and roofs, and to install a layer of light insulation material in the middle in order to get the best results of thermal insulation.
7. The bottom concrete layer must be completely dry before placing the insulation material panels on it.
8. In case of using the insulation layer in wall cavities, the cavities must be sealed against air leakage.

3.8 Properties of Thermal Insulation Materials:

Any insulation material may be or is produced in different forms, sizes and densities depending on the differences in the sources of raw materials, production processes of the different manufacturers and the additives used in the manufacturing process. This naturally results in significant variations in the properties and features of each product. Therefore, it is not sufficient to state the name of the insulation material, but one should also specify the properties of such material, such as the compressive strength, density, thermal conductivity etc. The most important property of an insulation material is its ability to resist the transfer of heat through its medium, and this is called thermal resistance. This property is dependent not just on the type of the insulation material,

but also on the size of the cells comprising the material, which can be controlled during the manufacturing process.

Insulation materials used in constructions can be evaluated according to the following properties:

1. Thermal Resistance (m^2k/W):

This is a measure of the ability of the material to limit the amount of heat transferred through it. The higher the value of the thermal resistance of a material the more efficient it is in thermal insulation, i.e. it will provide a higher level of insulation.

2. Compressive Strength (N/mm^2):

It is the ability of the insulation material to withstand loads placed upon it without disintegrating; neither shall it be squeezed or deformed. Since the insulation materials are integral parts of the wall or ceiling, they will certainly be subject to having loads or stresses placed upon them.

3. Density (Kg/m^3):

It is a property of building materials that influences thermal insulation. It is inversely proportional to the thermal insulation, i.e the lower the density the higher the thermal efficiency of the material. Humidity is one of the main factors that affect insulation because materials that have low densities are highly absorptive of water. Therefore, good care should be taken when it is used,

4. Durability:

Since the insulation materials are integral parts of the building, and buildings are expected to live for long periods of time that can exceed 25 years, the insulation material should be able to retain its thermal properties such as density, thickness, form and other properties as long as the building exists. It is unreasonable to expect to change the insulation material every few years because it disintegrated or lost its main properties.

5. Moisture Resistance:

The insulation material should be able to resist the penetration of moisture or water into its inside layers because absorbed water facilitates the transfer of heat and thus the material loses its thermal insulation value.

6. Fire Resistance:

It is essential that the insulation material have good fire resistance properties in term of incombustibility when subjected to high temperatures or direct flames. In case of fire, the insulation material should help prevent the spread of flames to other parts of the building.

7. Health and Safety:

Since the insulation material is part of the building, it is possible that the occupants of the building will get near to it from time to time. Therefore, the insulation material should be safe to touch whether during the manufacturing process, packaging, installation or use. It should not produce toxic gasses with the passage of time or when subjected to flames or sunlight and should, also, resist the growth of pests or fungi.

8. Ease of Installation:

Ease of installation means less work force is required when installing the material, because the installation probably may not require highly specialised skilled labour.

9. Cost:

This aspect is usually taken into account when purchasing the insulation material. However, insulation materials are not compared to each other based on price because the price depends on other factors such as size or thickness. Comparison of insulation materials is based on the level of the resistance to the transfer of heat that they provide.

10. Availability in the Local Market:

Although it is not a property of the insulation material, the availability of the material in the local market influences the decision to buy such material for use in the insulation of buildings.

The main purpose of using insulation materials in building is to minimize the transfer of heat through the walls and ceiling of the building. Since the amount of heat so transferred is inversely proportional to the thermal resistance of the insulation material, special attention should be paid to this aspect, in addition to other important properties such as thermal diffusion and the factors that influence the efficiency of the insulation material.

3.9 Insulation Applications

3.9.1 Location

Insulation is not just for roofs and outside walls. Many areas of a home that are often overlooked include ceiling with unheated spaces above including dormer ceilings, knee wall of attic spaces finished as living areas, sloped walls and ceilings, perimeter around slabs, floors above vented crawl spaces, floor over unheated or open spaces such as over garages or porches, basement walls, band and header joists, floor over unconditioned basements, soffits below cantilevered second floor rooms, knee wall of closets in "bonus" rooms and even areas where acoustical dampening is required such as laundry room or bathrooms.(Figure 3.9)

Gaps and voids are areas where insulation should be installed, thereby causing conductive and convective heat loss. A gap is a place where the insulation does not come all the way to the edge of the space to be insulated.

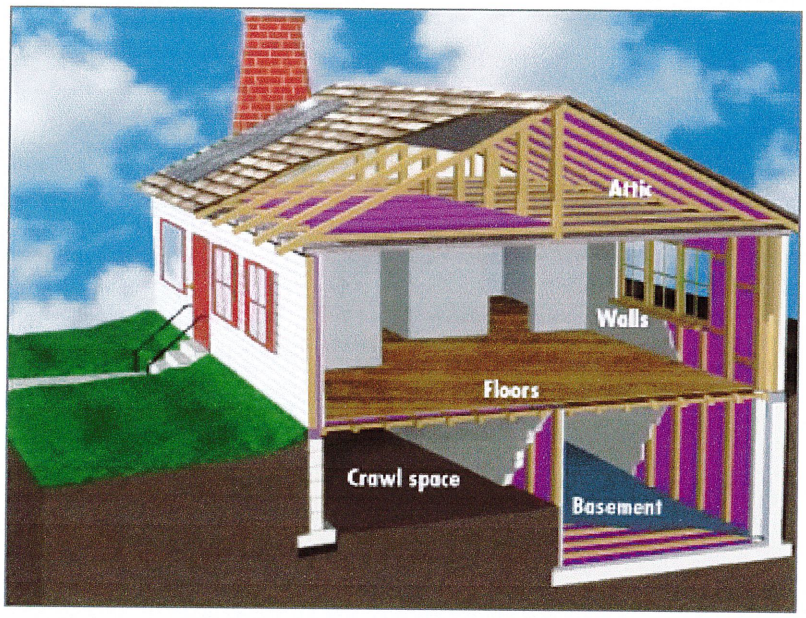


Fig.3.9 Insulation application at home

3.9.2 Positioning of Thermal Insulation Layers

Under steady temperature difference conditions, it would seem to be immaterial whether insulation materials are placed on the inside, in the middle or on the outside of walls, floors and roofs. Each system of positioning insulation materials has its advantages and disadvantages.

3.9.2.1 Thermal Insulation Placed on the Outside of Wall

This method is popular for the insulation of existing buildings where there is no cavity or where it is impracticable to fill the cavity. The method could be applied by positioning of a composite expanded polystyrene on the outside, using various ways of creating a cavity between the external insulation and the old building surface. This method is good in extending the life of old buildings and improving internal conditions to accord with present-day needs. Additional advantages are that there is no need to disturb either the building fabric or internal decorations.

3.9.2.2Thermal Insulation Placed Sandwiched Between Other Building

Is probably the most widely used method of thermal insulation. It has the advantage that the thermal insulation material need not have any particularly high compressive or other strength, as it is protected against both atmospheric attack and damage from the inside of the building.

3.9.2.3 Thermal Insulation Materials Placed on the Inside

The advantage of insulating the inside is that the room cools down very quickly because the thermal storage capacity of the insulation materials is small. Interior installation of insulating materials can be a fire hazard and produce toxic gases in a fire, it is therefore necessary to choose carefully the internal insulation materials.

3.10 Insulation Economics

When confronted with an opportunity to insulate a building or mechanical system, two very basic but important questions are likely to be asked: What will insulation cost? How much money will the insulation save? The answer to these questions depends on exactly how much insulation is added. As it turns out, some thickness of insulation will be the economic optimum for any given application and will result in the lowest summation of both energy and insulation cost.

3.10.1 Economic Analysis

The primary function of insulation is to reduce the loss of energy from a surface operating at a temperature other than ambient. The economic use of insulation

- Reduce plant-operating expenditures for fuel, power, etc.
- Improves process efficiency
- Increases system output capacity or may reduce the required capital cost.

There are two costs associated with the insulation type chosen. For any given thickness, there is

1. A cost for the insulation itself;
2. A cost for the energy lost through this thickness.

The total cost for a given period is the sum of both costs.

The optimum economic thickness is that which provides the most cost effective solution for insulating and is determined when total costs are a minimum. Since the solution calls for the sum of the lost energy and insulation investment costs, both costs must be compared in similar terms. Either the cost of insulation must be estimated for each year and compared to the average annual cost of lost energy over the expected life

of the insulation, or the cost of the expected energy loss each year must be expressed in present dollars and compared with the total cost of the insulation investment.

3.10.2 Cost of Lost Energy

Rate of energy transfer through the insulation, the cost or value affixed to that energy, and the operational hours per year determine the cost of lost energy per annum. The rate of the energy transfer is a function of the following:

1. The temperature difference across the insulation,
2. The thermal conductivity,
3. The thickness,
4. The thermal resistance of the external surface of the insulation.

The value of energy in a system is directly related to the end use of that energy.

The cost of purchasing or producing energy includes

1. Fuel or power costs,
2. Capital equipment costs,
3. Operating and maintenance expenditures.

Fuel or power costs have the greatest effect upon the dollar value of energy. The efficiency with these fuels are converted into process heat affects the value assigned to energy in a process. The energy conversion efficiency or coefficient of performance of the equipment must be considered. Since fuel and power costs will most likely change with time, the average cost of each over the life of the insulation project is used rather than today's costs.

The energy being conserved because of insulation requires capital equipment for its production. The capital cost of the energy plant must, therefore, be assigned to the dollar cost of energy. This cost is estimated per annum considering the plant depreciation period, the average annual energy production and the cost of money.

3.10.3 Cost of Insulation

The cost of insulation is the sum of the annual insulation investment cost and the yearly insulation maintenance expense. The initial cost of the insulation system is prorated over the chosen project life using the appropriate cost of money or required rate of return on the last increment of insulation applied.

The period over which the insulation investment cost is considered is a factor in selecting the economic thickness. If the chosen period is short, the annual insulation cost will be high, the economic thickness will be small, and the insulation system will not provide the lowest total annual cost over the service life of the insulation. It is therefore recommended that the insulation service life be used for the project period if user project payout periods do not otherwise dictate.

3.10.4 Life Cycle Costing (LCC)

Life cycle cost analysis (LCCA) is an economic evolution technique that determines the total cost of owning and operating a facility over period of time. The objective of LCC analysis is to choose the most-effective approach from series of alternatives so the least long-term cost of ownership is achieved.

Life cost cycle (LCC) analysis helps engineers justify equipment and process selection based on total costs rather than the initial purchase price of equipment or projects. LCC provides best result when both art and science are merged together with good judgment.

Life cost cycle analysis (LCCA) can be performed on large and small buildings or on isolated building system. Many building owners apply the principle of LCCA indecisions they make regarding construction or improvements to a facility.

The LCC analysis consists of finding the present worth of any expense expected to occur over the reasonable life of the system. To be included in the LCC analysis, any item must be assigned a cost, even though there are considerations to which a monetary value is not easily attached. For instance, the cost of a gallon of diesel fuel may be known; the cost of storing the fuel at the site may be estimated with reasonable confidence; but, the cost of pollution caused by the generator may require an educated

guess. Also, the competing power systems will differ in performance and reliability. To obtain a good comparison, the reliability and performance must be the same. This can be done by upgrading the design of the least reliable system to match the power availability of the best. In some cases, you may have to include the cost of redundant components to make the reliability of the two systems equal. For instance, if it takes one month to completely rebuild a diesel generator, you should include the cost of a replacement unit in the LCC calculation. A meaningful LCC comparison can only be made if each system can perform the same work with the same reliability.

LCC Calculation

The life-cycle cost of a project can be calculated using the formula:

$$\mathbf{LCC = C + M_{pw} + E_{pw} + R_{pw} - S_{pw}}$$

where the pw subscript indicates the present worth of each factor.

- The capital cost (C) of a project includes the initial capital expense for equipment, the system design, engineering, and installation. This cost is always considered as a single payment occurring in the initial year of the project, regardless of how the project is financed.
- Maintenance (M) is the sum of all yearly scheduled operation and maintenance (O&M) costs. Fuel or equipment replacement costs are not included. O&M costs include such items as an operator's salary, inspections, insurance, property tax, and all scheduled maintenance.
- The energy cost (E) of a system is the sum of the yearly fuel cost. Energy cost is calculated separately from operation and maintenance costs, so that differential fuel inflation rates may be used.
- Replacement cost (R) is the sum of all repair and equipment replacement cost anticipated over the lifetime of the system. The replacement of a battery is a good example of such a cost that may occur once or twice during the life of a PV system. Normally, these costs occur in specific years and the entire cost is included in those years.
- The salvage value (S) of a system is its net worth in the final year of the life-cycle period. It is common practice to assign a salvage value of 20 percent of original cost for mechanical equipment that can be moved. This rate can be modified depending on other factors such as obsolescence and condition of equipment.

Future costs must be discounted because of the time value of money. One dollar received today is worth more than the promise of $1 next year, because the $1 today can be invested and earn interest. Future sums of money must also be discounted because of the inherent risk of future events not occurring as planned. Several factors should be considered when the period for an LCC analysis is chosen.

The discount rate selected for an LCC analysis has a large effect on the final results. It should reflect the potential earnings rate of the system owner. Whether the owner is a national government, small village, or an individual, money spent on a project could have been invested elsewhere and earned a certain rate of return. The nominal investment rate, however, is not an investor's real rate of return on money invested. Inflation, the tendency of prices to rise over time, will make future earnings worth less. Thus, inflation must be subtracted from an investor's nominal rate of return to get the net discount rate (or real opportunity cost of capital).

Different discount rates can be used for different commodities. For instance, fuel prices may be expected to rise faster than general inflation. In this case, a lower discount rate would be used when dealing with future fuel costs.

Formulas

1. The formula for the single present worth (P) of a future sum of money (F) in a given year (N) at a given discount rate (I) is

$$P = F/(1 + I)^{N}.$$

2. The formula for the uniform present worth (P) of an annual sum (A) received over a period of years (N) at a given discount rate (I) is

$$P = A[1 - (1 + I)^{-N}]/I.$$

3. The formula for the modified uniform present worth of an annual sum (A) that escalates at a rate (E) over a period of years (N) at a given discount rate (I) is

$$P = A\{(1+E)/(I-E) *[1 - [(1+E)/(1+I)]^{N}]\}$$

4. The formula for the annual payment (A) on a loan whose principal is (P) at an interest rate (I) for a given period of years (N) is

$$A = P\{I/[1 - (1 + I)^{-N}]\}.$$

3.11 Insulation And Environment

Decisions about insulation are among the most important we will make relative to the environmental impact of buildings. Because insulation reduces the energy consumption, it provides ongoing environmental benefits throughout a building's life. However, not all insulation materials are equal environmentally.

The raw materials used to produce insulation vary widely, ranging from the sand used in fiberglass to the petrochemicals in foam plastic insulation and the old newspaper in cellulose insulation. Environmental concerns with raw material acquisition include, on the negative side, depletion of limited resources and pollution resulting from mining. On the positive side is the recycled content of many common insulation materials.

The most obvious resource limitation among materials used to produce insulation is the availability of fossil fuels used in foam plastic insulation. Polystyrene is produced from ethylene, a natural gas component, and benzene, which is derived from petroleum. Polyisocyanurate and polyurethane are made from polymeric methylene Diioscyanate and polyol, both of which are derived from petroleum. While fossil fuels are not going to run out any time soon, the reserves are finite, and as they dwindle in the next century, costs are likely to rise.

While other insulation materials are not made from petrochemical feed stocks, most require fossil fuel energy for mining, manufacture, and transport, so they lead indirectly to fossil fuel depletion).

Another raw material that is potentially in short supply is the boron used in fiberglass insulation and as a fire retardant in some cellulose insulation. Fiberglass insulation is the number one end-use of boron, most of which comes from two primary deposits: the largest in the southwestern U.S. and Turkey. Boron improves the flexibility of fiberglass and the energy

efficiency of manufacture. Fiberglass insulation is approximately 6-8% boron oxide (B2O3) by weight.

Environmental impacts from raw material acquisition include air pollution, water pollution, and erosion from mining of minerals (for example, sand and limestone used in fiberglass, diabase rock used in rock wool, and bauxite for the aluminum used in foil facings and radiant barriers).

Often these environmental impacts are multi-tiered. For example, mining usually produces tailings waste, which results in runoff with high levels of suspended solids, which increases turbidity in surface waters, which can cause deoxygenation of those waters, which in turn can kill fish. Pollution from oil spills and well-head leaks occurs when extracting and transporting the fossil fuels used to make plastic foam. The same fuels provide the energy for mining and other resource extraction.

3.11.1 Recycling

Recycled content is the most recognized environmental feature of building products. Materials with recycled content have three advantages:

1) They require less natural resource;
2) They divert materials from the solid waste stream; and
3) They use less energy during manufacturing.

The insulation industry is full of good examples of recycled material use. Considerable use of recycled materials in producing insulation has been driven to some extent by the U.S.

A number of examples of insulation materials with recycled content are as follow:

Cellulose

Cellulose is perhaps the best example of recycled material use in insulation. Most cellulose insulation is approximately 80% post-consumer recycled newspaper by weight; the rest is comprised of fire retardant chemicals and--in some products--acrylic binders. The cellulose industry used approximately 840 million pounds (381 million kg) of recycled

newspaper in 1994, according to Dan Lea of the Cellulose Insulation Manufacturers Association (CIMA).

New cellulose insulation technologies are helping that recycled newspaper go further. There is increasing use of lower-density cellulose produced by "fiberizing" the newspaper (breaking it down into individual fibers that are fluffier). The industry is switching to this process from the older hammermill process because it results in a better product--cleaner, less dust, slightly higher R-value--and, most important, because it stretches the resource base. More manufacturers are offering *stabilized* cellulose to prevent settling of loose-fill attic insulation.

Mineral Wool

While mineral wool was at one time the most common type of insulation, its market share was largely lost to fiberglass in the 1960s and 1970s. In the past few years, however, the product appears to have begun a comeback. There are currently several manufacturers of mineral wool in the U.S. and about eight plants that produce it.

"Mineral wool" actually refers to two different materials: slag wool and rock wool. Slag wool is produced primarily from iron ore blast furnace slag, an industrial waste product. Rock wool is produced from natural rocks, such as basalt and diabase. Slag wool accounts for roughly 80% of the mineral wool industry, compared with 20% for rock wool. Given the relative use of these two materials, mineral wool has, on average, 75% post-industrial recycled content. According to the North American Insulation Manufacturers Association, over 938 million pounds (425 million kg) of blast furnace slag were used in 1992 to produce slag wool.

Fiberglass

All fiberglass insulation manufacturers use at least 20% recycled glass cullet in their insulation products to comply with the EPA recycled-content procurement guidelines. Fiberglass is certified by Scientific Certification Systems (SCS) to contain 25% recycled glass (18% post-consumer bottles and 7% post-industrial cullet) and they have most actively promoted that environmental benefit.

Recycled glass content in excess of 90% is feasible. Each percent of glass cullet (over 10%) substituted for raw sand reduces energy use by about 1% .

Polystyrene

Recycled plastic resin is used in some extruded and expanded polystyrene. Expanded polystyrene (EPS) can also be made out of recycled polystyrene. The simplest recycling involves crumbling the old EPS into small pieces and re-molding them into usable shapes. Any polystyrene can be recycled into building insulation, but because of fire retardants, old building insulation cannot usually be recycled into non-building applications.

Polyisocyanurate

The polyisocyanurate foam insulation industry also uses recycled material in its products. The Polyisocyanurate Insulation Manufacturers Association (PIMA) says that almost all products today meet the EPA procurement guidelines for federally funded buildings, which call for a minimum 9% recycled content. Rather than using recycled foam, however, manufacturers buy polyol chemical components with recycled content. The industry is one of the largest markets for mixed-color recycled PET beverage containers, which have traditionally been difficult to recycle. In addition to the raw chemicals having recycled content, the foil facings used on polyiso are typically 70-80% recycled aluminum.

Radiant Barriers

Like foil facings on polyisocyanurate insulation, the aluminum used in radiant barriers is also mostly recycled. At least one radiant barrier insulation material, Low-E Insulation(TM), made by Environmentally Safe Products, Inc. of New Oxford, Pennsylvania, also uses recycled plastic in the foam core.

3.11.2 Pollution

Nearly all manufacturing processes generate pollution. So, too, with insulation. Much of the pollution generated by insulation production is a result of energy use (generally fossil fuel combustion).With some insulation materials, there are industrial processes that result in non-energy-related pollution. To manufacture isocyanate, a precursor of

polyisocyanurate and polyurethane insulation, two chlorine-based chemical intermediates are used: phosgene and propylene chlorohydrin. Citing pollution problems, a number of environmental groups, including Greenpeace, are calling for the phase-out of certain industrial uses of chlorine .

The styrene used in polystyrene insulation is identified by EPA as a possible carcinogen, mutagen, chronic toxin, and environmental toxin. Further, it is produced from benzene, another chemical with both environmental and health concerns.

Most fiberglass insulation is produced using a phenol formaldehyde (PF) binder to hold the fibers together. Though exact quantities of binder used in manufacture of fiberglass are not disclosed by industry. A new type of fiberglass-Miraflex (TM)--that does not require a binder is being introduced in the market, because there are no binders or other chemicals (such as colorants) in this product, pollution-control equipment is not required, and pollution emissions during manufacturing will be much less of a concern.

3.11.2.1 CFCs and HCFCs

The most significant pollutants found in insulation materials are chlorine-based chemicals that destroy the earth's protective ozone layer. Chlorofluorocarbons, or CFCs, which are also greenhouse gases, were used until recently as blowing agents in extruded polystyrene, polyurethane, polyisocyanurate, and phenolic foam. As revelations about the role CFCs play in ozone depletion came to light and regulations to restrict their use were enacted, however, these industries have turned to other, less damaging, foaming agents.

Among building insulation materials, extruded polystyrene (XPS) led the shift to less damaging hydrochloro-fluorocarbons (HCFCs).

Other CFC users were not so fortunate. Polyisocyanurate, polyurethane, and phenolic foam were all foamed with CFC-11, and the best replacement found, HCFC-141b, had not been tested for toxicity so was not on the market. Thus, those industries could not shift away from CFCs as quickly. In mid-1993, PIMA announced that the polyiso industry had completed the shift from CFC-11 to HCFC-141b. Spray polyurethane and the two Canadian phenolic foam products are now also foamed with HCFC-141b.

Unfortunately, for these industries, the HCFCs that replaced the CFCs cannot be used for long either. While HCFCs are only 5% to 11% as damaging to ozone as CFCs (because they do not last as long in the atmosphere), they are almost as damaging for the period of time when they are there, and all are significant greenhouse gases (believed to cause global warming). Foam insulation manufacturers and chemical producers are working hard to find zero-ozone-depletion alternatives.

Among foam insulation materials, there are several alternatives to those made with ozone-depleting chemicals:

1) Expanded polystyrene (EPS) is the only common rigid foam boardstock insulation made with neither CFCs nor HCFCs. During manufacture, polystyrene beads are expanded with pentane, a hydrocarbon that contributes to smog but is not implicated in ozone depletion or global warming; the pentane quickly leaks out of the insulation and is replaced by air.
2) While the polyurethane industry as a whole has gone the route of replacing the CFC-11 with HCFCs, one foam producer and an insulation contractor have bucked the trend and gone to a non-ozone-depleting hydrofluorocarbon (HFC). While HFCs are ozone-safe, they are significant greenhouse gases.
3) Icynene(TM) is a mixture of carbon dioxide and water. This eliminates polyurethane's HCFC-related environmental problems but also means a lower R-value. Like polyurethane, Icynene is foamed into wall cavities, but the resultant open-cell foam is soft, not rigid. In fact, it is marketed as much for its air sealing characteristics as its insulation properties. A recent development with Icynene is a second formulation that can be foamed into closed cavities.
4) Water-Blown Polyurethane is another manufacturer, that do not require HCFCs. They have both a closed-cell water-blown polyurethane (RT-2050) with an installed density of about 2 lbs/ft^3 (32 kg/m^3), and an open-cell water-blown polyurethane with an installed density of .5-.8 lb/ft^3 (8-12.8 kg/m^3). The latter is probably quite similar to Icynene.
5) Tri-Polymer Foam is a non-CFC, non-HCFC cavity-fill insulation used primarily in masonry block walls. It is essentially a phenolic foam and was developed as an alternative to urea formaldehyde foam insulation around 1980. It has very good fire resistance properties but does exhibit some shrinkage over time, which degrades its thermal performance.

6) Air Krete(TM) has gained a following both for environmental and health reasons. It is an inorganic foam produced from magnesium oxide (derived from sea water). It is foamed under pressure with a microscopic cell generator and compressed air; no CFCs or HCFCs are used. Because of its inorganic composition, Air Krete has very low VOC emissions, is totally inert, and non-combustible. It is foamed in place in closed wall or masonry block cavities, or behind mesh in open cavities to form a lightweight and rigid, but very friable, foam.

3.11.2.2 Indoor Air Quality

Though indoor air quality issues are different from environmental issues, they are related and should be considered at the same time. Concern about health effects of insulation materials dates back to the 1970s, when improperly installed urea formaldehyde foam insulation (UFFI) caused high levels of formaldehyde emissions in tens of thousands of homes. No insulation materials in use today exhibit indoor air quality problems approaching those of UFFI, but the rapidly growing interest in healthy homes is spurring a close examination of health impacts.

Some argue that the fibers released from fiberglass insulation may be carcinogenic, like asbestos. A spate of recent technical articles about the carcinogenicity of glass fibers has been damaging to the image of the fiberglass industry, as has the requirement for cancer warning labels. Most industry observers consider it a reaction to growing health concerns about glass fiber. They has increased the use of binder in its loose-fill fiberglass insulation to reduce the amount of loose fibers escaping into the air, but higher levels of phenol formaldehyde binder raise concern among some about formaldehyde off-gassing.

Because the fibers are stronger and less brittle, the product may not have to carry the cancer warning; also, this type of fiberglass contains no chemical binders or dyes, so there should be no offgassing.

There are also claims that the fire retardant chemicals or respirable particles in cellulose insulation may be hazardous. Much of the concern about fiberglass and cellulose has been generated by competing manufacturers or trade associations, and it has become difficult to pick out areas of real concern from all the hype and exaggeration bandied about. Properly installed, neither fiberglass nor cellulose should pose any health risks.

Some individuals have acute chemical sensitivity to the small quantities of chemicals that off gas from nearly all common insulation materials. The binders used in conventional batt insulation, inks from the recycled newspaper in cellulose, and VOCs released from foam insulation are examples of such offgassing. This has led to increasing interest in such products as Air Krete(TM), discussed above.

3.12 Building Codes, Insulation Standard,and Regulation

Building standards and model codes that address the energy-efficient design of residential building have been around for 30years. It was the energy crisis of the 1970s, however, that launched a plethora offederal regulations, testing standards, and guidelines have now been developed not only to provide more energy-efficient home construction but also to help provide consumer safety, eliminate fraud and even assist in home mortagage finacing. One of the international standard is ASHRAE standard.

3.12.1 The American Society of Heating, Refrigerating and Air-Conditioning Engineers Standards.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is an international organization with over 50,000 members and numerous chapter located throughout world. ASHRAE writes standards and guidelines to guide industry in the delivery of goods and services to the public. These standards and guidline include uniform methods of testing for rating purposes, recommended practices in designing and installing equipment, and provide other industry related information.

The original ASHRAE standard 90-1975, "Energy Conservation in New Building" was first published in 1975. The scope of this document covered both residential and commercial buildings and become the historical and technical basic for most current model codes and for residential construction.

ASHRAE standard 90.2,"Energy-Efficient Design of New Low Rise Building" was first published in 1993. This standard was specifically created to provide desidn requirement for the efficient use of energy for new residential dewellings that are three stories or less a bove grade. These include single houses, multifamily structures of three stories or

fewer a bove grade, and manufactured houses (both mobile homes and modular homes).

This standard deals with the building envelope, heating equipment and systems, air-conditioning equipment and systems, domestic water-heating equipment and systems, and prouision for overall building design alternatives and tradeoffs.

Standard 90.2 has been modified since its publication by several published adderda and continues to be under continuous maintenance per ASHRAE procedures.

3.12.2 Implementation of Thermal Insulation in Bahrain

The Kingdom of Bahrain witnessed a significant growth in construction and development. This led to significant increases in the consumption of electricity, which in turn called for the construction of more power generating stations with ever-increasing consumption of fuel. To reduce the cost of energy to the Kingdom and consumers alike, more and more studies were prepared to enable the promulgation of laws that help reduce the consumption of electricity.

Electricity is used inside buildings for airconditioning, lighting, cooking, entertainment etc. Research and studies conducted in Bahrain show that aircondioners use more than 65% of the total electricity used in a building. The average consumption of electricity for airconditioning depends on three main factors:

1. The rate of heat transfer from and to the building, which depends on a number of factors including the shape and orientation of the building, glass areas and the thermal properties of the building envelop etc.

2. The behaviour of the occupants of the building insofar as how they control the airconditioning and lighting in the building.

3. The general policy of the Kingdom with respect to determining electricity tariffs and the issue of building laws and regulations.

There is no doubt that the shape, design, planning of and the materials used in construction of a building have significant effects on its requirements of electricity for controlling and maintaining the temperature of the inside of the building at a comfortable level to its occupants, and to provide the necessary lighting. Therefore, architects should prepare the necessary studies and analysis that help in making use of climate characteristics with a view to reduce dependency on artificial airconditioning and to maximize the use of daylight instead of artificial lighting.

Studies and experiments show that controlling the thermal characteristics of the building's envelop is the most efficient factor in obtaining the required thermal performance. On this basis, the Building Thermal Insulation Regulation was issued. This regulation focuses on the thermal performance of buildings and in particular, the thermal characteristics of the roof, external walls and the percentage of the external glass areas, with a view to reduce the transfer of heat through the envelop of the building. It also determines the maximum permissible limits of the heat transfer coefficient (U-Value) for roof and external walls as well as the determining the type of glass for windows and external areas. One of the most important methods for complying with the requirements of the aforesaid Regulations is to use thermal insulation materials which help reduce the transfer of heat from the outside to the inside of the building in summer and from the inside to the outside in winter.

Heat is transferred from and to a building through the following:

1. Walls and roofs.
2. Windows and glass areas.
3. Ventilation openings.

Points 1 and 2 will be discussed further here:

The heat transferred through walls and roofs in summer constitutes the major portion, about 60-70%, of the amount of heat that need to be eliminated or reduced by the use of artificial airconditioning. For this reason, the use of thermal insulation in walls and roofs becomes very important in reducing the consumption of electricity. Thermal insulation has many advantages including the following:

1. Reducing the consumption of electricity for cooling and heating the building.

2. Reducing the capacities of the required airconditioning equipment, and therefore, the initial costs will be reduced.

3. Protecting the building from the effects of changes in thermal compression resulting from expansion and contraction.

4. Reducing the electricity bill for the subscriber.

5. Providing more comfortable environment for the occupants.

6. Helping in protecting the environment by reducing gas emission from power generating stations.

Windows and glass areas are the most vulnerable points with respect to the transfer of heat through conduction and emission. Therefore, it is advisable to minimize the use of glass in areas that are more exposed to weather conditions and direct sunlight and to always use insulated and double-glazed glass. (See Appendix (D) (ministerial order no.8 of 99 with respect to building thermal insulation regulation)).

3.12.2.1 Legislation.

1. First: Text of Regulation

a. Thermal insulation shall be used in accordance with established engineering methods in the walls and ceilings of buildings that require airconditioning, provided that the following conditions and requirements shall be complied with.

1. The Heat Transfer Coefficient shall not be more than 0.6 watts per square meter degrees centigrade for roofs.

2. The Heat Transfer Coefficient shall not be more than 0.75 watts per square meter degrees centigrade for walls.

3. Insulated glass must be used in all the windows of buildings with a height of more than three stories or where the glass area in their facade is between 10% to 20% of the area of the facade. However, for buildings with a glass area of more than 20% of

their facade area, insulated double glazing glass must be used for their windows.

b. Thermal insulation shall be used in new airconditioned buildings and in renovated airconditioned buildings where it is required to demolish the walls and/or roofs, as well as in airconditioned extensions to existing buildings.

Second: Regulatory Authority

The Ministerial Order delegated the authority to amend the requirements, conditions, materials and methods of thermal insulation to the Technical and Engineering Affairs Directorate at the Municipality in co-ordination with the authorities concerned with the implementation of the Order, provided that such amendments are approved by the Minister.

Third: Implementation of the Regulation

The Ministerial Order with respect to Thermal Installation (Regulation) shall be implemented in co-ordination between the concerned authorities in accordance with the mechanism. These authorities are:

1. **Municipality:** It shall not issue building permits unless the plans and drawings submitted by architects/owners are in compliance with the thermal insulation requirements as stipulated by the Regulation.

2. **Ministry of Electricity and Water:** It makes sure that the plans and drawings submitted to the Municipality to obtain building permits are in compliance with the thermal insulation requirements, and that the thermal insulation is carried out in accordance with the method/manner contained in the proposed plans and drawings.

3. **Ministry of Works and Agriculture:** It assists the Ministry of Electricity and Water in studying new thermal insulation systems and materials and in determining their heat transfer coefficient.

4. **Thermal Insulation Implementation Committee**: It assists the Ministry of Electricity and Water in ensuring the implementation of thermal insulation in buildings in respect of which building permits were issued by the Municipality, in accordance with the

requirements stipulated in the conditions contained in such permits that relate to thermal insulation.

Fourth: Methods of Implementing Thermal Insulation

The Regulation specified a number of proposed engineering methods for carrying out thermal insulation in walls and ceilings of buildings .These methods are meant to provide building owners with options that are most appropriate to their buildings, which they may decide upon after consultation with their architects. In case of a desire to use a different insulation method, the Ministry of Electricity and Water will consult with the Ministry of Works in connection with the study and approval of the proposed new system. (Ministry of Electricity and Water, 2002)

3.12.2.2Thermal Insulation Implementation Mechanism

To facilitate the implementation, the Ministerial Order with respect to thermal insulation will be implemented by procedures the stages of which will match the procedures for obtaining building permits. The Committee entrusted with the implementation will follow up all the procedures required through the two stages of planning and execution. This will be done in co-ordination between the Ministry of Electricity and Water, Municipalities, Ministry of Works and Agriculture and the concerned engineering offices/architects.

Thermal Insulation Implementation Committee

The Committee will be comprised of the governmental bodies that are concerned with ensuring the compliance of the documents submitted along with the building permit application with the requirements of the Ministerial Order on thermal insulation together with the authorities responsible for ensuring that the consultant engineer/property owner apply these requirements to the building before giving him a certificate of completion for the building.

Role of the Thermal Insulation Implementation Committee

The Thermal Insulation Implementation Committee ensures that the requirements of the Ministerial Order on thermal insulation are: implemented through the two stages of planning and implementation as follows:

Execution stage

1. The Ministry of Electricity and Water (Electricity and Water Conservation Directorate) receives the documents that are required from engineering offices.

2. The concerned engineer at the Ministry of Electricity and Water will, in co-ordination with the Thermal Insulation Implementation Committee, make sure that the documents attached to the application for a building permit and submitted by the engineering offices is complete in relation to the thermal insulation requirements. In particular, he will make sure that the following documents are complete:

    a. The drawings and that they contain the correct insulation method.

    b. Information contained in the tables for the calculation of the heat transfer coefficient for the ceiling and walls and the percentages of glass areas contained in "Thermal Insulation Application Form".

    c. Check the correctness of the calculation of the heat transfer coefficient (U-Value) for the roofs and walls.

    d. Check that the heat transfer coefficient values are for ceilings and walls do not exceed the value set forth in the Ministerial Order and stipulated in Articles (1) and (2) of the Thermal Insulation Regulation.

    e. Check the calculation of the glass area and its percentage of the total area of the external walls.

    f. Ensure that the appropriate type of glass is used for windows and other glass surfaces in accordance with the requirements set forth in Article 3 of the Thermal Insulation Regulation.

3. If the aforesaid documents contain thermal insulation materials, systems or methods that do not conform to the commonly accepted materials, systems or methods, the application will be referred to the Ministry of Works and Agriculture – Construction Projects and Maintenance Directorate to study the documents and advise the Ministry of Electricity and Water on the matter.

4. The Minister of Electricity and Water stamps the Thermal Application Form and gives it to the engineering office, after ensuring that the building conforms with all of the thermal insulation requirements.

5. Municipalities will not issue a building permit unless the engineering office produces the Thermal Insulation Implementation Form duly stamped by the Ministry of Electricity and Water.

Execution Stage

1. The Ministry of Electricity and Water in co-operation with the Thermal Insulation Implementation Committee will, after receiving the "thermal insulation implementation follow up notices" form from the engineering office, test samples and visit the site to check the correctness of the information.

2. The Municipalities will not receive the form of "Supervising Engineering Office Follow up of Construction Works" except after receiving a declaration from the engineering office that they have already sent the "thermal insulation implementation follow up notices" for the various stages of construction to the Ministry of Electricity and Water.

3. Municipalities will not issue a "Building Completion Certificate" unless the "Supervising Engineering Office Follow up of Construction Works – the final stage" form is stamped by the Ministry of Electricity and Water. This form can be obtained from the Municipalities.

Role of Engineering Offices / Consultant Engineers

The engineering office will fulfill the requirements of the Ministerial Order with respect to thermal insulation when preparing the drawings of the building at the execution stage, and ensure that thermal insulation is

used at the execution stage in accordance with the drawings and requirements approved by the Municipalities. The role of the engineering offices is summarised as follows:

At the Planning/ Plan Preparation Stage

1. Attach the illustrative drawing of the method used in the thermal insulation of roofs and buildings and the positioning of the external windows.

2. Fill in the required information in the tables contained in the "Thermal Insulation Implementation Form".

3. The engineering office will submit the above-mentioned information to the Ministry of Electricity and Water – Electricity and Water Conservation Directorate to obtain their approval before applying for a building permit from the Municipalities.

Execution Stage

1. The engineering office ensures that insulation materials are used for walls and ceilings and that the approved type of glass is used for windows.

2. The engineering office informs the Ministry of Electricity and Water of the commencement of the installation of the thermal insulation in ceilings and walls, and at least two weeks before the expected date completion by sending a ""thermal insulation implementation follow up notice" to the Ministry.

3. The engineering office obtains the seal of the Ministry of Electricity and Water on "Supervising Engineering Office Follow up of Construction Works – the Final Stage" as a pre-condition for obtaining the "Building Completion Certificate".

Third: Implementation of the Regulation

The Ministerial Order with respect to Thermal Installation (Regulation) shall be implemented in co-ordination between the concerned authorities in accordance with the mechanism. These authorities are:

5. **Municipality:** It shall not issue building permits unless the plans and drawings submitted by architects/owners are in compliance with the thermal insulation requirements as stipulated by the Regulation.

6. **Ministry of Electricity and Water:** It makes sure that the plans and drawings submitted to the Municipality to obtain building permits are in compliance with the thermal insulation requirements, and that the thermal insulation is carried out in accordance with the method/manner contained in the proposed plans and drawings.

7. **Ministry of Works and Agriculture:** It assists the Ministry of Electricity and Water in studying new thermal insulation systems and materials and in determining their heat transfer coefficient.

8. **Thermal Insulation Implementation Committee**: It assists the Ministry of Electricity and Water in ensuring the implementation of thermal insulation in buildings in respect of which building permits were issued by the Municipality, in accordance with the requirements stipulated in the conditions contained in such permits that relate to thermal insulation.

Fourth: Methods of Implementing Thermal Insulation

The Regulation specified a number of proposed engineering methods for carrying out thermal insulation in walls and ceilings of buildings . These methods are meant to provide building owners with options that are most appropriate to their buildings, which they may decide upon after consultation with their architects. In case of a desire to use a different insulation method, the Ministry of Electricity and Water will consult with the Ministry of Works in connection with the study and approval of the proposed new system.

Other counteries in the regain have implemented the energy conservation measure like Kuwait, started well ahead and came up with same reliable code of Energy practicee.based on which,it has passed a compulsory regulations settingup aminimum limit for thermal resistance of wall and roof. Qatar,also has issued a circular that is comulsory in wall insulation for government buildings, but recommended rather than compulsory for private sector.

Dubai issuing the Administrative Decree no. 77 for the year 2001, which pertains to the adoption of the technical specification list of the thermal insulation system in the buildings of Dubai . It took a major step towards implementing the "green building" (buildings with high environmental quality) by making it mandatory for all new buildings coming up in the emirate to have proper thermal insulation systems in place. The new regulation has been mandatory since April 2003.

Also the Kingdom of Saudi Arabia applied a mandatroy insulation code of practice for construction of commerial and residential building for encouraging the design of new buildings to be constructed, operated and maintained in a manner that reduces the use of energy without constraining the building's functions,nor the comfort of the occupants and with appropriate regared for cost considerations.

Table (3. 4) General Properties of Insulation Materials Recommended for Used in Building

Material	**Density (kg/m^3)**	**Thermal Conductivity (k) W/m.°C**	**Thermal Resistance R=1/k m.°C/W**	**Compressive strength Kg/cm^2**	**Water Absorption (% volume)**	**Fire Resistance**	**Vapor Permeability**	**Toxicity**	**Environmental/Heath concerns**
Fiber glass	9.6-16	0.041	15.3-22	0.05	<1% by weight	Non-combustible	>100 per in	some	Quite safe environmentally, some concern that fiber may be carcinogenic, but greater health concern with loose-fill fiberglass than fiber batts.
Rock & slag wool	24-40	0.04-0.05	20-25.7	0.2	<2% by weight	Non-combustible	>100 per in	none	Quite safe environmentally, some concern that fiber may be carcinogenic and may pose health risk.
Cellulose	35-48	0.04-0.045	22.2-25.7	5.7	5-2% by weight	combustible	high	Develops Co when burned	Environmentally attractive, provides market for recycled newspaper and cardboard.
Perlite (loose-fill)	32-160	0.047-0.06	17.4-25.7	-	Low	Non-combustible	high	none	Very safe environmentally
Vermiculite (loose-fill)	64-160	0.047-0.06	16.7-20.8	-	none	Non-combustible	high	none	-
Insulating concrete	192-1400	0.12-0.17	5.9-8.3	-	-	Non-combustible	Varies with density	none	-
Expanded polystyrene (molded)	13-32	0.23-0.26	26.7-30.6	1-2	<4% by volume	combustible	1.2-3	Develops Co when burned	Foam produced with pentane gas, may contribute smog and ground level ozone
Expanded polystyrene (extruded)	13-32	0.029	34.7	2-3	<0.7% by volume	combustible	0.6	Develops Co when burned	Produced with HCFC 142b which depletes stratospheric ozone to some extent
Polyurethane (Foam)	32	0.018-0.024	40.3-53.5	1-3	negligible	combustible	2-3	Develops Co when burned	Most urethane produced with HCFCs, which deplete stratospheric ozone. Possible substitute blowing agent but with decreased thermal properties
Urea-formaldehyde (foam)	40 wet 9-14 dry	0.035	29.16	-	32% by weight	combustible	4.5-100	As burning wood	-
Phenolic Foam	30-60	0.036	27.73	1-3	1-4	Non-combustible	1-4	none	-

- Ministry of Electricity and Water,2002
- Bahrain University ,1995

CHAPTER FOUR

4. ENERGY-10

Energy-10 is the windows-based software designed to used on commercial, institutional and residential buildings with one or two thermal zones and of approximately 3,000 squre meters (10,000 square feet) and under. It relies on a "whole building approach" and integrates daylighting, passive solar heating, and low energy cooling strategies with energy-efficient shell design and mechanical equipment. The program facilitates decision- making early in the design process. Energy-10 has been developed directly with the building industry via a task force that includes architects, engineers, builders and utility representatives.

Energy-10 is a conceptual design tool for low-energy building. It is software component of aproject called Designing Low-Energy Building with Energy-10, which is being conducted for the U.S. Department of Energy (DOE). The program does hour-by hour simulations for typical year.

The Energy-10 computer program has been developed as a design tool for smaller building that can be characterized by one or two thermal zones. It was prepared under the leadership of the National Renewable Energy Laboratory and produced with Funds made available by the United States Department of Energy.

Energy-10 demonstrates the consequences of various design decision. The evaluation are comprehensive, based on hour-by hour calculations through all 8760 hours of the year. Weather data used are representative of typical long-term average conditions for a large selection of United States locations and Bahrain weather data is included also. Currently, the program evaluates a range of smaller libraries, stores, government facilities, and low-rise residential buildings.

It has been carefully and thoroughly reviewed by knowledgeable engineers and analysts. However, it is a complex program and it is impossible to guarantee that it is completely free of bugs. It could possibly contain errors and produce misleading results.

4.1 Mission and Vision of Energy-10

Mission

To provide a tool that an architect will use routinely to guide his or her decision while developing the building design.

Vision

Eventually all buildings will be designed to be delightful living, working, and learning environments, enhanced by natural light; require a minimum of energy to operate; and not impair the environment of following generations.

Energy-10 is quite different from energy simulations of the past, because the calculations have been so time and cost intensive, simulations have typically during design development or even later. Perhaps only calculation would be made, usually to confirm that the proposed design met a predetermined performance goal. Often, requirements were set by a standard or by local regulations. This type of evolution add on value to the design process because the results of the analysis have no effect on the design. The exception might be when the performance goal is not met, leading to a painful design decisions. In either case, designers have generally viewed energy efficiency as an onerous requirement.

4.2 Graphic Output

ENERGY-10 offers a rich selection of graphic output options to make it easy and fast to assimilate the results of the billions of calculations that are made to execute an annual hour-by-hour simulation. These range from bar charts that show annual results to hour-by-hour line graphs showing heat flows, energy use, or delighting savings. (Figures 4.2.1, 4.2.2& 4.2.3).

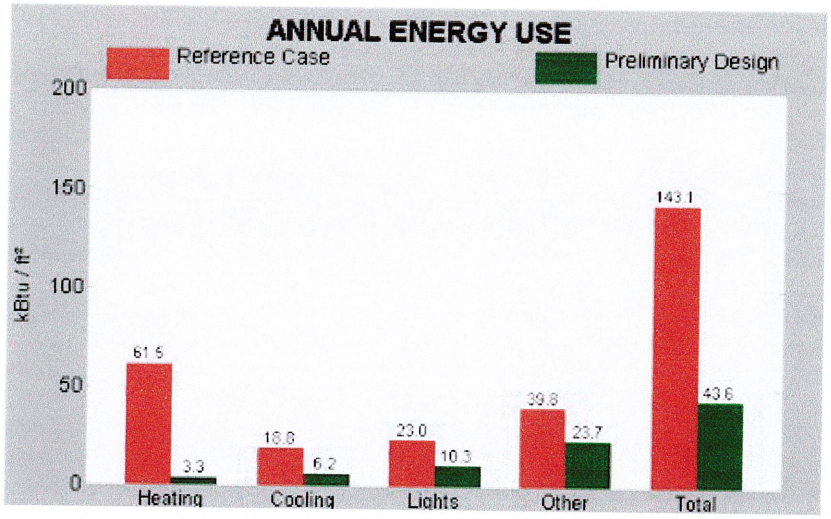


Figure 4.2.1 Annual Energy Use output result

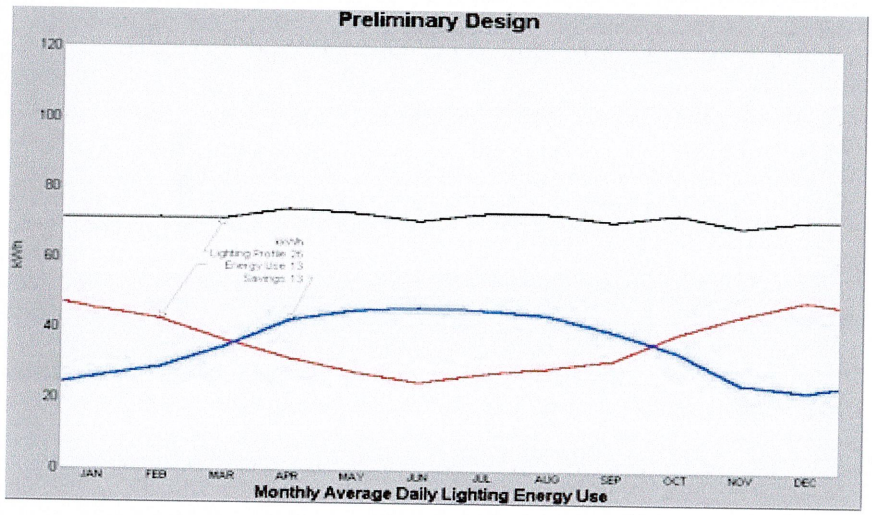


Figure 4.2.2 Monthly Average Lighting output result

This graph shows savings due to daylighting. Lighting in the reference case is 35 MWh. Nine MWh is saved by more efficient lights and ballasts; 13 MWh is saved by dimming the lights; leaving only 13 MWh required, a 63% reduction.

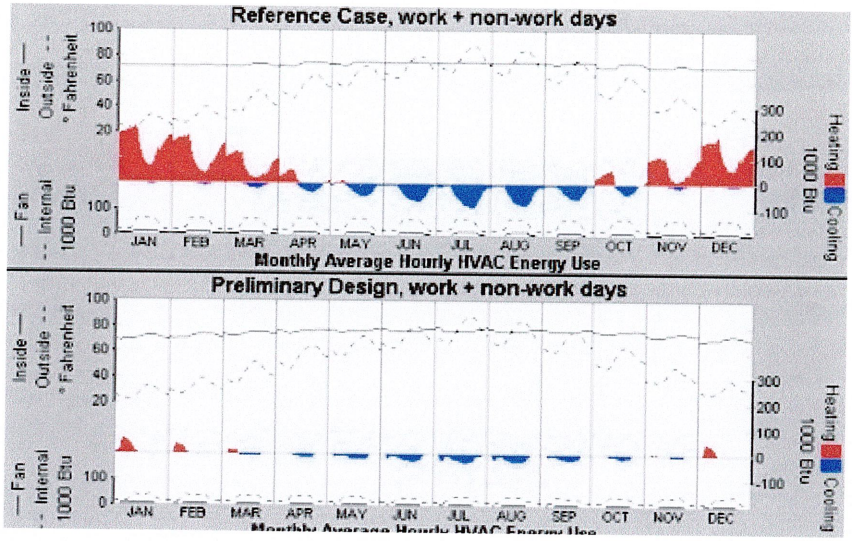


Figure 4.2.3 Monthly Average Hourly HVAC output result

More than 20 view options shows typical days in each month, comparing the two buildings. Temperatures and heat flows are shown. This contains information about both the daily behavior and how this changes month to month.

4.3 Simulation Analysis

ENERGY-10 gives you comprehensive evaluations of energy use with a technique called *simulation*, the most widely accepted method for doing building energy analysis. NASA uses simulation to plan spacecraft missions; you can use simulation to plan your building. Simulation predicts conditions in the building ACH day of the year, based on assumed occupancy characteristics. (Figures 4.3.1)

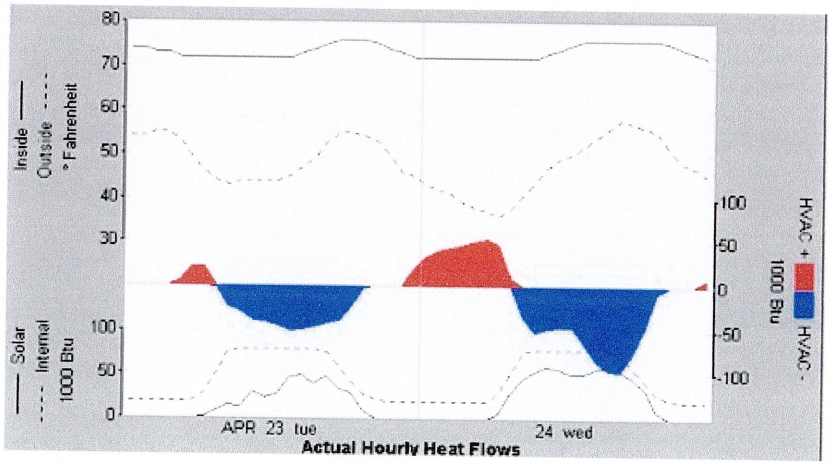


Figure 4.3.1 Actual Hourly Heat Flow output result

In ENERGY-10 this is done by calculating heat transfer from point to point within the building each hour throughout a simulated year. Weather data consists of site-specific, hour-by-hour values such as temperatures, solar radiation, humidity, and wind speed. Each month of data is from a different year, selected to be typical of the long-term average for that particular month.

The graphs generated by ENERGY-10 show typical simulation results. The advantage of simulation analysis is that it provides a reasonably realistic picture of how an actual building would perform, assuming that it is constructed and operated in accordance with your specifications and your suppositions regarding operational behavior, such as thermostat settings, HVAC control settings, and internal gains.(Figure4.3.2)

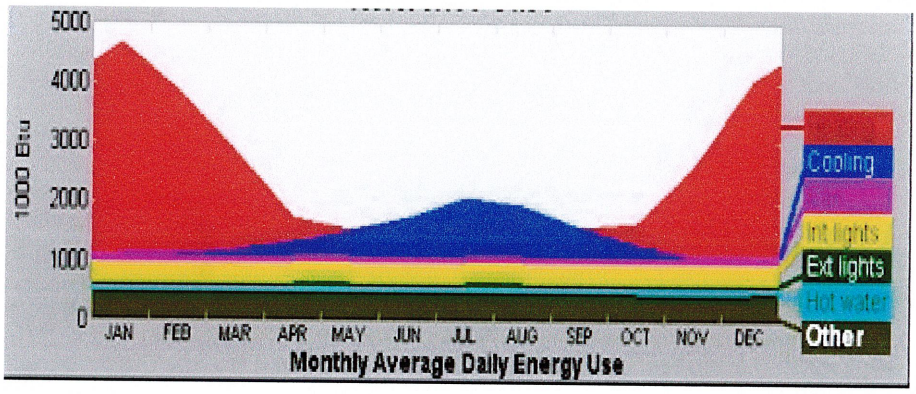


Figure 4.3.2 Monthly Average Energy Use output result

The simulation analysis in ENERGY-10 accounts for a detailed evaluation of solar gains through windows, heat flowing into and out of walls, thermal storage in all building materials, and HVAC performance. The simulation is performed for an entire year, summing hourly energy consumption into monthly totals, determining monthly costs, and then annual totals. It is a little like monitoring a building before it is constructed.

Daylighting in the building is simulated in a similar way, accounting for visible transmittance through windows, switching or dimming characteristics of the lighting controls, and reduction in heat energy generated by the lights, which, in turn, affects the building's thermal performance.

The daylighting analysis divides the building into five lighting zones and employs the split-flux method. The thermal analysis is done using a thermal-network mathematical modeling approach. HVAC analysis is quasi-steady state. (Figure 4.3.3)

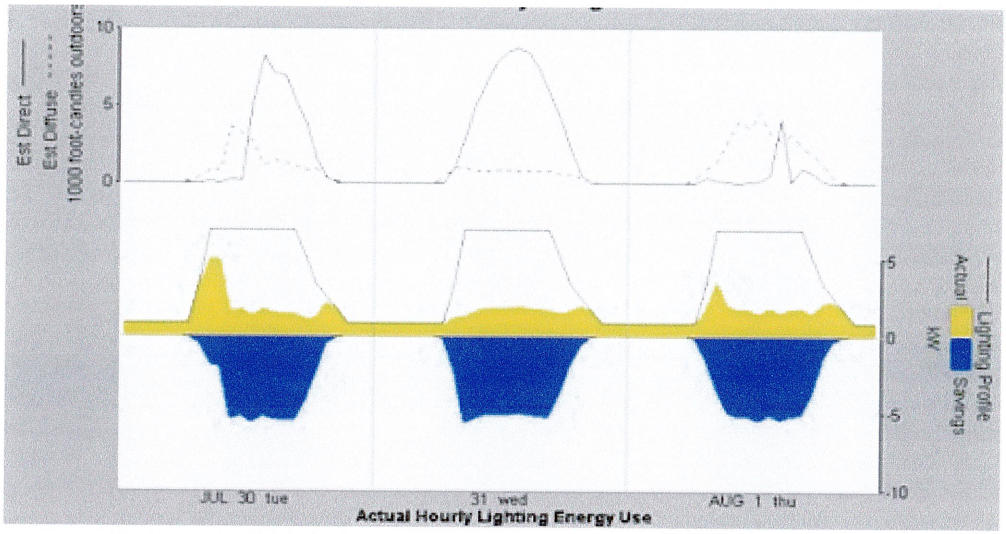


Figure 4.3.3 Actual Hourly Lighting Energy Use output result

CHAPTER FIVE

5. STANDARD RESIDENTIAL BUILDING ZAYED TOWN PROJECT

5.1 Introduction.

Comparative evaluation of energy conservation strategies in housing using different types and widths of thermal insulation is to be made reference to a typical housing design. This is to ensure that the study conducted, the comparative assessment preformed and the results obtained are realistic for practical applications and this therefore meaningful.

To insure that, the results obtained by this study is greatly representative and applicable for a large sector of housing stoke in the kingdom of Bahrain, the standard house characteristics must represent Bahrain housing regarding ; design type , spaces standards, architectural features, materials and construction methods.

This chapter explains the principles for the choice, description and specification of the typical house adopted for this study.

5.2 The Choice of the Zayed Town Standard House.

Bahrain's Residential Buildings has different designs. The most standard designs were studied by the Ministry of Housing in Bahrain. Two types of those houses were constructed in Zayed Town, the E and 3A types.

Choosing of these two types as standard design for the purpose of simulation and comparative analysis are due to the following reasons:

1- First of all, Zayed town represent the modern cities as well as it is a unique project create a showcase site for the future public housing projects in Bahrain and the Gulf.

2- Those houses are resided by many Bahraini families of varying Socio-economic status and hence represent a cross section of Bahrain population.

3- The construction materials used in those houses are locally available and the construction of walls and roofs is typical to what is commonly built in Bahraini houses.

4- Those houses are designed by local Architects in order to reflect the Bahrain's traditional designs.

5- They have a typical space standards and spatial organization representative of Bahrain two stories housing.

6- The construction of those houses was carried by Bahraini contractors.

7- Those houses specification meets the required characteristics of the typical Bahraini house.



Figure 5.2 Site Development Master plan of Zayed Town

5.3 Description of Standard Houses.

The two types of a standard house adopted for this study are the two story dwelling. The ground floor consists of "Majlis", living hall, store, toilet, kitchen and another hall with a stairs leading to the first floor.

The first floor in the house type 3A consists of three bedrooms, two bathrooms and a hall. In type E, the first floor consists of four bedrooms, store and a hall. The standard houses main features is shown in table (5.3).

Figures 5.3(a), 5.3(b), 5.3(c) and 5.3(d) illustrate the plans and architectural drawing for the standard house type 3A and type E respectively.

Table (5.3) the main features of standard houses.

House Type	3A	E
Shape	Rectangular	
Height	Two story building 6m high	Two story building 6.7m high
Volume	1183.2 m^3	1837.14 m^3
Area	197.2 m^2	274.2 m^2
External walls area	153.6 m^2	332.32 m^2
Roof area	98.6 m^2	137.1 m^2
No. of windows	11	12
Windows total area	11.76 m^2	15.26 m^2
Glass type	24 mm double glazing (Aluminum frame)	
Lighting	10W/m^2	
Shading	Only for front windows	
People	6	
Equipment load	3KW	
A.C. system	Window unite	
Wall	Constructed with 200mm (8") thick hollow concrete block, covered from both side with sand-cement plaster.	
Roof	Flat and consists of 150mm thick pre-cast concrete slab with a water proofing membranes and two layers of 50mm (2") polythene sheet.	

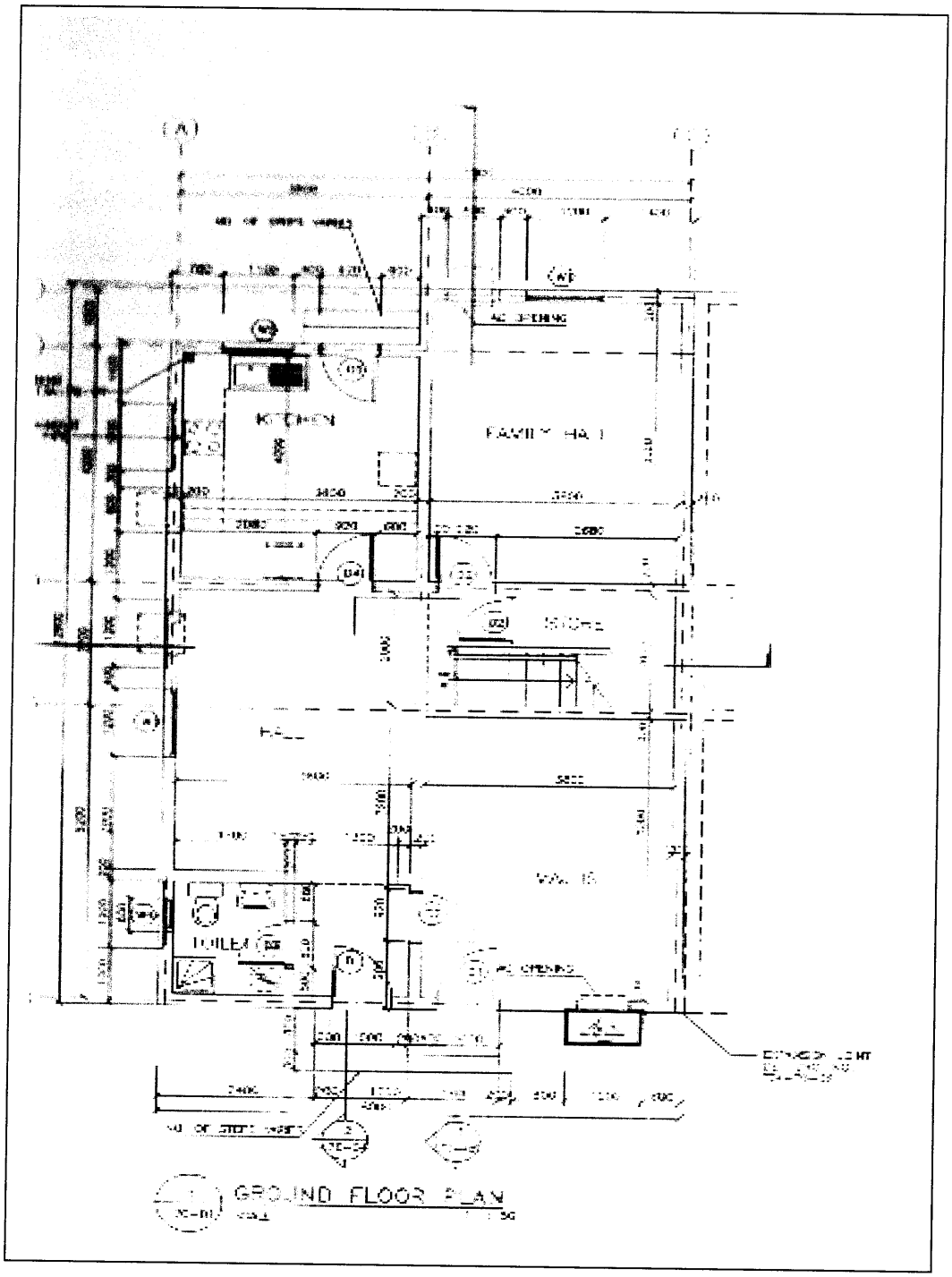


Figure 5.3 (a) ground Floor plan of standard house type 3A

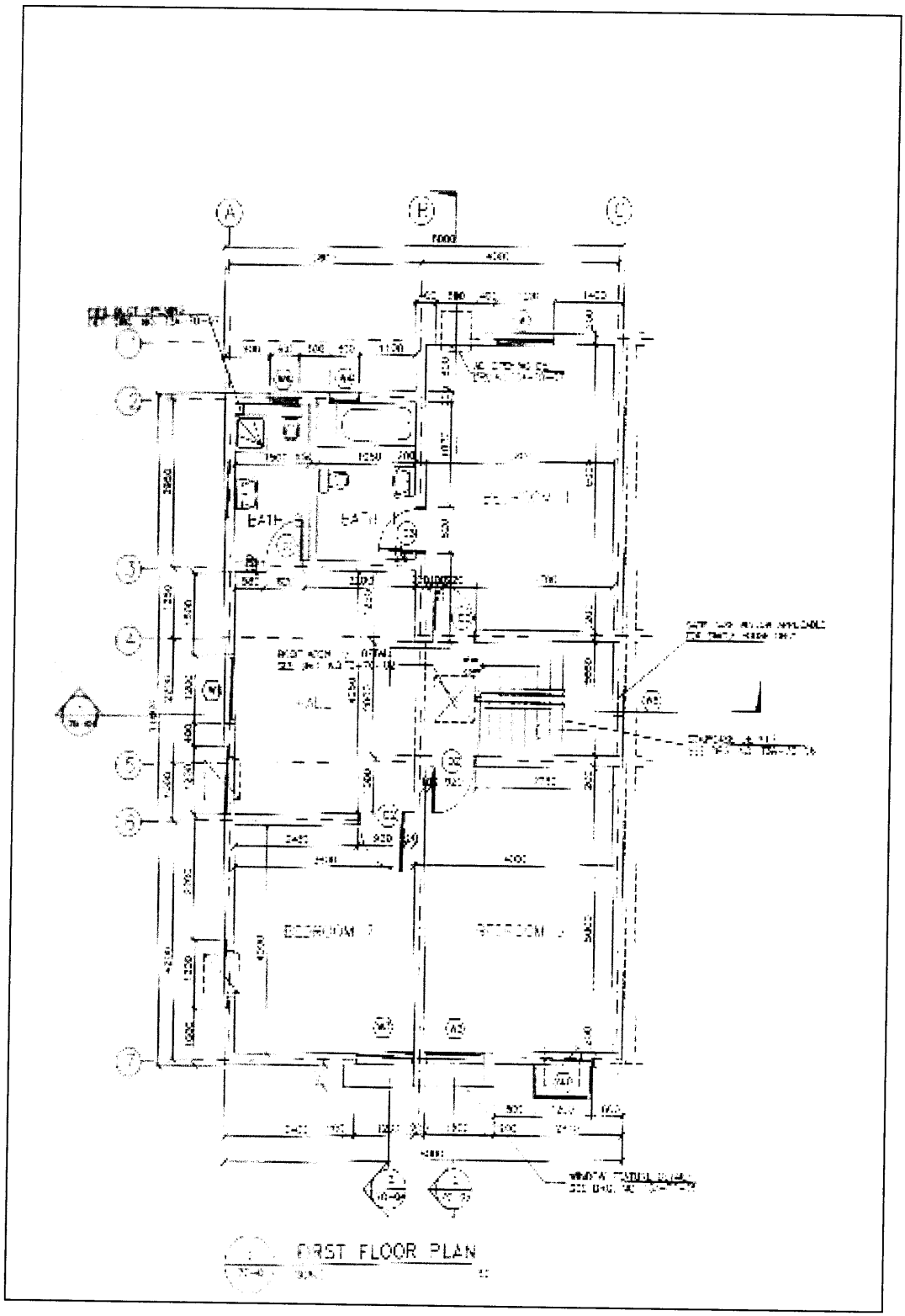


Figure 5.3 (b) First floor plan of standard house type 3A

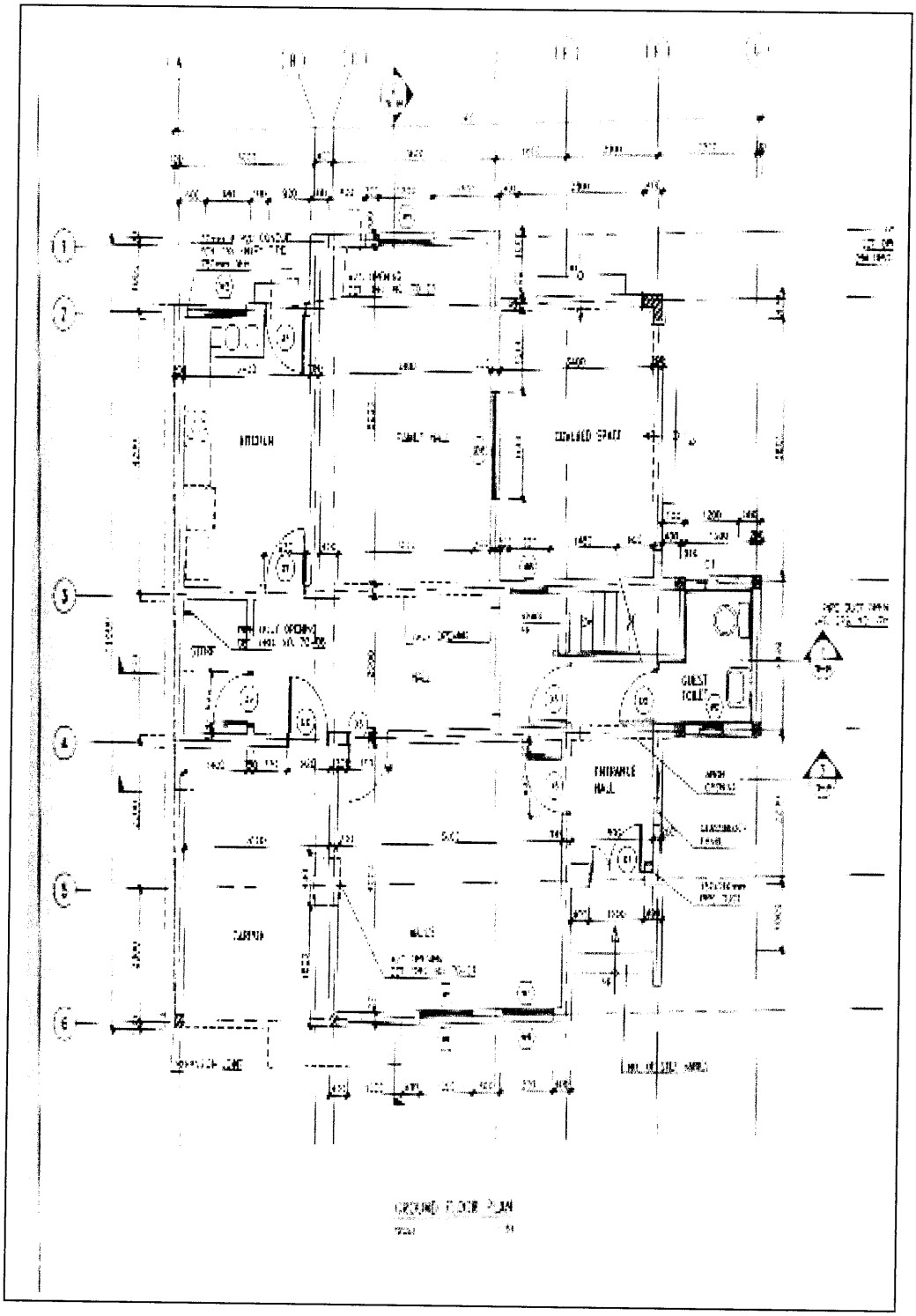


Figure 5.3 (c) Ground floor plan of standard house type E

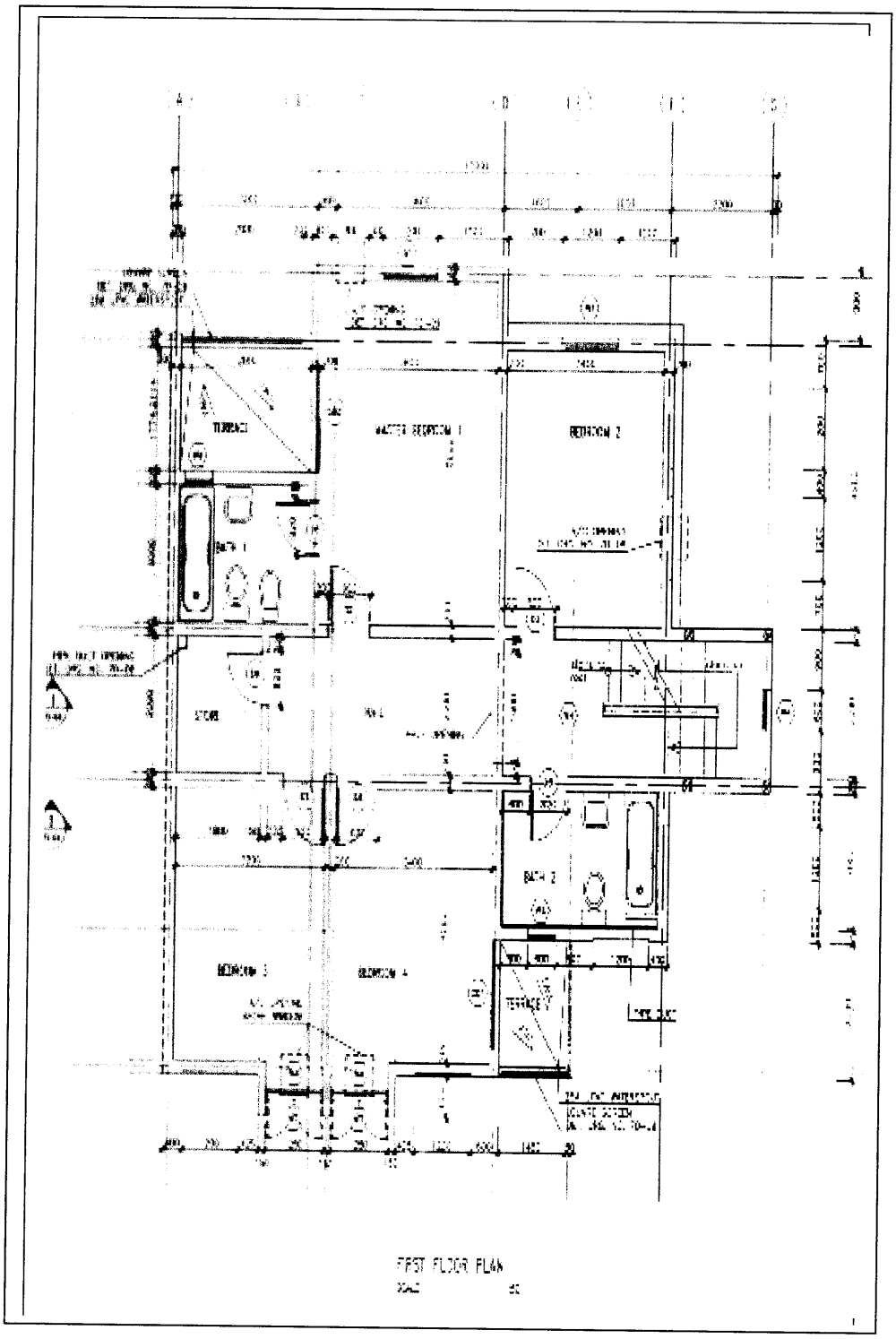


Figure 5.3 (d) First floor plan of standard house type E

5.3.1 Shape and Orientation.

Zayed Town consists of 273 units distributed on the whole plot area, 165 units type 3A and 108 units type E.

The 3A type has a rectangular shape with long facades in north/south orientation and most of this type front elevation was oriented to the east direction.

Where, type E has squre shape and found to have varying direction ,but the most of this type has long facades east/west with front elevation was oriented in south direction.

5.3.2 Areas and Facades.

The total build up area for house type 3A is about 197.2 squre meter with a total height of 6 meters for all of its facades and 3 meters for each floor. The facades are also, similar in the number of walls, two walls per facade, with a total number of eleven windows. (figurs 5.3.2 (a) ,(b), (c) ,& (d)).

Where, type E house has a total build up area about 274.2 squre meter and a total height of 6.7 meters with 3.35 meter height for each floor.

Similary to type 3A, type E has two wall per façade, with a total number of twelve windows. (figurs 5.3.2 (e) ,(f), & (g))

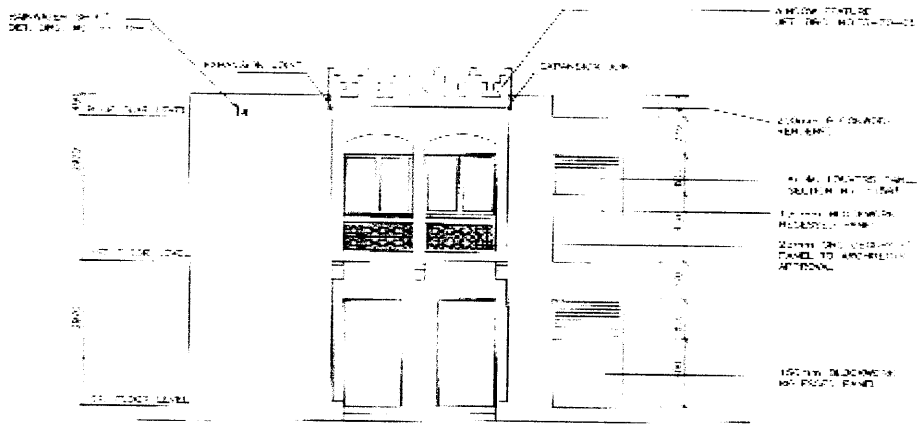


Figure 5.3.2 (a) Front elevation for standard house type 3A

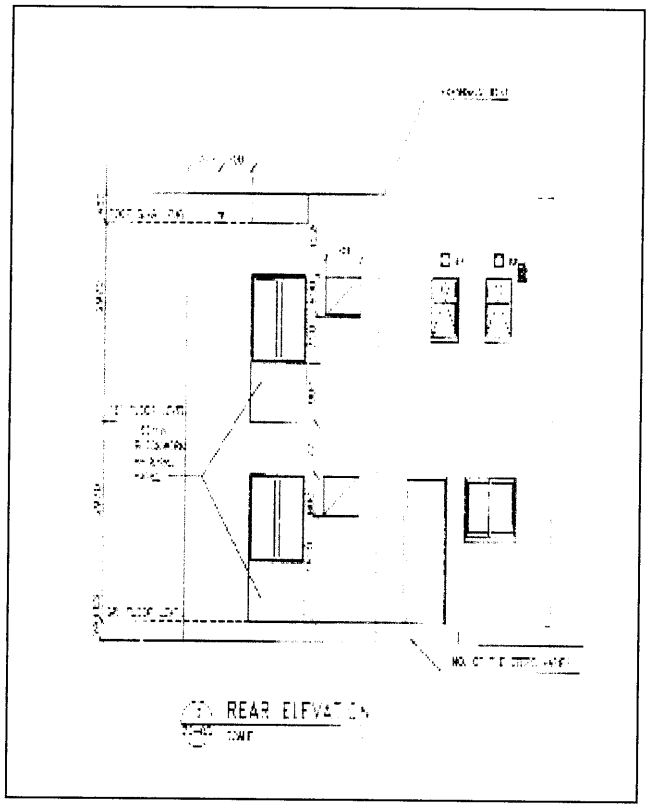


Figure 5.3.2 (b)

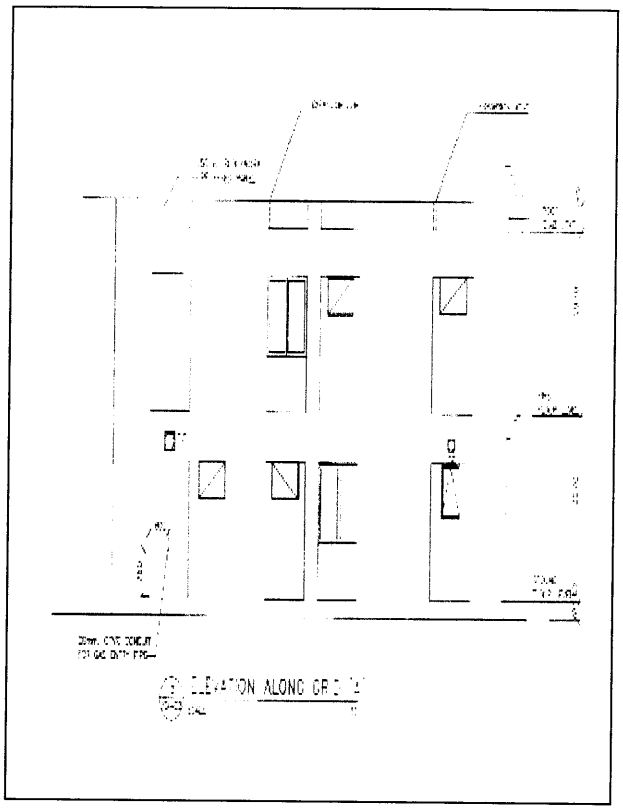


Figure 5.3.2 (c)

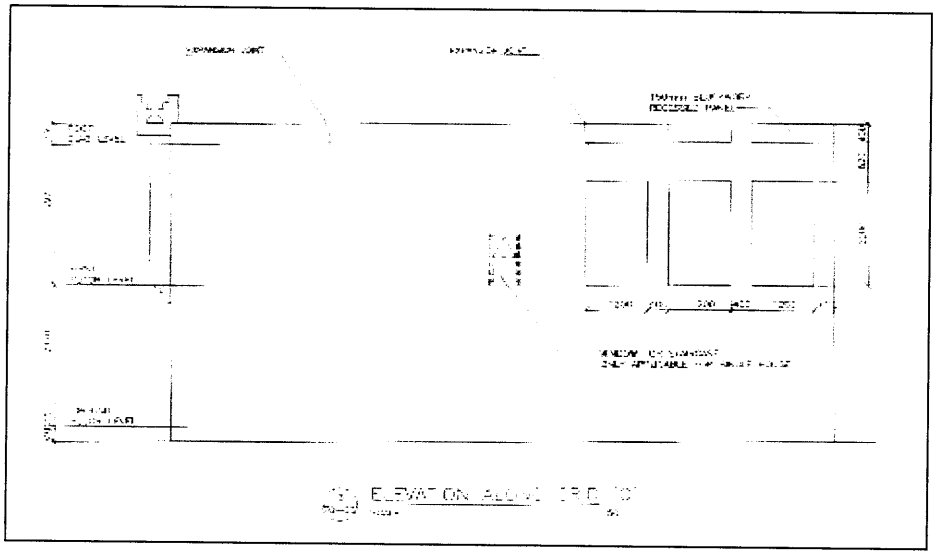


Figure 5.3.2 (d)

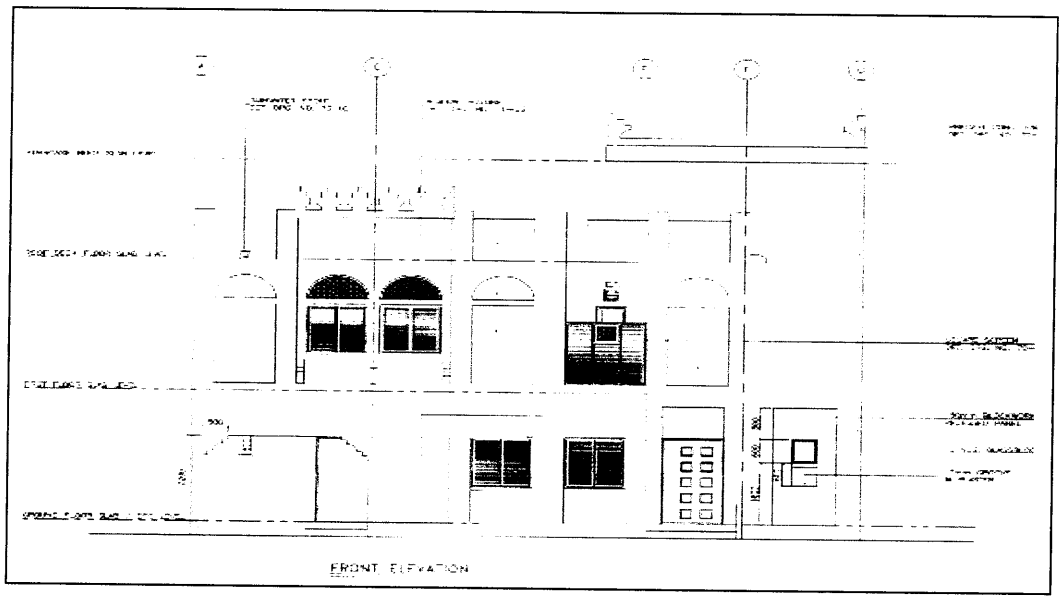


Figure 5.3.2 (e) Front elevation for standard house type E

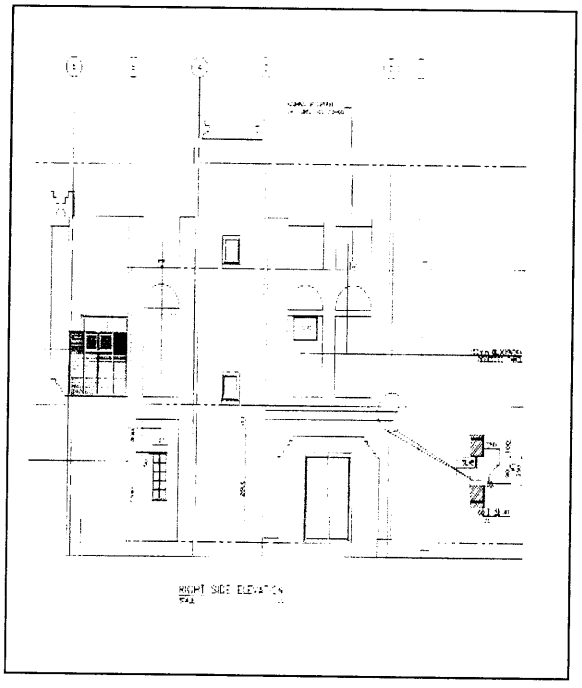


Figure 5.3.2 (f)

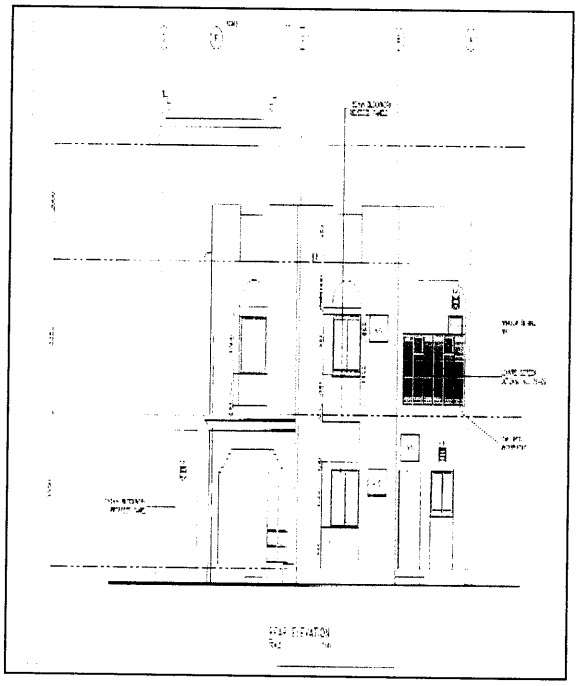


Figure 5.3.2 (g)

5.3.3 Materials and Construction Composition.

The construction material used in Zayed Town house are normal materials with hollow core slabs and load bearing blocks.

Wall:

All the walls are of the same construction composition. The outside wall are commonly constructed with 200mm (8") thick hollow concrete blocks, coved from both side with sand-cement plaster. .

Roof:

The roof is flat and consists of a 150 mm (6") thick pre-cast concrete slab coverd with a water proofing mebrance and two layers of 50mm (2") polythene sheet. (Figure 5.3.2 (b)).

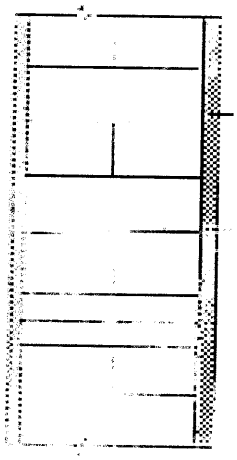


Figure 5.3.3 (a) Actual Wall construction

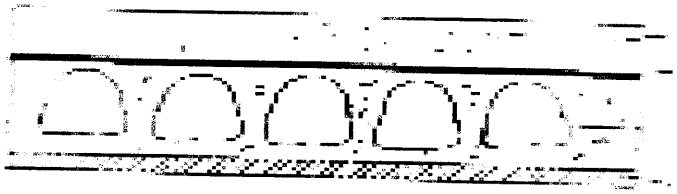


Figure 5.3.3 (b) Actual Roof construction

Windows and Doors

Windows are made of aluminum frame with 24 mm double glazing, where the doors are constructed mainly of Wood of flush construction, with 25% soild materials.

5.4 The Choice of the Different Roof and wall construction.

Our choice of selecting wall and roof constructions to be used in this study based on the Survey that done on the residential building construction in Bahrain.

The survey result shows that, most of the residential building are constructed using the wall bearing method and there are four different wall constructions that is commonly used in Bahrain residential buildings. These walls are shown in Figures 5.4 (a), (b), (c) & (d)

The survey result also shows that, there are five different roof construction commonly used in Bahrain. They are the wooden beam roofing "Murabaa", cast in site reinforced slab, precasted slab , hollow casted slab and insulated roof . They are shown in Figures 5.4 (e), (f), (g), (h) & (i)

Wall 1

-Inside air film
1-Sand cement plaster (10mm)
2-20 cm concrete block
3- Insulation type & thickness "variable"
4- Cladding (20mm)
- Outside air film

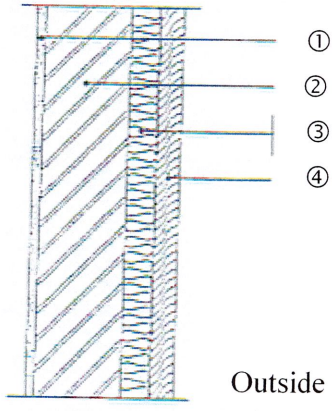


Figure 5.4 (a)

Wall 2

-Inside air film
1-Sand cement plaster (10mm)
2-10 cm concrete block
3- Insulation type & thickness "variable"
4- 15 cm concrete
5- Sand cement plaster (10mm)
- Outside air film

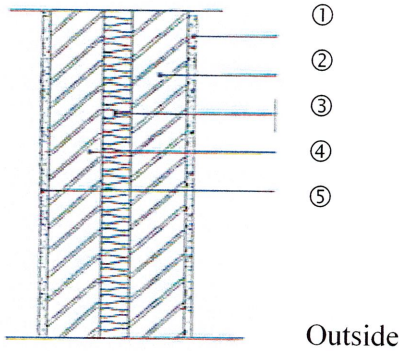


Figure 5.4 (b)

Wall 3

(Insulated Sandwich wall)

-Inside air film
1-Sand cement plaster (10mm)
2-Insulated concrete block
3- Sand cement plaster (10mm)
- Outside air film

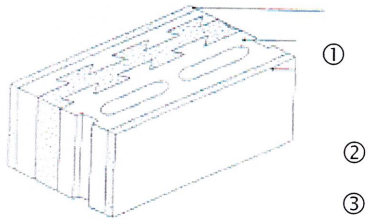


Figure 5.4 (c)

Wall 4

-Inside air film
1-Sand cement plaster (10mm)
2-200 standard blocks filled with Insulation / type & thickness "variable
3- Sand cement plaster (10mm)
- Outside air film

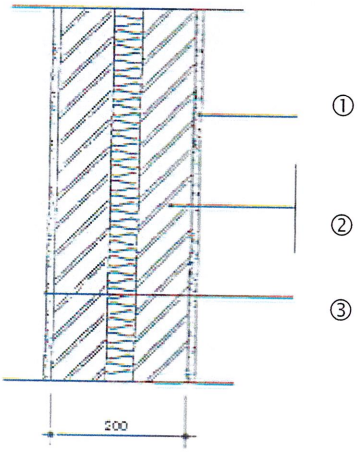


Figure 5.4 (d)

Outside

Roof 1

- Outside air film
1-Cement screed (50mm)
2- Waterproofing
3- Concrete slab (150mm)
4- Plywood
5- Wood beam (Murabaa)
- Inside air film

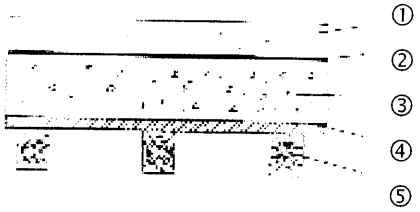


Figure 5.4 (e)

Roof 2

- Outside air film
1-Cement screed (50mm)
2-Water proofing
3- Concrete slab (150mm)
4- Plaster of gypsum finish (10mm)
- Inside air film

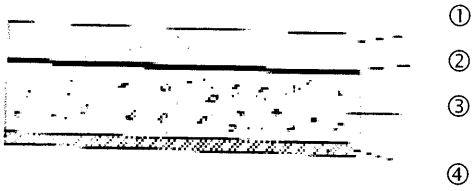


Figure 5.4 (f)

Roof 3

- Outside air film
1-Cement screed (50mm)
2-Water proofing
3- Hollow core concrete slab (150mm)
4- Plaster of gypsum finish
- Inside air film

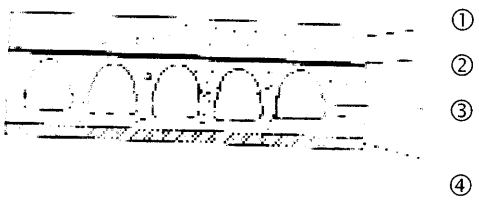


Figure 5.4 (g)

Roof 4

- Outside air film
1-Chipping (50mm)
2- Insulation type & thickness "variable"
3- Waterproofing
4-Cement screed (50mm)
5-Heavy weight concrete slab (150mm)
6- Plaster finish (10mm)
- Inside air film

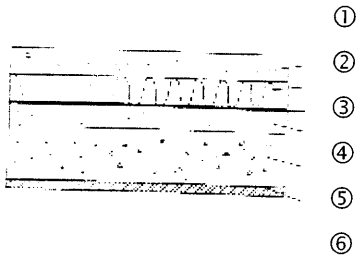


Figure 5.4 (h)

Roof 5

- Outside air film
1-Roof tile (20mm)
2-Cement mortar (20mm)
3- Waterproofing
4- Insulation type & thickness "variable"
5- Hollow core concrete slab (150mm)
6- Plaster finish (10mm)
- Inside air film



Figure 5.4 (i)

5.5 The Choice of the Insulation thickness and materials.

Three types of insulation materials commonly used in Bahrain building construction and recommended by the Ministry of Electricity and Water were used in this study to apply them to the different wall and roof construction with different thickness.

The selected insulation materails are polystyrene, fiberglass and polyurethane.

The insulation thicknesses are 20, 30, 40, 50 and 60mm for wall construction and 50, 75, 100, 150 mm for roof construction.

CHAPTER SIX

6. RESULTS ANALYSIS AND DISSCUSSION

6.1 Introduction.

The results obtained from the simulation are presented in monthly and yearly totals. The energy performance is based on calculating the effect of adding insulation to the roof and walls on the air conditioning load of a standard house.

ENERGY-10 includes the capability to do a comprehensive evaluation of life-cycle costs. The year-by-year cash flow of the building is determined and discounted to the present value.

First cost is of paramount importance to a building owner. In the ENERGY-10 analysis, this includes a fixed cost component, the cost of purchasing and installing the HVAC equipment, and added costs due to upgrading the construction associated with applying one or more of the Energy-Efficient Strategies (insulation).

Life-cycle cost provides a way to balance this first cost against future costs, including: mortgage payments, fuel costs ,electric costs maintenance, replacement of HVAC equipment on a periodic basis, resale of the building, property taxes and the benefits due to deducting any combination of the following: utility costs, maintenance costs, replacement of HVAC equipment, mortgage interest and property taxes depreciation.

Each of these costs is calculated for each year of the building life and discounted to its equivalent present value using a discount rate. The sums for each category are totaled to obtain the LCC components, which are then totaled to get the total LCC for the building.

Separate calculations are done for Actual house condition and Best case condition (the best insulation material at optimum insulation thickness for roof and wall) and the difference in the two LCC values is computed. This difference is the net present value, NPV. Other criteria calculated and displayed are benefit-to cost ratio (CBR), and simple payback (SPB).

Also, the emissions of CO2, SO2, and NOx resulting from building energy use are presented in the Summary Information table and Emissions bar graph.

The simulation results will be presented in this Chapter as follows:

1- Analysing the energy performance, LCC and emission of gases from a standard houses types E & 3A.

2- Analysing different insulation materials and widths to reach the best material to be used and the optimum thickness for both roof and walls.

3- Analysing the energy performance, LCC and emission of gases after using the best materials and the optimum thickness condition for both standard houses types.

4- Analysing different construction materials for roof and wall to find the best and suitable roof and wall construction for both standard houses types.

5- Comparing the Analysis of a standard houses with houses using the best roof and wall construction, the best insulation materials and the optimum thickness.

6.2 Analyzing the Energy simulation results for a standard house (Type E & type 3A).

The simulation studies shows that the yearly total energy use in standard house type E was about 114.3 kWh/m^2 and 91.2 kWh/m^2 for Air conditioning load (Figure 6.2.1).

Also, the simulation results show that the yearly total energy use in standard house type 3A was about 128.5 kWh/m^2 with Air conditioning load of 104 kWh/m^2. (Figure 6.2.2)

The different in the cooling load for the two types of the standard house can be attributed to many factors that affecting the cooling load consumption such as building area, building orientation and number of windows.

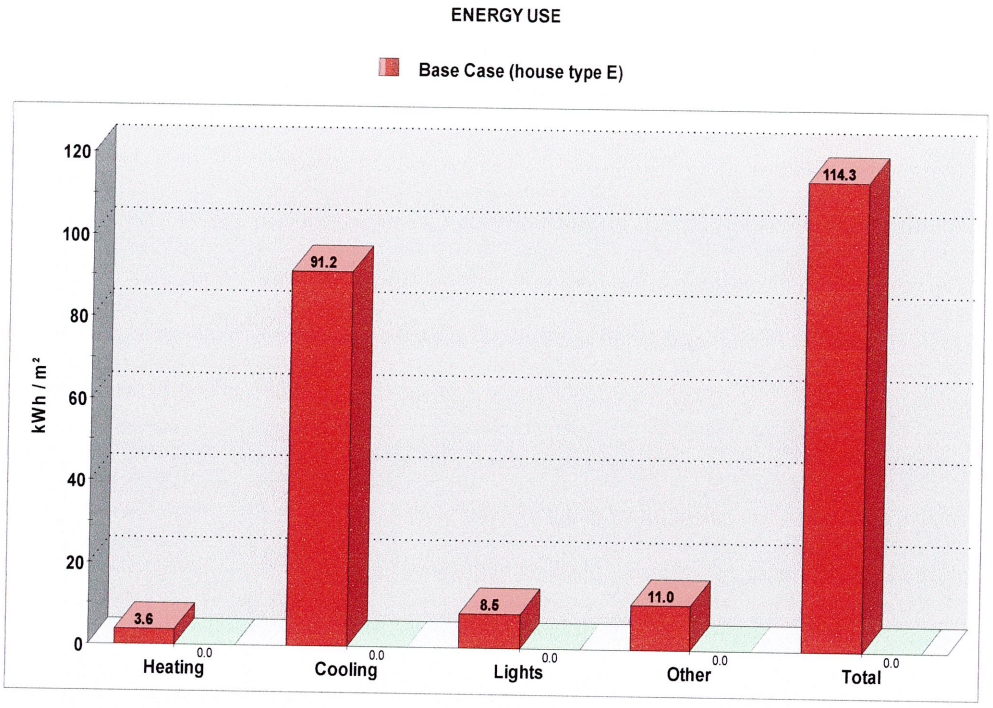


Figure 6.2.1 Annual Energy use and Cooling, heating load for house type E

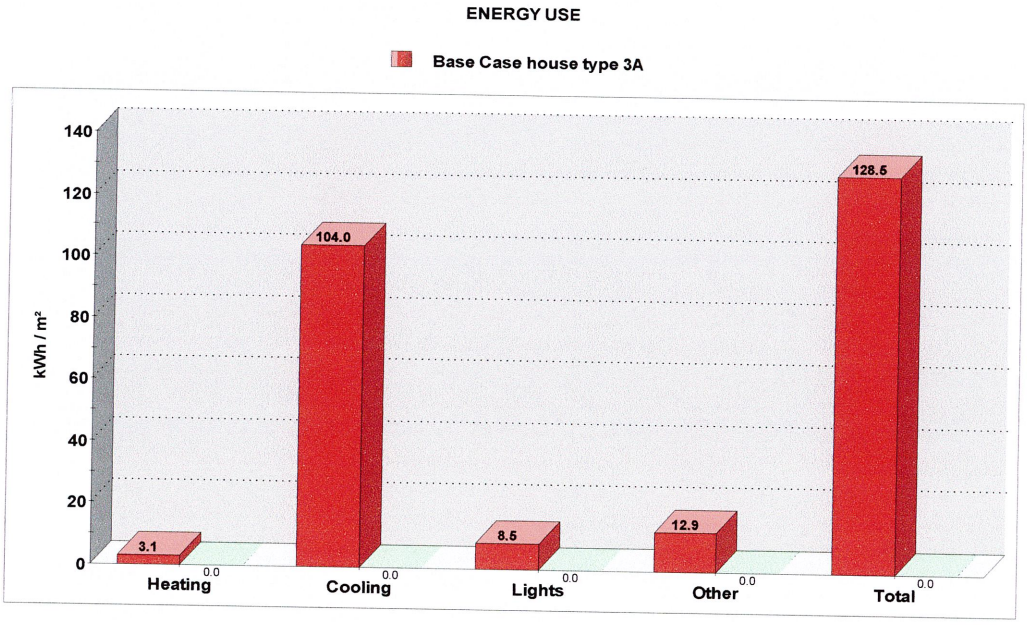


Figure 6.2.2 Annual Energy use and Cooling, heating load for house type 3A

The results show that, the monthly cooling consumption of both standard houses increase rapidly during the summer month (June –September) and its reaches the maximum at August . It is in this month about 4378 kWh and 4645 kWh for type E and type 3A respectively.
(Figure 6.2.3 & Figure 6.2.4)

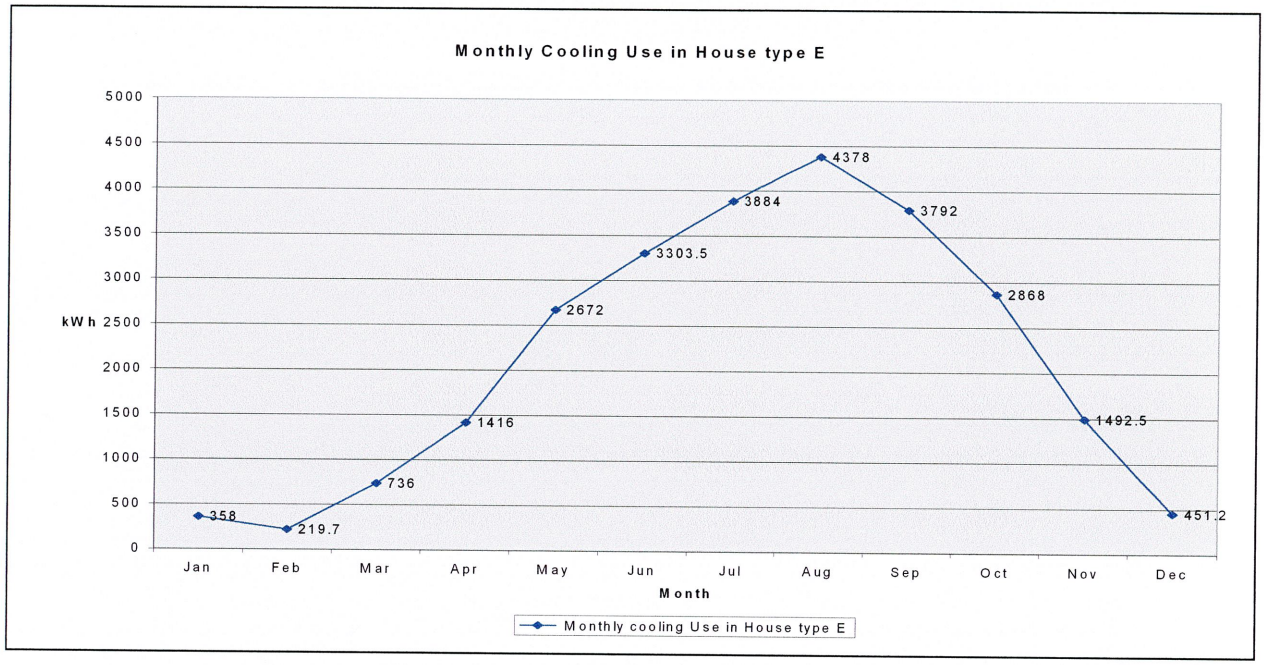


Figure 6.2.3 Monthly Cooling load for house type E

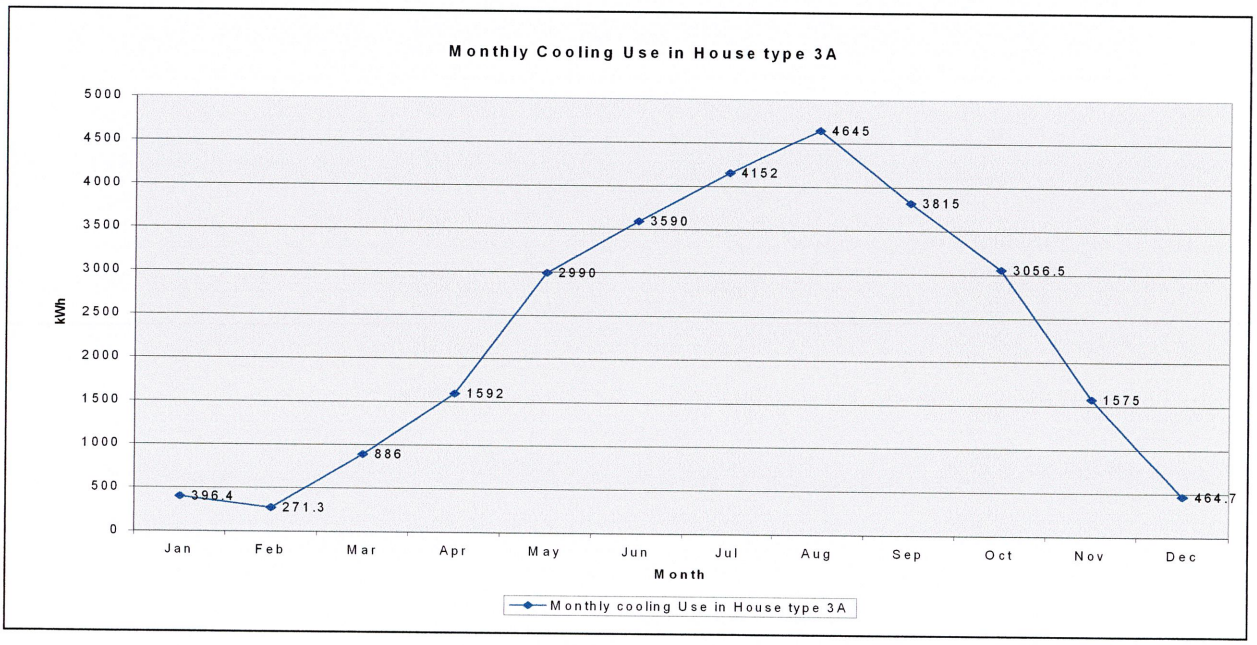


Figure 6.2.4 Monthly Cooling load for house type 3A

The monthly total electric consumption for the two types of the standard house reached the maximum in August and it is about 5044.5 kWh and 5314.4 kWh for type E and type 3A respectively. (Figure 6.2.5 & Figure 6.2.6).

More than 80% of the energy use in both house types is actually consumed by the cooling load during summer season. The obvious reason for that is the higher temperature and relative humidity of the long summer months in Bahrain (hot and humid weather). The use of Air conditioning in the summer cause drastic increase in the power consumption.

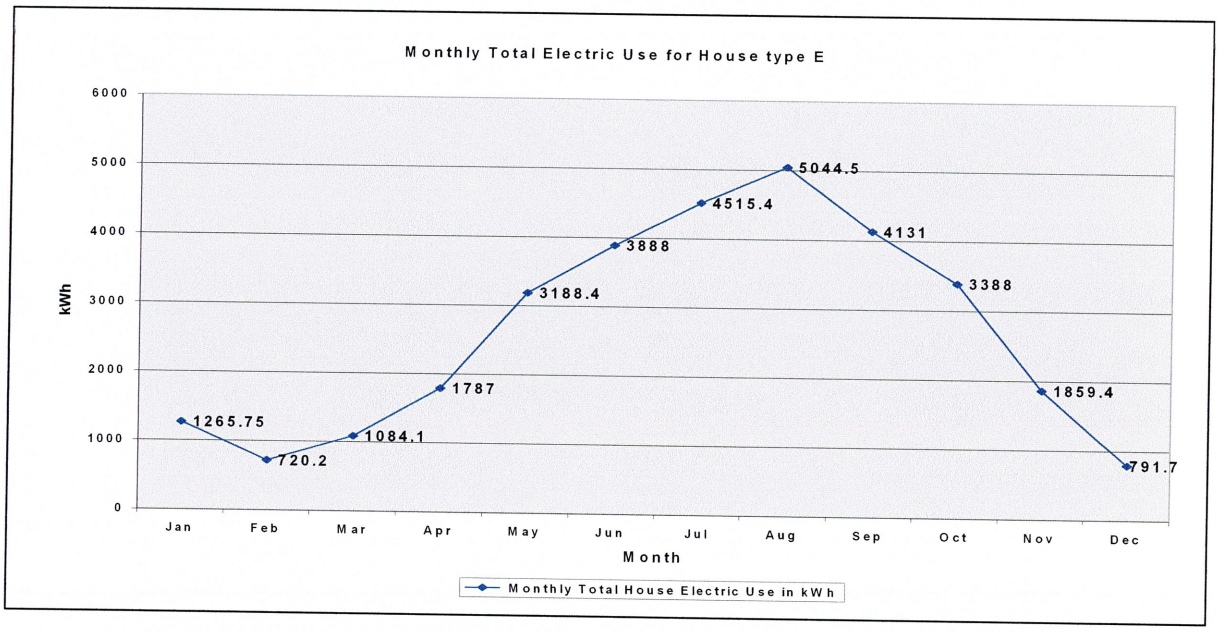


Figure 6.2.5 Monthly Total Electric Use in house type E

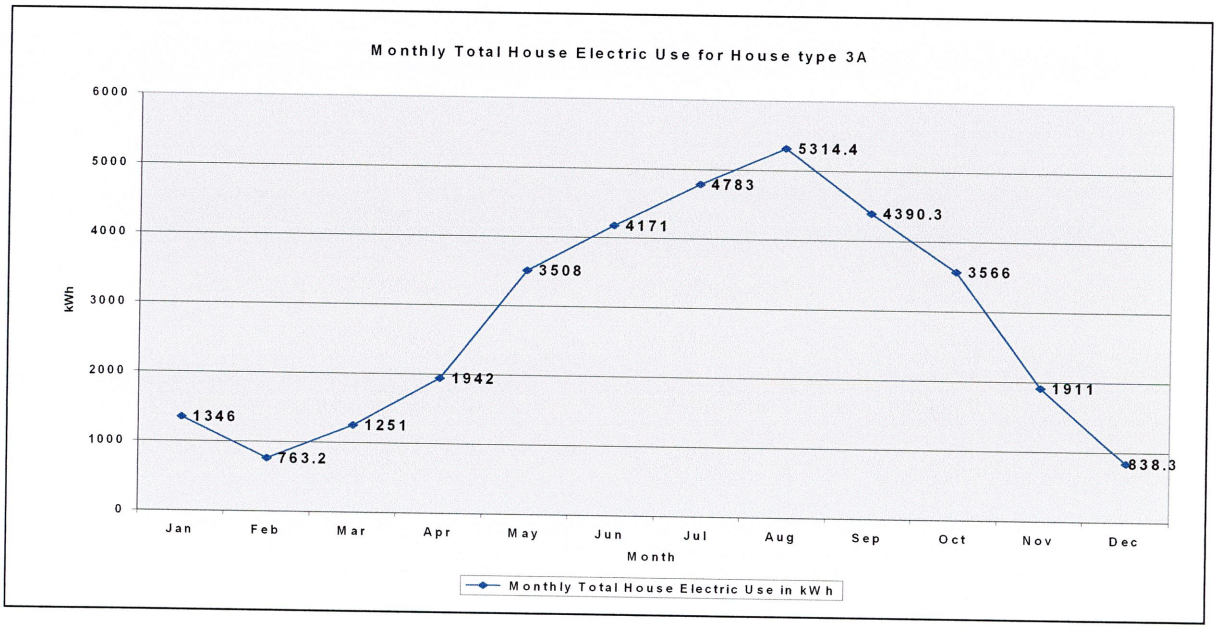


Figure 6.2.6 Monthly Total Electric Use in house type 3A

The life cycle cost Analysis for type E house shows that, the Capital cost of the house is about BD35,553 , utilities cost of BD11300, HVAC cost of about BD 4243 and total life cycle cost of BD51,096 (Figure 6.2.7).

The life cycle cost Analysis for type 3A house shows that, the capital cost of the house is about BD27,696 ,utilities cost of BD11490, HVAC cost of about BD 3143 and total life cycle cost of BD42,329 (Figure 6.2.8).

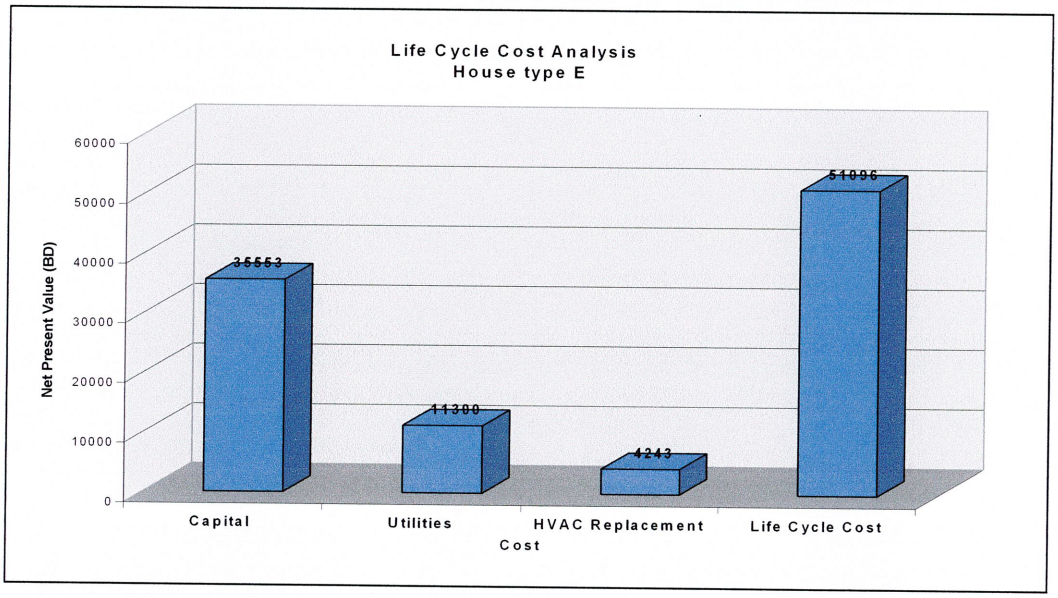


Figure 6.2.7 Life Cycle cost Analysis for house type E

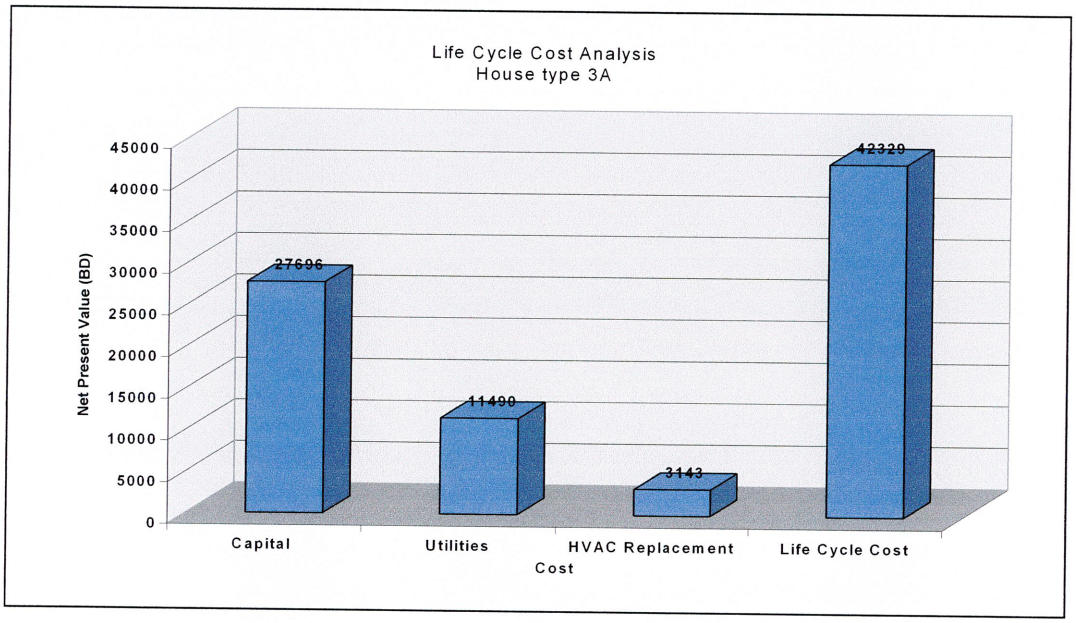


Figure 6.2.8 Life Cycle cost Analysis for house type 3A

The ENERGY-10 converts the energy consumption (fuel and electricity) into emissions of CO2, SO2, and NOx resulting from building energy use. Figures 6.2.9 & 6.2.10, shows the amount of the emissions of CO2, SO2, and NOx resulting from building energy use for house type E and 3A respectively.

The annual emission results show that, the amount of pollutant as follows:

- SO2 is about 112 kg and 91 kg for house type E and 3A respectively.
- NOx is about 58kg and 47 kg for house type E and 3A respectively.
- CO2 is about 19107 kg and 15447 kg for house type E and 3A respectively.

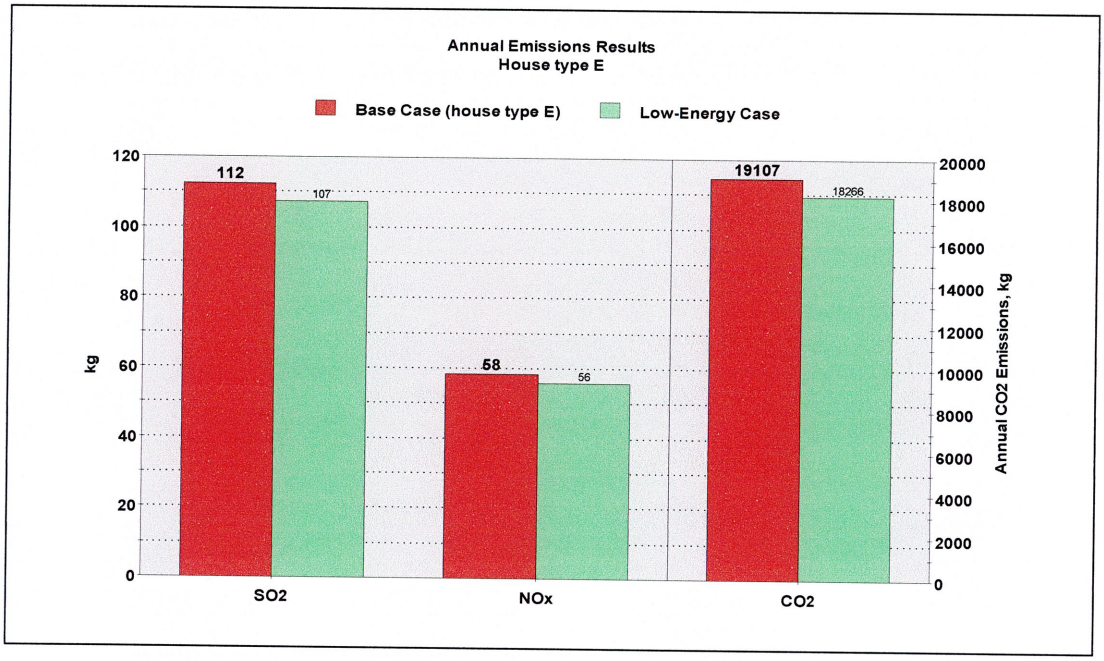


Figure 6.2.9 Annual Emission for house type E

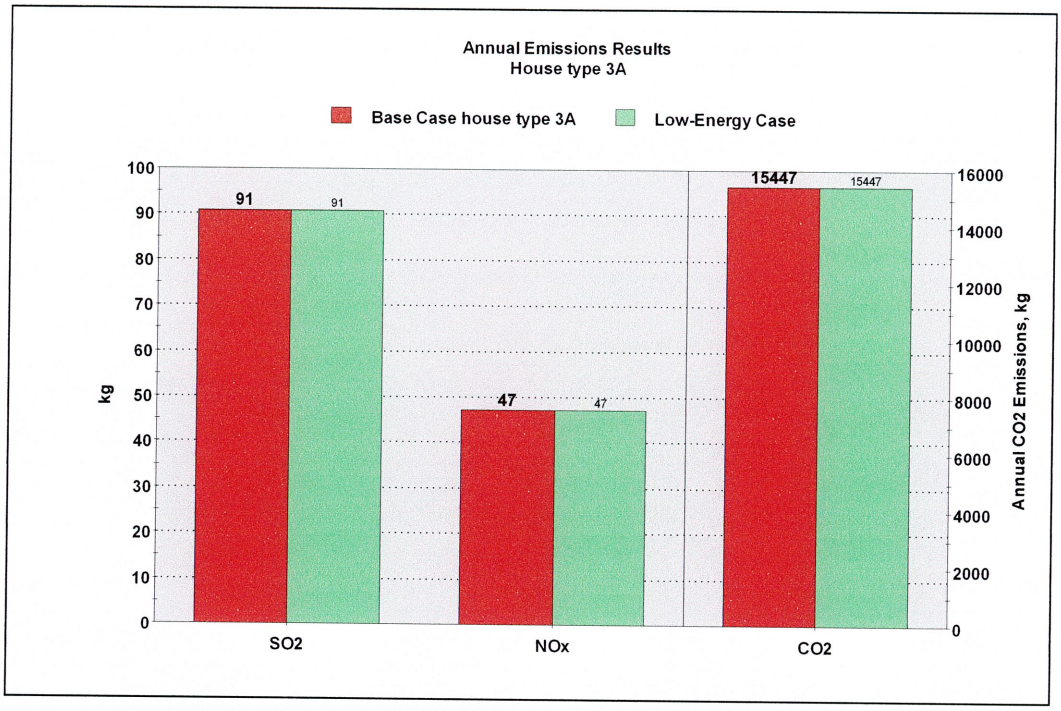


Figure 6.2.10 Annual Emission for house type 3A

More data are available in Appendix (A) regarding the simulation results of both types of actual standard houses.

6.3 Analysing different insulation materials and widths.

6.3.1 Optimum Insulation thickness

The optimum thickness of insulation is the best determining in economical and energy conservation terms. This can be achieved by comparing the saving that can be obtained for a range of insulation thicknesses considered.

The range of insulation thicknesses for the three types of thermal insulation investigated is from 20, 30, 40, 50 and 60 mm for wall construction and from 50, 75, 100, 150 mm for roof construction.

6.3.1.1 Optimum Insulation thickness for Roof Construction

The simulation result shows that, the saving increase with the increase of the insulation thickness. It is also shows that a 100 mm thickness is optimum and economical for the roof construction of standard house in Bahrain.

6.3.1.2 Optimum Insulation thickness for Wall Construction

The simulation result shows that, the saving increase with the increase of the thickness. It is also shows that a 50 mm thickness is optimum and economical for the wall construction of standard house in Bahrain.

6.3.2 Best Thermal Insulation Material.

Thermal insulation is defined by ASHRAE as a material or assembly of materials used primarily to provide resistance to heat flow to reduce energy use, enhances comfort, reduce the size of AC system and reduce the cost.

Three types of insulation materials commonly used in Bahraini building construction (polystyrene, fiberglass and polyurethane) were used in this study to add them to the different wall and roof construction with different thickness. The main properties of the three insulation materials was shown in table (3.4)

The simulation showed that, when adding the polyurethane insulation to different types of roofs (100mm) and walls (50mm) construction, a significant reduction was achieved in annual cooling load. It was 29.6 % and 32 % for house type E and type 3A respectively.

Where the reduction in annual cooling load from using fiberglass and polystyrene was about (25%, 20% and 27.2%, 18%) for house type E and type 3A respectively (Figures 6.3.1 (a) & 6.3.1 (b)).

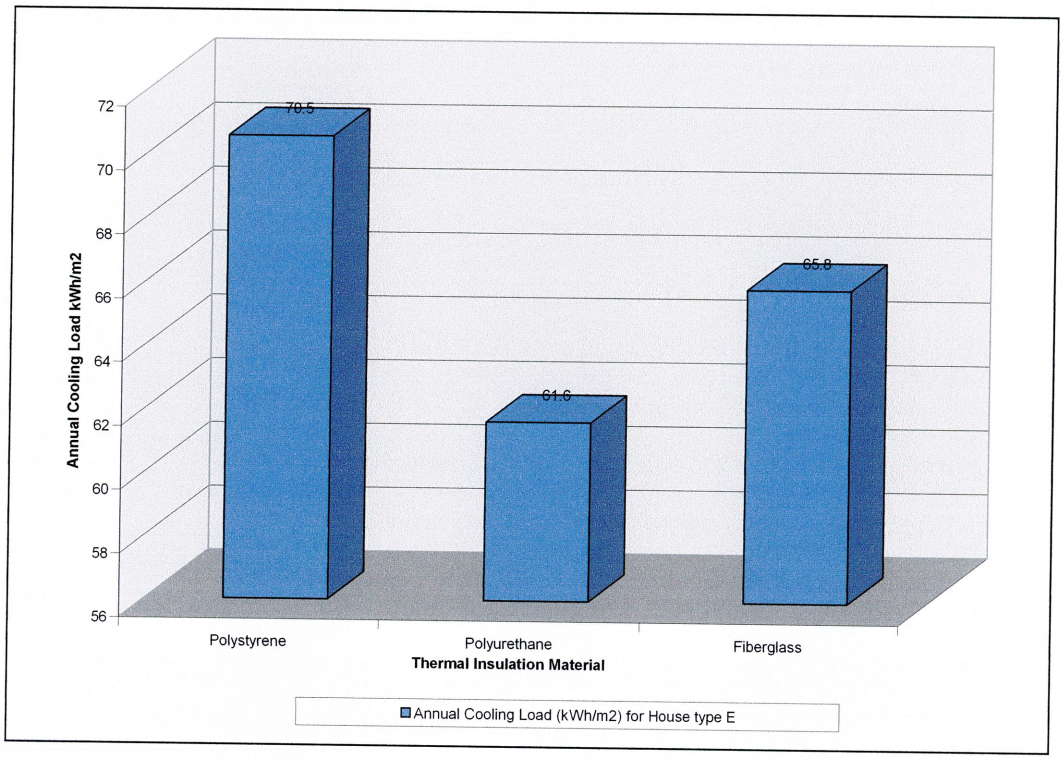


Figure 6.3.2(a) Best Thermal Insulation Material for house type E at 100mm roof and 50mm wall thickness

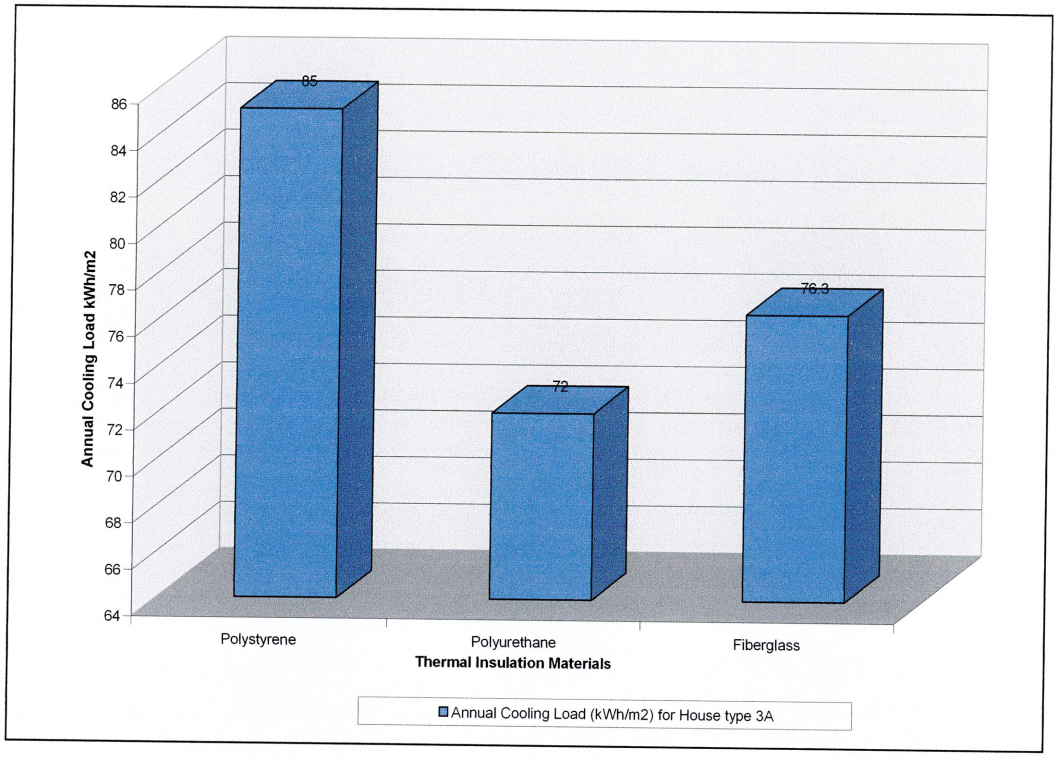


Figure 6.3.2(b) Best Thermal Insulation Material for house type 3A at 100mm roof and 50mm wall thickness

Also, a U-value of 0.4W/m^2°C for polyurethane of 100mm is recommended to use in roof construction of standard houses and a U-value of 0.56W/m^2°C for polyurethane of 50 mm is recommended to use in wall construction of standard houses.

A sample of the simulation results related to best walls and roof constructions; best thermal materials and optimum insulation thickness are shown in Appendix (C).

6.4 Analysing the Effect of the Application of Insulation on the standard house (Type E & type 3A).

The application of insulation with actual roof construction and it is effect on the energy use of the two types of standard house is analyzed. This was compared with the base case (without insulation) of each type.

Polyurethane is found to be the best insulation material used for buildings and 100 mm is the optimum insulation thickness used in roof. This is shown in section 6.3.

The result show that, the addition of 100mm thickness polyurethane insulation to the actual roof construction reduce the energy use and cooling load by about 21%, 18 % and 25%, 22% for house type E and type 3A respectively.(Figures 6.4.1 & 6.4.2)

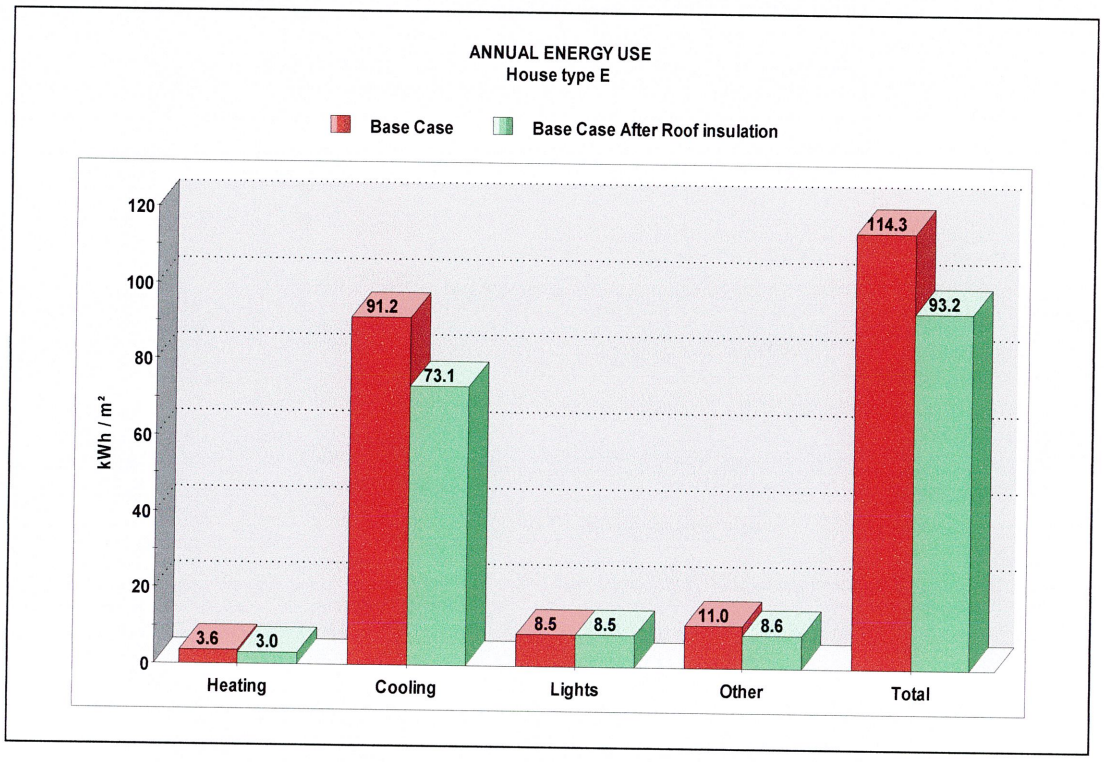


Figure 6.4.1 Annual Energy use and Cooling, heating load for house type E after using 100mm polyurethane insulation on actual Roof

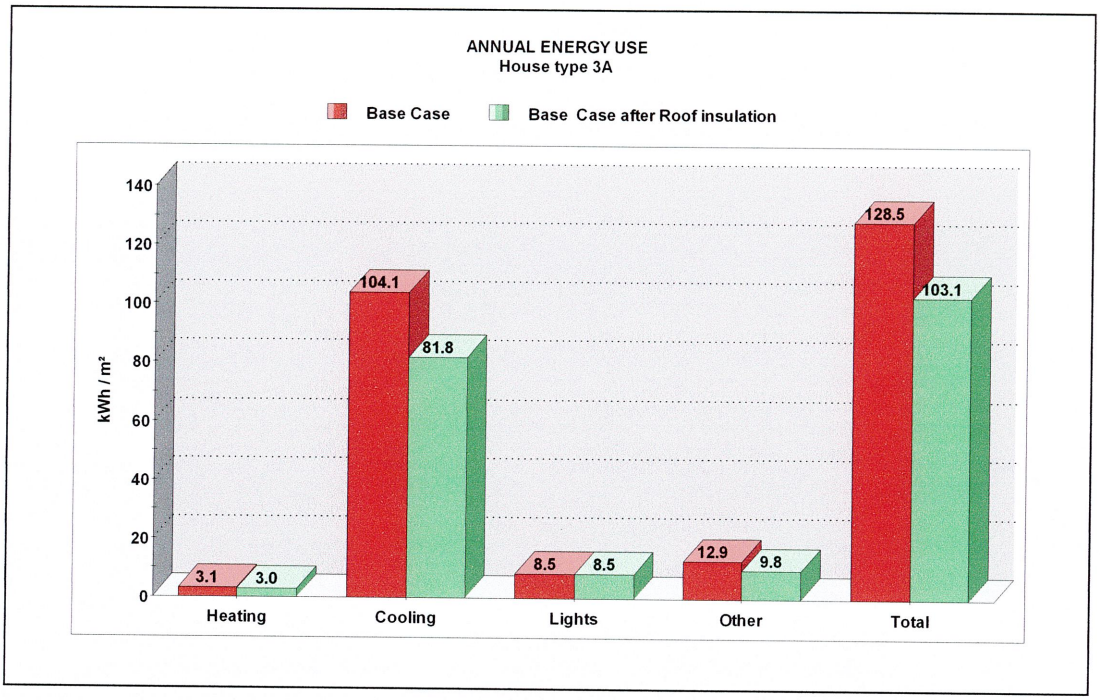


Figure 6.4.2 Annual Energy use and Cooling, heating load for house type 3A after using 100mm Polyurethane insulation on actual Roof

Similarly, the application of insulation with wall construction is also analyzed and compared with the actual wall construction of the both type of the standard house (without insulation).

The analysis show that, the effect of application of polyurethane insulation to the actual wall construction with insulation thickness of 50mm (optimum insulation thickness used in wall. For details section 6.3) reduce the energy use and cooling load by a bout 19%, 16% and 22%, 19% for the house type E and type 3A respectively. (Figures 6.4.3 & 6.4.4)

The simulation result showed that if we applied 100mm of polystyrene insulation to the actual houses roof and 50mm of polystyrene insulation to actual house walls, a significant improvement occur on energy use and cooling load on the both types of standard houses.
The energy use and cooling load were reduced by about 25%, 21% and 29%, 25% for the house type E and type 3A respectively. (Figures 6.4.5 & 6.4.6)

The simulation results show that, there is a significant reduction in energy use and cooling load after adding the insulation to both roof and walls.

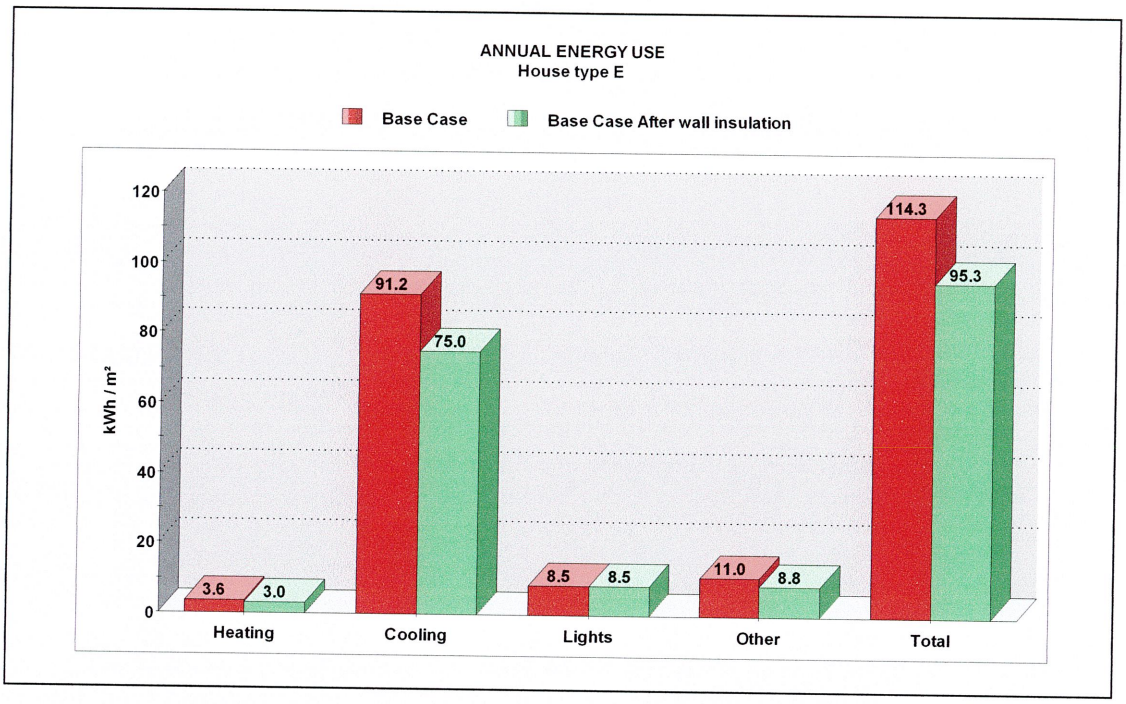


Figure 6.4.3 Annual Energy use and Cooling, heating load for house type E after using 50mm polyurethane insulation on actual Wall

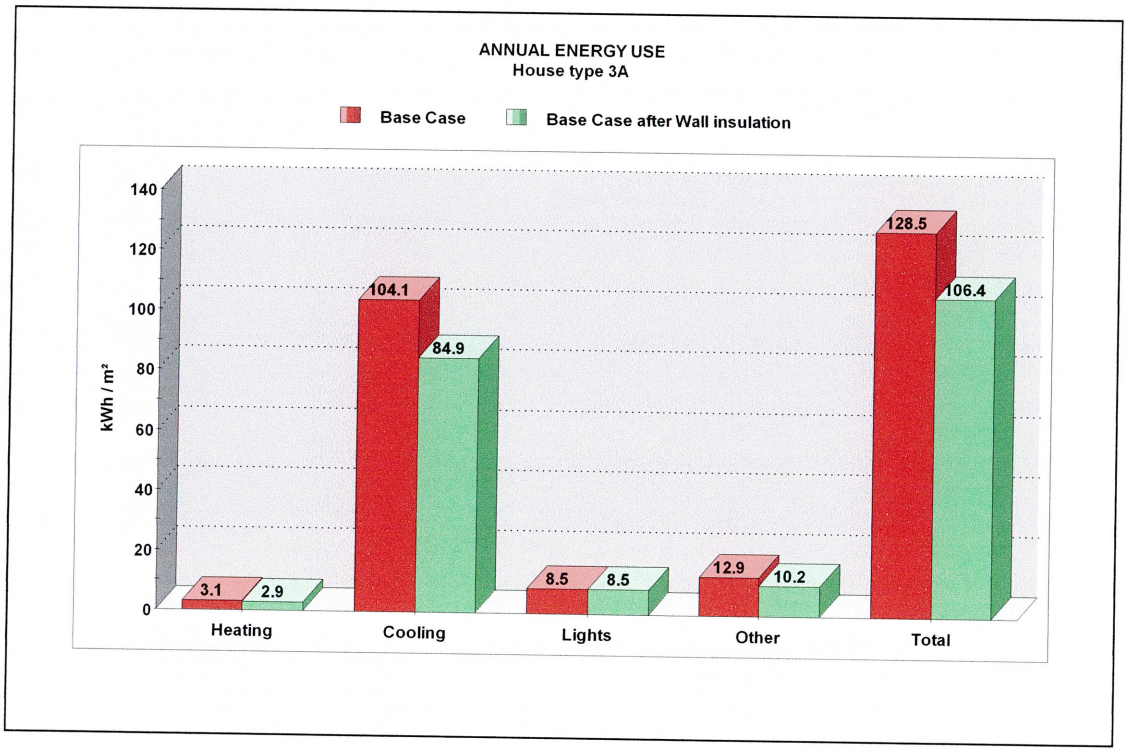


Figure 6.4.4 Annual Energy use and Cooling, heating load for house type 3A after using 50mm polyurethane insulation on actual Wall

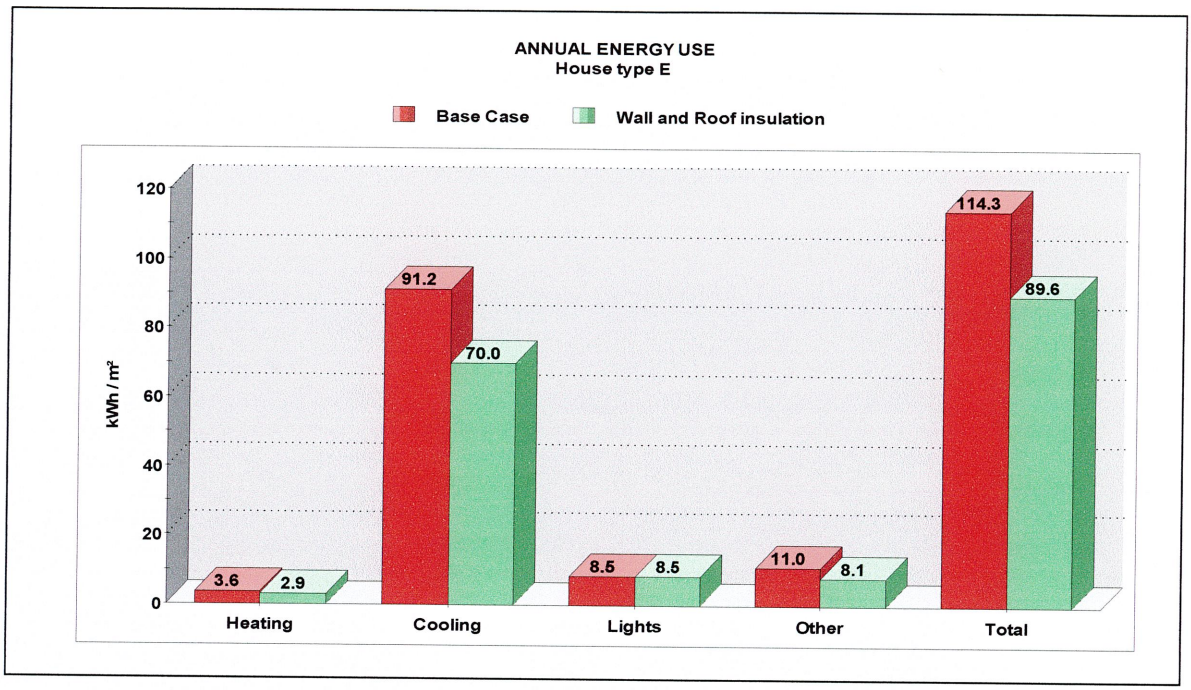


Figure 6.4.5 Annual Energy use and Cooling, heating load for house type E after 100mm & 50mm polyurethane insulation on actual Roof and Wall respectively

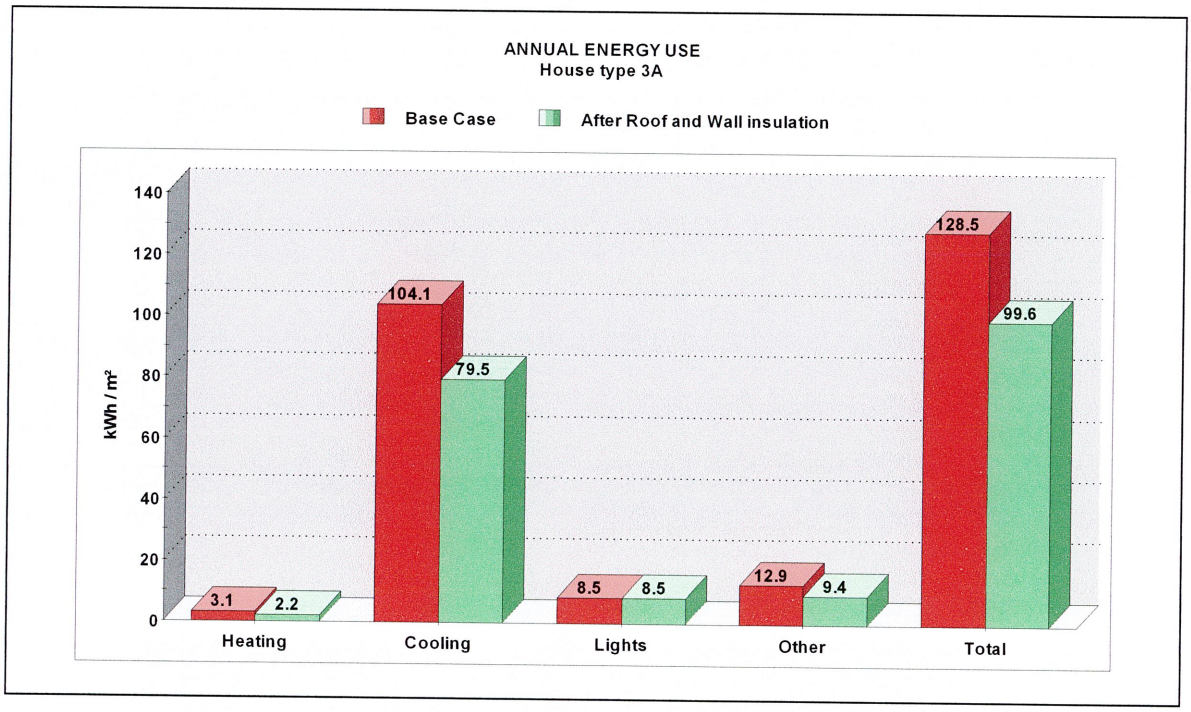


Figure 6.4.6 Annual Energy use and Cooling, heating load for house type 3A after 100mm & 50mm polyurethane insulation on actual Roof and Wall respectively

Figures 6.4.7 and 6.4.8, shows that Life Cycle Cost of the actual houses were reduced due to the application of insulation to the both roof and walls of these houses with a saving cost of about BD1045.5 and BD 1007.24 for the house type E and type 3A respectively.

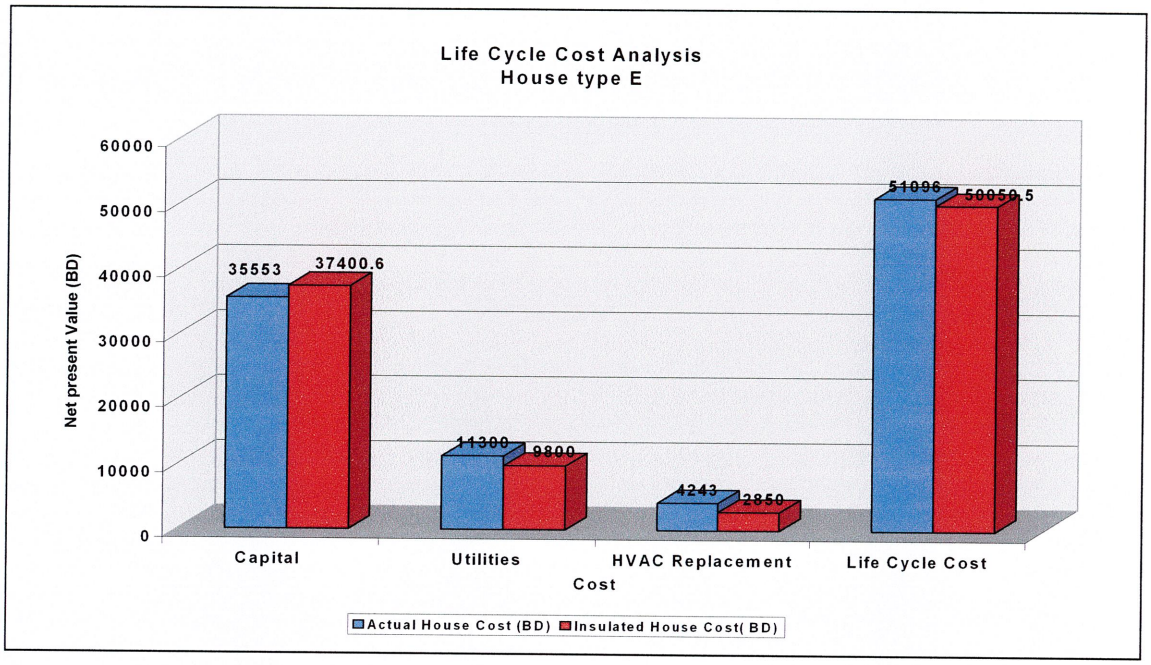


Figure 6.4.7 Life Cycle Cost Analysis for house type E after using Insulation on actual Roof and Wall

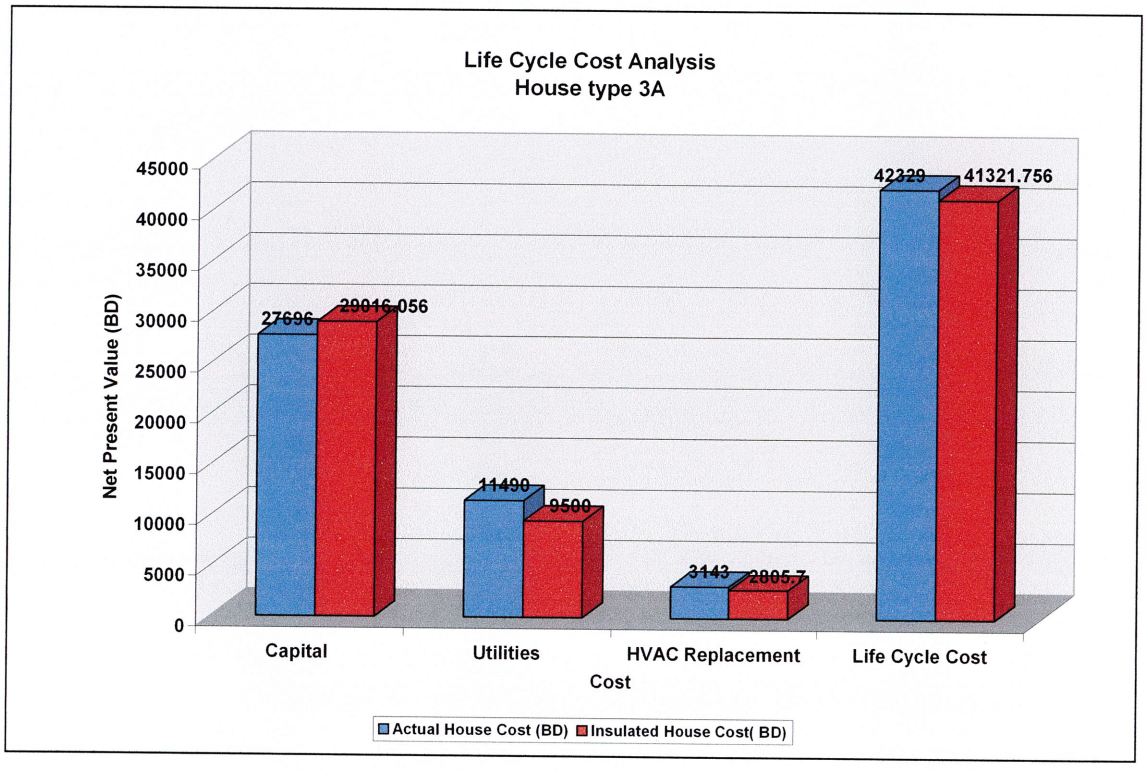


Figure 6.4.8 Life Cycle Cost Analysis for house type 3A after using Insulation on actual Roof and Wall

Figures 6.4.9 and 6.4.10, shows that the amounts of emission of the major pollutants SO_2, NOX, CO2 reduced annually due to the application of insulation to the base case of standard houses. It reduced by about 16%, 8%, 14.6% and 8%, 4%, 9% for the house type E and type 3A respectively.

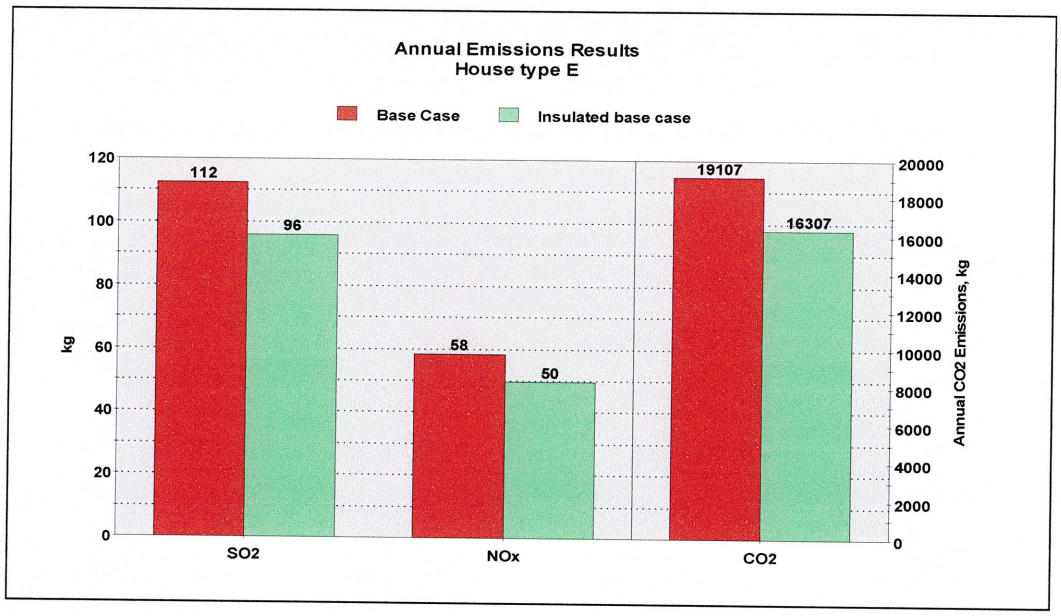


Figure 6.4.9 Annual Emission for house type E after using Insulation on actual Roof and Wall

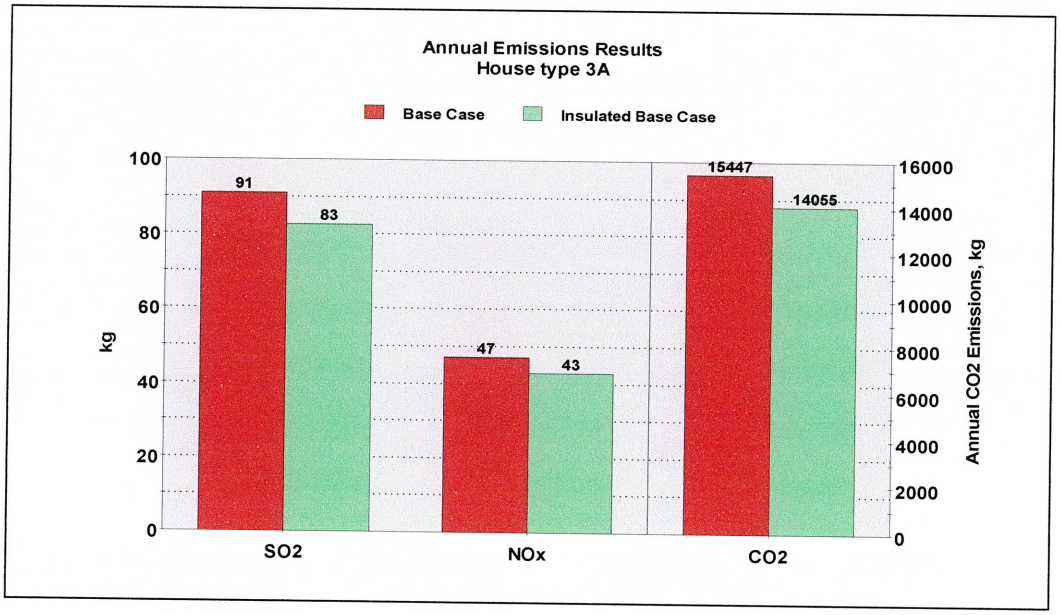


Figure 6.4.10 Annual Emission for house type 3A after using Insulation on actual Roof and Wall

More results about application of different insulation material and thickness on actual standard house is shown in appendix (B)

6.5 Analysing different Roof and Wall construction materials

6.5.1 Best Roof Construction.

Five different roof construction commonly used in Bahrain were investigated in this simulation study. They are wooden beam roofing (Murabaa), cast in site reinforced slab and precasted type slab and hollow casted slab, and a base case roof construction. This was shown in chapter five.

The simulation investigation showed, that the energy use for the insulated roof #4 (insulated cast insite reinforced slab) was lower and better than, the other roofs construction and reduce the cooling load by 16 % and 18 % for type E and type 3A respectively.(Figures 6.5.1 (a) & 6.5.1 (b))

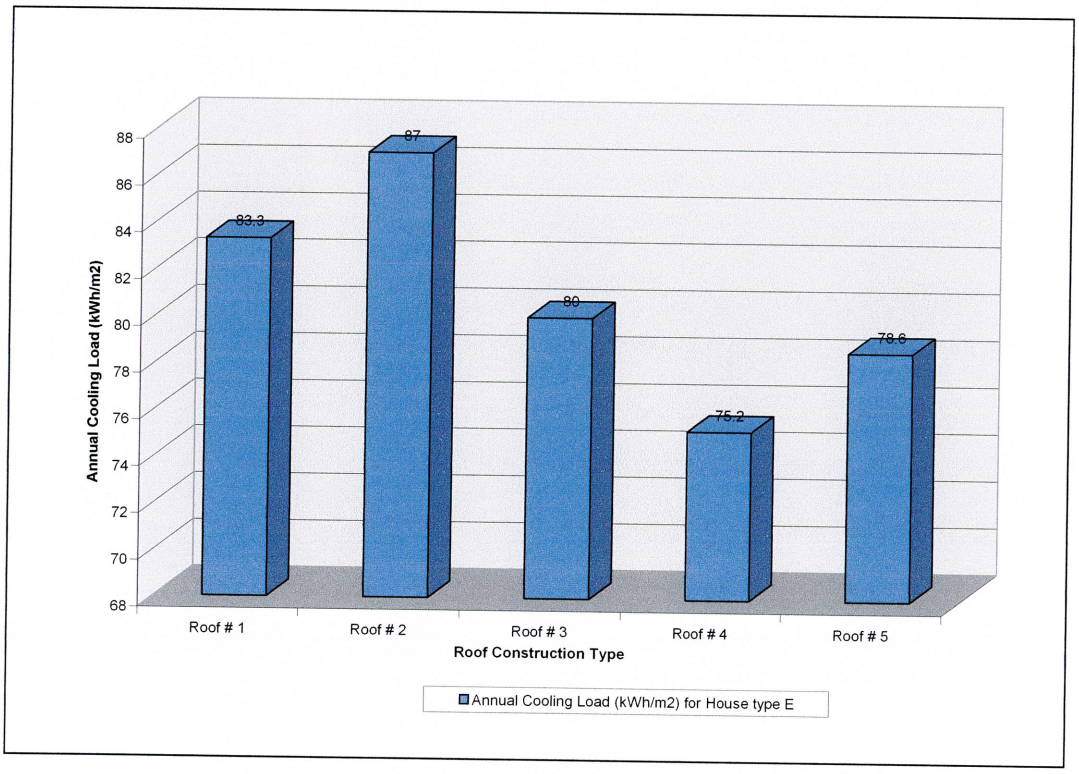


Figure 6.5.1(a) Best Roof Construction for house type E

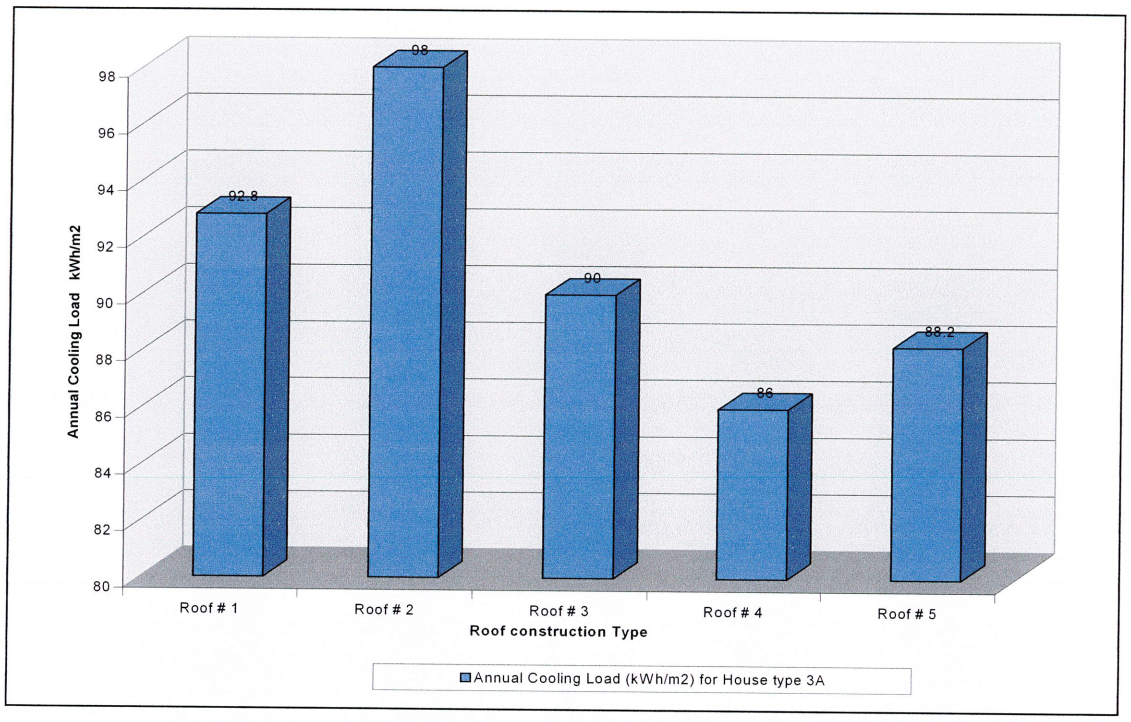


Figure 6.5.1(b) Best Roof Construction for house type 3A

6.5.2 Best Wall Construction.

Most of the residential Building in Bahrain is constructed using wall bearing method. Four different wall construction (shown in chapter 5) including the base case were investigated by the simulation study.

The simulation investigation showed that, the energy use for both types of standard house when using wall construction #2 (insulated double block wall) has a significant improvement compared with other walls constructions and reduces the energy and cooling load by about 14 % and 17 % for house type E and type 3A respectively. (Figures 6.5.2 (a) & 6.5.2 (b))

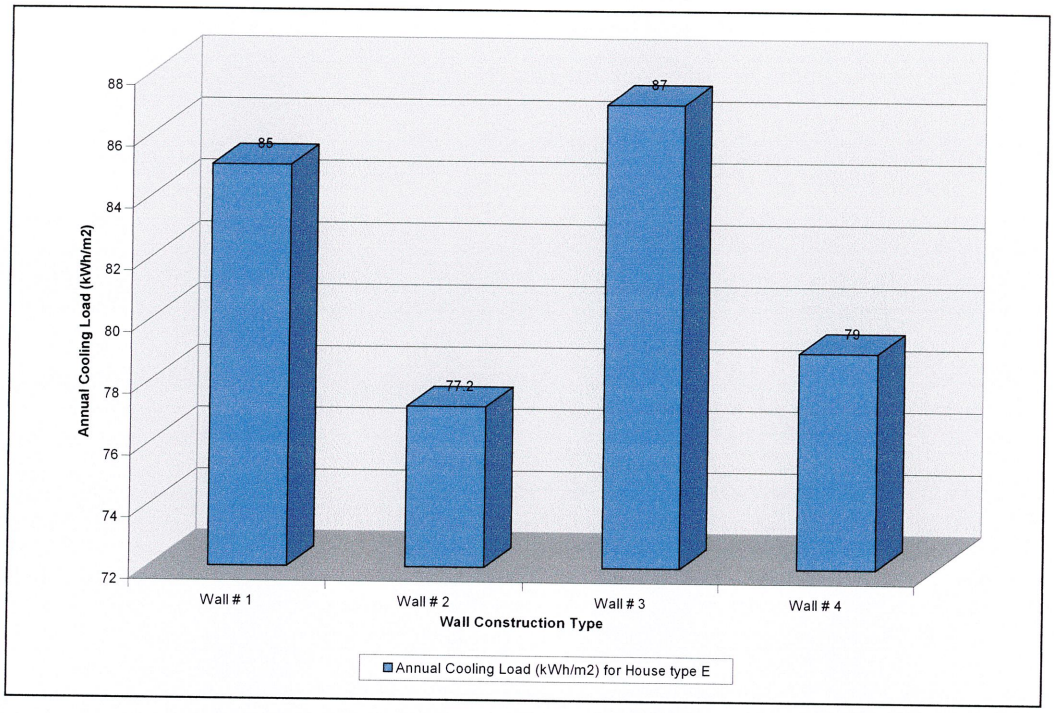


Figure 6.5.2(a) Best Wall Construction for house type E

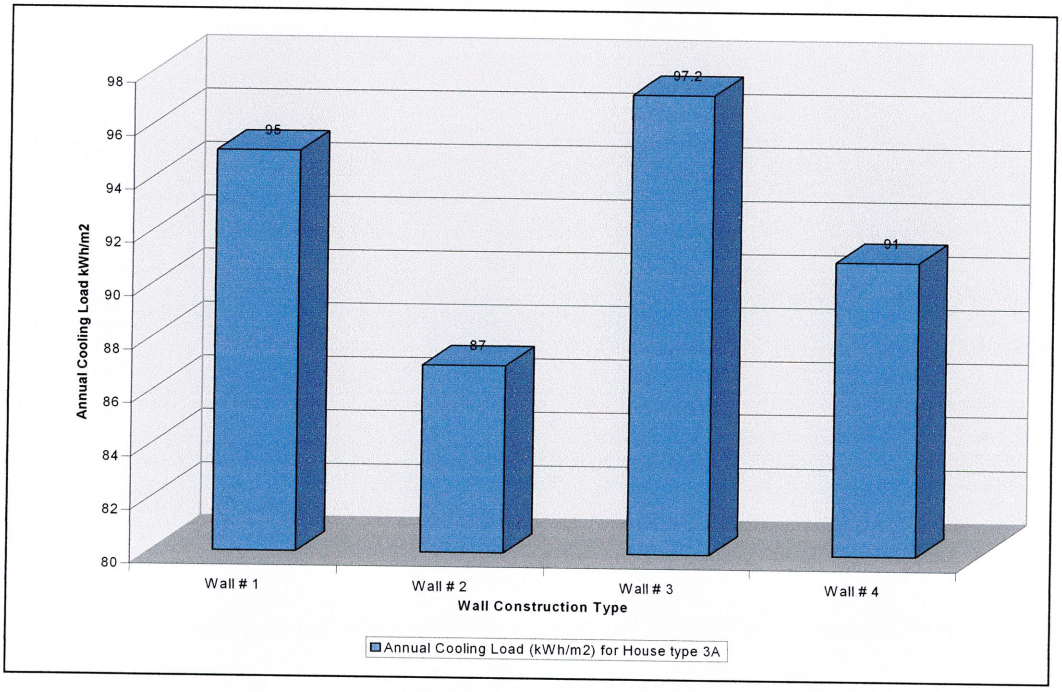


Figure 6.5.2(b) Best Wall Construction for house type 3A

6.6 Simulation Comparison between the standard house (Type E & type 3A) with Best House condition (houses uses best roof, best walls, best insulation materials and optimum insulation wall & roof thickness)

6.6.1 Analysis of the Energy Simulation Results.

The study showed that, when we apply the optimum thickness of polyurethane insulation (100mm in roof and 50mm in wall) to best wall and roof constructions to the both types of the standard house, a significant improvement occur to the house annual energy use and the cooling load compare to the base case result.

Significant reductions in cooling load at about 34%, 30% and 32 %, 28% for the house type E and type 3A respectively. (Figure 6.6.1(a) & Figure 6.6.1(b))

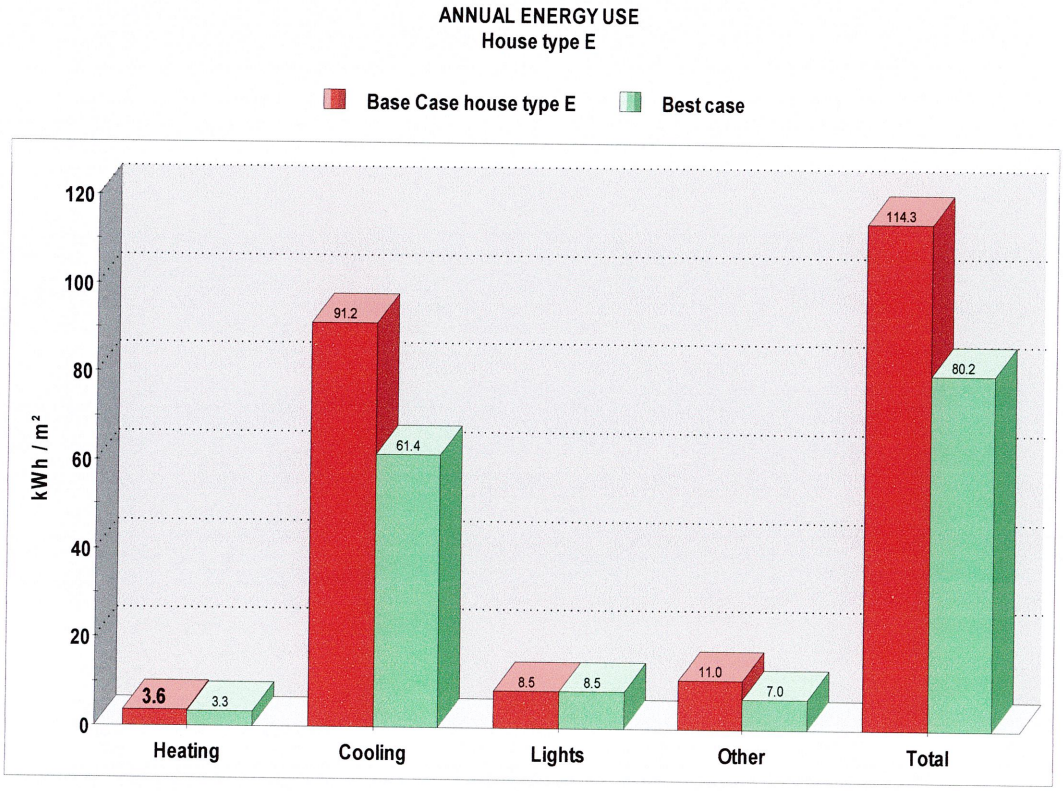


Figure 6.6.1(a) Annual Energy use and Cooling,, heating load for house type E

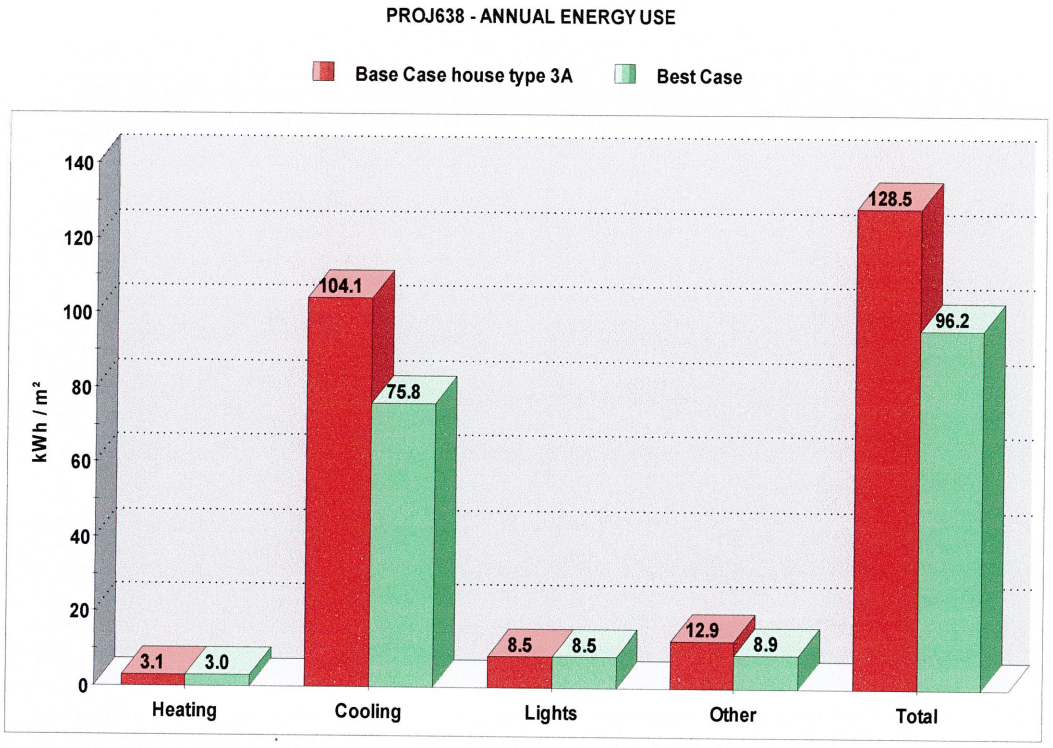


Figure 6.6.1(b) Annual Energy use and Cooling,, heating load for house type 3A

Further more, the application of best condition on standard house lead to a siginificant reduction on the monthly cooling of both standard houses during the summer month (June–September) as shown in Figure 6.6.1(c) and Figure 6.6.1(d)

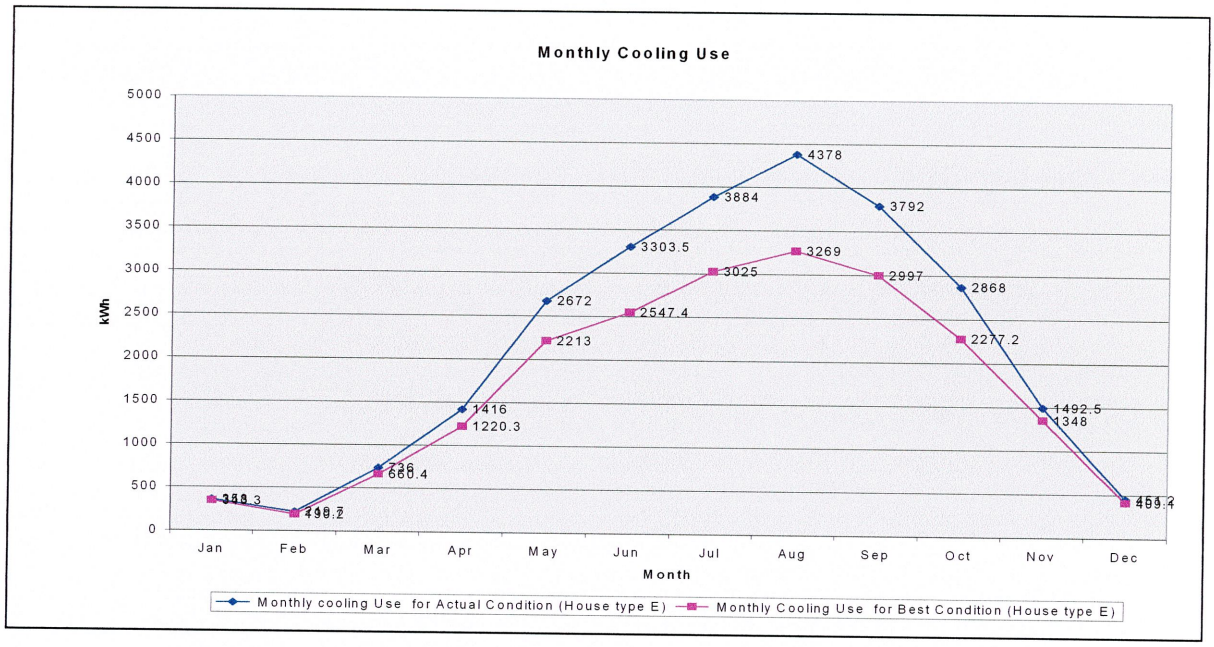


Figure 6.6.1(c) Monthly Cooling Use in house type E

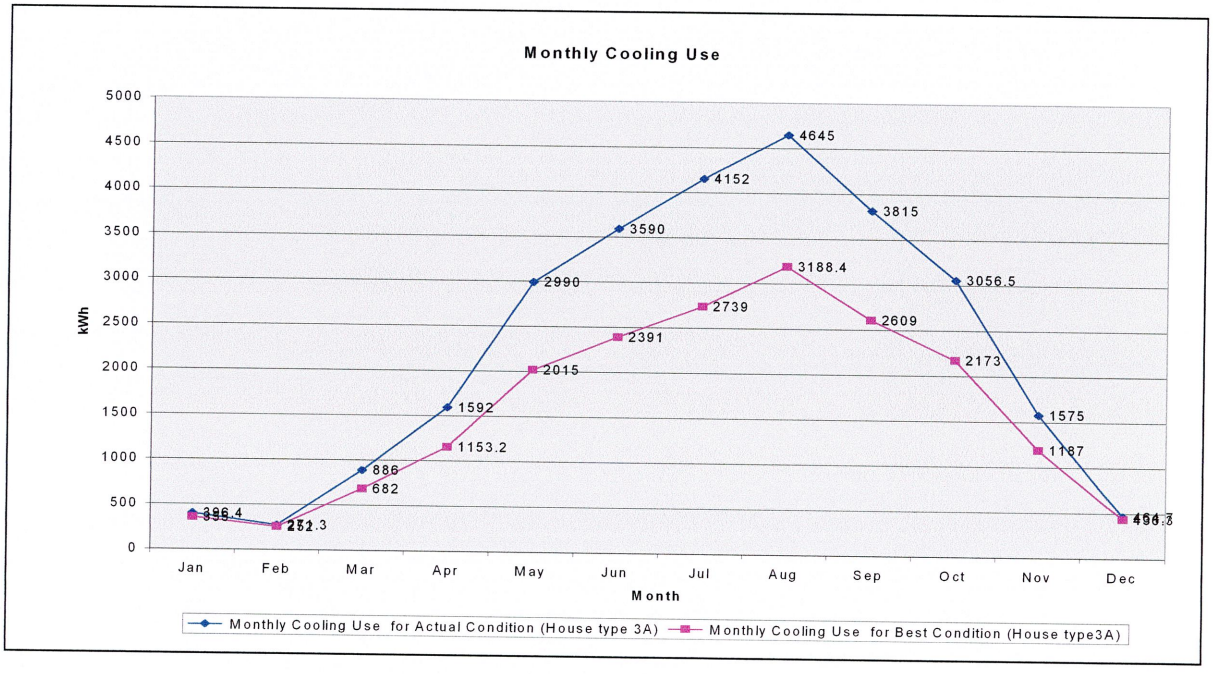


Figure 6.6.1(d) Monthly Cooling Use in house type 3A

The overall effect of the application of best condition on standard house was reflected in the reduction in the monthly electric demand for the two types of the standard house.

For example, in August the total electric load was reduced from 5044.5kWh to 4077 kWh and from 5314.4 kWh to 3675 kWh for type E and type 3A respectively. (Figures 6.6.1(e) and 6.6.1(f))

The simulations results indicate that the application of best condition on standard houses is significant in reducing the cooling load as well as the electricity consumption.

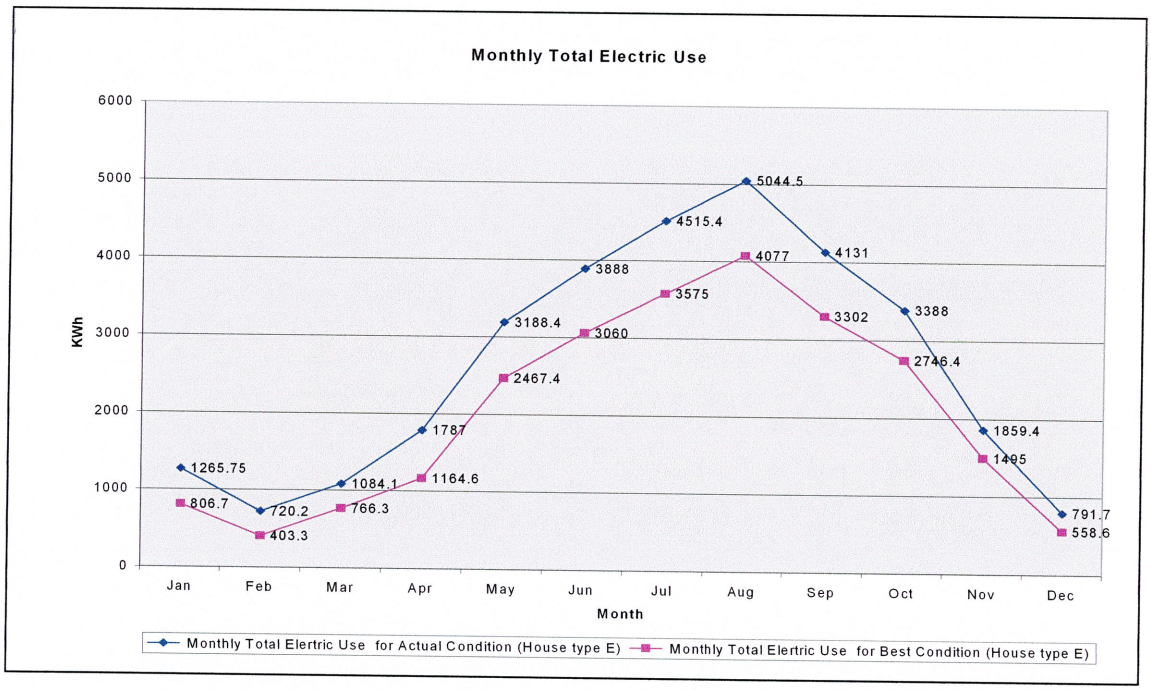


Figure 6.6.1 (e) Monthly Total Electric Use in house type E

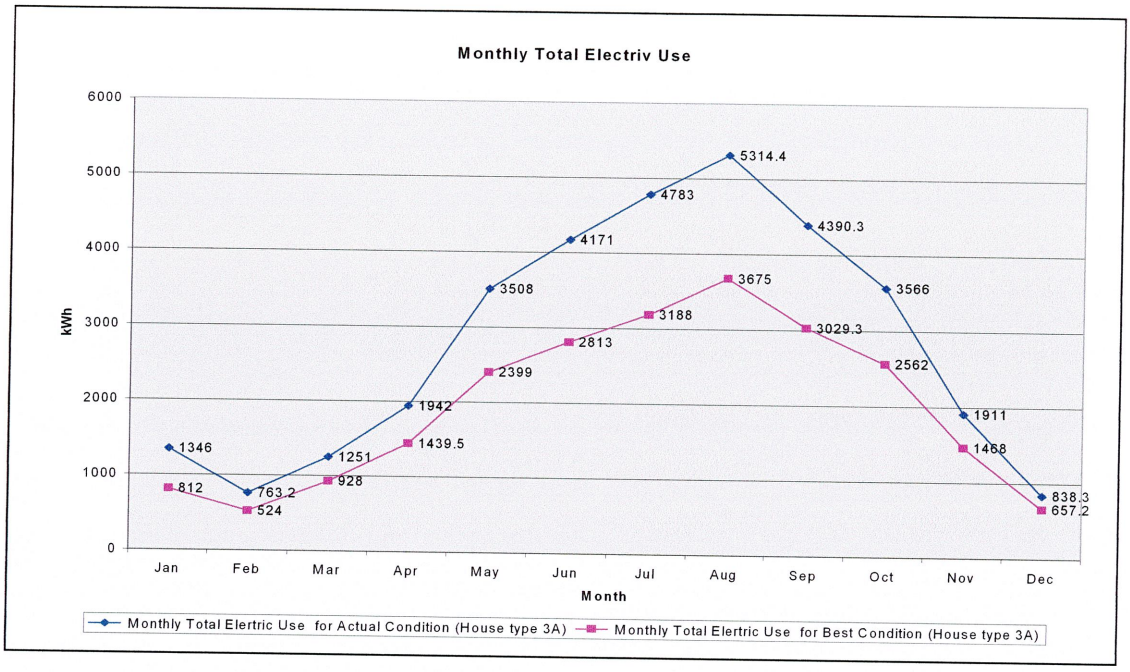


Figure 6.6.1 (f) Monthly Total Electric Use in house type 3A

6.6.2 Life Cycle Cost Analysis.

Comparative analyses of energy saving due to the application of insulation have being investigated. It is expressed and illustrated in monetary terms to provide a meaningful means to the comparison of the economical benefits for this modification to the standard house.

Figures 6.6.2 (a) and 6.6.2 (b), shows that the capital cost of the standard houses increased when we used the insulation in construction due to adding of insulation cost to the actual construction cost of best condition.

The energy cost (utility cost) is reduced by about BD 3500 and BD3490 for type E and type 3A respectively.

Also the life cycle cost of both types is reduced due to the total saving cost. The saving in the life Cycle cost is about BD 3878.36 and BD 4117.8 for type E and type 3A respectively. This result shows that, the Best condition house is more cost effective than Base case house.

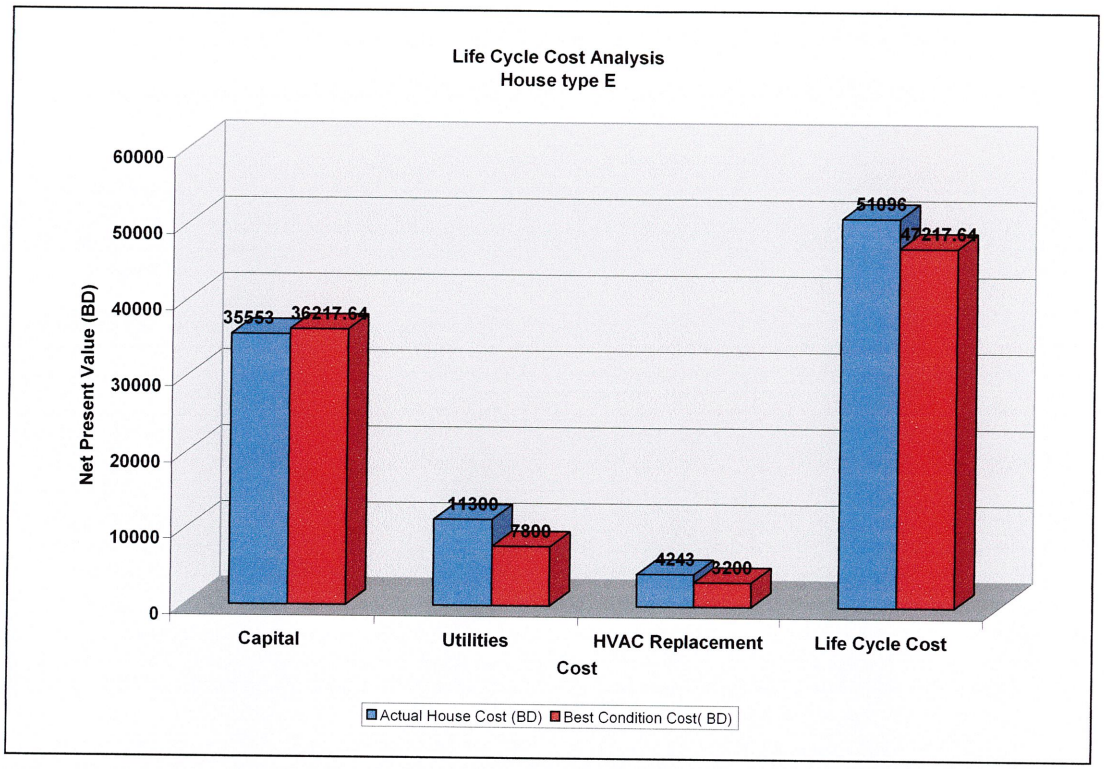


Figure 6.6.2 (a) Life- Cycle cost Analysis for house type E

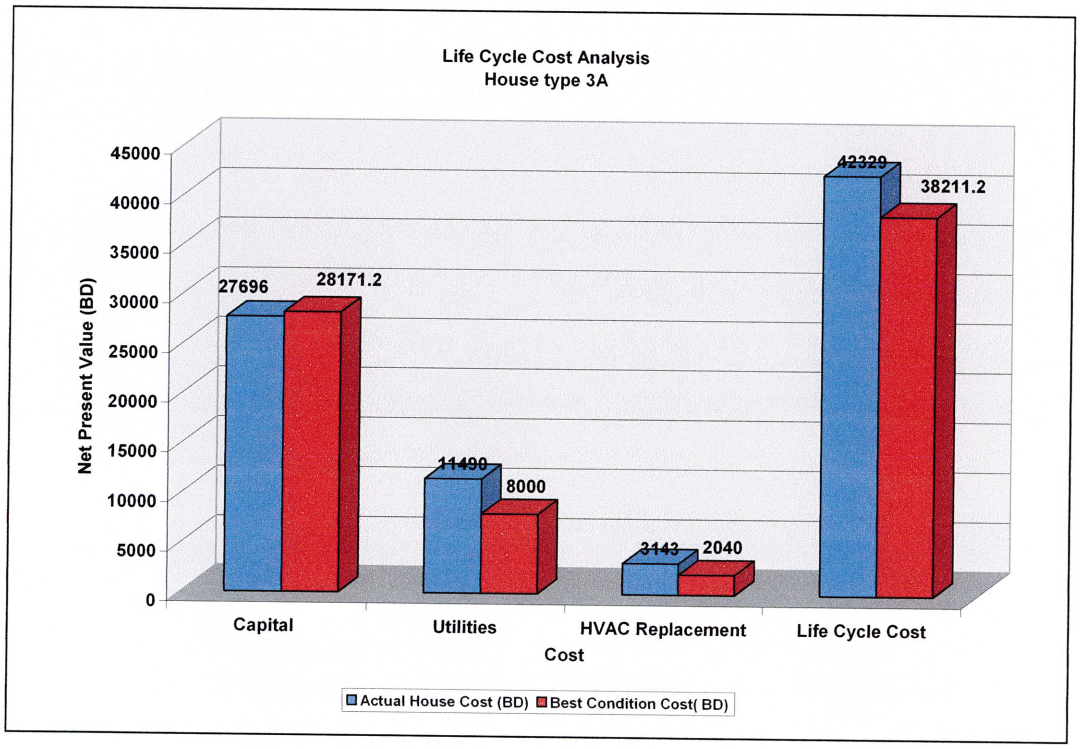


Figure 6.6.2 (b) Life- Cycle cost Analysis for house type 3A

Separate calculations were done for base case and best condition case and the difference in the two LCC values is computed. This difference is the net present value, NPV.

Other criteria calculated are internal rate of return (IRR), benefit-to cost ratio (CBR), and simple payback (SPB). Table (6.6.2).

Table (6.6.2) Summaries the Cost Analysis after Appling the Insulation Strategy.

Standard house	Type E	Type 3A
Money Saving (BD)	3878.36	4117.8
Simple Payback	2.4 years	2.65 years
Benefit/Cost Ratio	1.8	1.5

The results clearly show a short pay back period, due to addition of insulation to both roof and walls. These short pay back periods provide a most practical proof to convince the consumers for using insulation by the great financial benefits indicated.

The advantages of insulation as far as the owner is concerned are not limited to saving in only power but it is extended to the life of building, since it's component will be protected against the severe weather of Bahrain, subsequently they will last longer with minimum maintenance. Many studies have also shown that, insulated houses make people more comfortable.

As far as the government is concerned the saving is based on the amount of subsidy saved, added to that, is the amount of saving in generation fuel (natural gas) resulted from such reduction in electricity production. Such fuel could have been utilized more efficiently by selling it in the international market.

Also the demand for building new power stations would be decreased or at least postponed while utilizing the money for other vital projects to improve the national economy and enhance its infrastructure.

6.6.3 Emission Analysis.

The energy conservation in building has many benefits. It the reduction of pollution as a result of reducing the amount of fossil fuels burned to generate the unneeded electric energy.

Based on this, the amount of natural gas saved due to energy conservation in buildings, will reduce the annual amount of the major pollutant gases in the Bahrain environment.

Figures 6.6.3 (a) and 6.6.3 (b), show the amounts of the major pollutants reduced annually due to the application of Best case condition to the standard house. This is also presented in table (6.6.3).

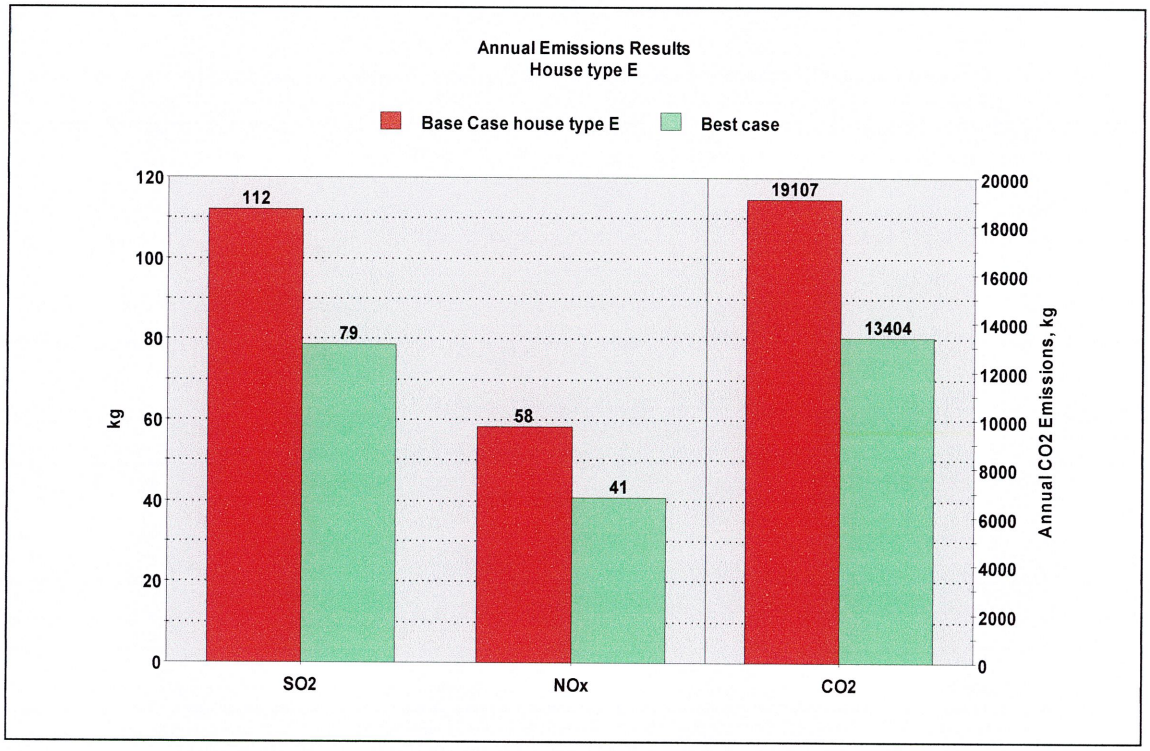


Figure 6.6.3(a) Annual Emission for house type E

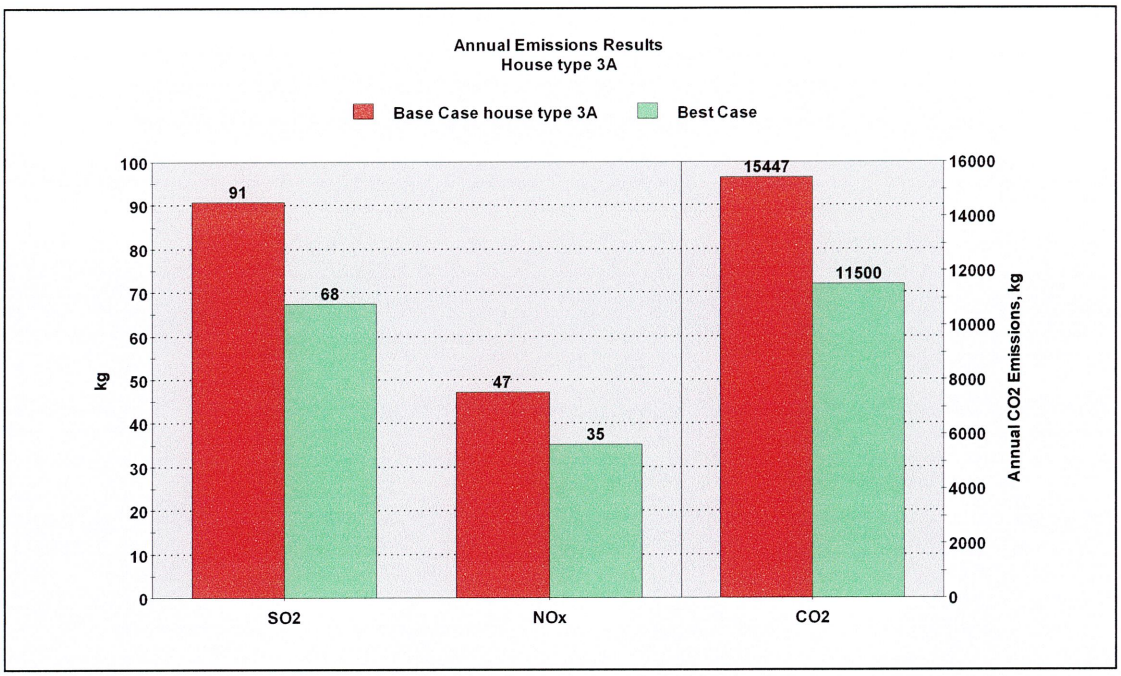


Figure 6.6.3(b) Annual Emission for house type 3A

Table (6.6.3)

Percentage of the Pollutants Reduction	Standard Houses	
	Type E	Type 3A
SO_2	33%	23%
NO_2	17%	12%
CO_2	29.8%	26%

A closer look to the figures and the table, reveals that using thermal insulation in houses has a significant reduction of the amounts of the pollutant that cause environmental problem.

Saving energy makes environmental sense too, because it is universally recognized that we are changing our climate in ways we cannot predict, by altering the composition of earth's atmosphere as a result of our burning fossil fuels for cooling and electricity.

The more efficiently we can use energy, the less we need it to maintain our life style and less pollution will be released in to atmosphere.

Moreover, everyone will benefit from the reduction of pollution resulting from reducing the combustion of natural gas producing electricity.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATION

7.1 Conclusion.

Energy conservation is important for many reasons; economic, environmental and social. It makes economic sense because energy is a commodity, which we cannot afford to waste. Bahrain government spends several millions a year on fuel. The calculation showed that 20% the government budget, could be saved by investing in energy conservation. This would yield in huge money savings that would boost the economy when spent on other goods and services.

The systematic investigations conducted with the use of Energy 10 Software showed the potentials of energy saving from the application of insulation to the standard houses.

However, the potential of energy conservation for the housing applications in Bahrain were investigated. Practical technical information was generated for the energy conservation related to the using of the different types and widths of thermal insulation and different roof and walls constructions. Based on these a comparative energy performance and life cycle cost analysis were performed with reference to a standard housing design.

From the comparative energy performance and cost analysis the following conclusion can be summarized.

1- The standard houses type E and 3A.

- The simulation study shows that the yearly total energy use and air conditioning load of standard houses type E and type 3A was 114.3kWh/m^2 , 91.2 kWh/m^2 and 128.5 kWh/m^2 ,104 kWh/m^2 respectively.

- The monthly total electric consumption and monthly cooling load for both standard houses increases rapidly and reach its maximum value during the month of August. Its was 5044.5 kWh, 4378 kWh

and 5314.4 kWh, 4645 kWh for houses type E and 3A respectively for this month.

- The life cycle cost was about BD51,096 and BD42,329 for houses type E and 3A respectively.

- The total annual pollutant emission of SO2, NOX, CO_2 due to energy consumption was 112 kg, 58 kg, 19107and 91 kg, 47 kg, 15447 kg for houses type E and 3A respectively.

2- Best Insulation material and the optimum thickness for both roof and walls.

- The material to be used for insulation from economic view was found to be polyurethane material due to its biggest energy saving in air cooling load for specific width.

- Polyurethane insulation was the best insulation materials in terms of reducing the energy use and cooling load of the standard houses.

- The optimum insulation thickness for the roof was 100mm with corresponding U-value of about 0.4 $W/m^2°C$ of polyurethane insulation.

- The optimum insulation thickness for the wall was 50mm with corresponding U-value of about 0.56 $W/m^2°C$ of polyurethane insulation.

- The simulation result shows that, the saving increase with the increase of the insulation thickness. It is also shown that a 100mm for roof and 50mm for wall is the optimum and economical for roof and wall construction of standard house in Bahrain. The result is shown in Appendix (B).

2-The effect of applying insulation to the both walls and roof construction of the standard houses.

- The addition of polyurethane insulation to the actual roof construction with insulation thickness of 100mm reduced the

energy use and cooling load by about 21%, 25% and 18%, 22% for houses type E and 3A respectively.

- The addition of polyurethane insulation to the actual wall construction with insulation thickness of 50 mm reduced the energy use and cooling load by about 19%, 22% and 16%, 19% for houses type E and 3A respectively.

- The application of 100mm polyurethane insulation to the actual roof construction and 50mm of polyurethane insulation to the actual wall construction will reduce the energy use and cooling load by about 25%,29% and 21%,25% for houses type E and 3A respectively.

- Life Cycle Cost of the actual houses are reduced due to the application of insulation to the both roof and walls of actual houses with a saving cost of about BD1045.5 and BD 1007.24 for the house type E and type 3A respectively

- The amounts of emission of the major pollutants SO_2, NOX, CO2 reduced annually by about 16%, 8%, 14.6% and 8%, 4%, 9% for the house type E and type 3A respectively.

3- The Best construction materials for roof and wall.

- The best house condition was analyzed using five different roof construction and four wall construction with 100mm and 50mm of polyurethane insulation material on roof and wall.

- Roof construction #4 (insulated cast in site reinforced slab) was the best roof construction in terms of reducing the energy use and cooling load of the standard houses.

- Wall construction #2 (insulated double concrete block) was the best wall construction in terms of reducing the energy use and cooling load of the standard houses.

3- The effect of applying Best condition to the standard houses.

The application of the best condition to the standard houses lead to a significant reduction as follows:

- Reductions in energy use and air cooling load by about 34%, 30% and 32 %, 28% for the house type E and type 3A respectively.
- Reducing the monthly cooling load and monthly electric consumption of the standard house by about 3697kWh, 8253kWh and 4642 kWh ,10288 kWh for the house type E and type 3A respectively.
- Reducing the Life Cycle Cost of the standard house with saving cost of about BD 3878.36 and BD 4117.8 for type E and type 3A respectively.
- Payback period was about 2.4 year, 2.65year for type E and type 3A respectively.
- The benefit /cost ratio was about 1.5, 1.8 for type E and type 3A respectively.
- Energy conservation has a favorable affect on the environment, the application the best condition on the standard house has been reduced the amount of pollutant gases as follow:
- Reducing the Sulfur dioxide (SO_2) by about 33%, 23% for type E and type 3A respectively.
- Reducing the Nitrogen oxides (NO_x) by about 17%, 12% for type E and type 3A respectively.
- Reducing the Carbon dioxide (CO_2) by about 29.8%, 26% for type E and type 3A respectively.

It was shown from the analysis that, using thermal insulation in roof and wall has high saving, economic and environmental benefits.

- **Energy Used and Cooling Load Percentage Reduction.**

	Actual Standard Houses		After Appling Thermal Insulation		Best House Condition	
Standard House Type	E	3A	E	3A	E	3A
Energy Used (kWh/m^2)	114.3	128.5	19%	16%	34%	32%
Cooling Load (kWh/m^2)	91.2	104	22%	19%	30%	28%

- **Life Cycle Cost Saving.**

	Actual Standard Houses		After Appling Thermal Insulation		Best House Condition	
Standard House Type	E	3A	E	3A	E	3A
LCC/ Money Saving (BD)	51,096	42,329	1045.5	1007.24	3878.8	4117.8

- **Emission Gases Reduction.**

	Actual Standard Houses		After Appling Thermal Insulation		Best House Condition	
Standard House Type	E	3A	E	3A	E	3A
SO_2	112 kg	91 kg	16%	8%	33%	23%
NOx	58 kg	47 kg	8%	4%	17%	12%
CO_2	19107 kg	15447 kg	14.6%	9%	29.8%	28%

7.2 Recommendations.

Bahrain has witnessed a high rate of economic development and a high rate of building construction in the last decades, accompanied by a substantial growth in population, which has resulted in a very high-energy demand. The excessive demand for air-conditioning is attributable to extreme temperature during the summer months.

Due to the economical benefits of energy conservations for consumer, national economy and environment, the following recommendations are directed to the concerned levels of responsibility.

- Statutory regulating authorities must establish a set of regulations governing building energy consumption and performance. These regulations are to be considered and incorporated in the design and construction of buildings. Such as the maximum allowable energy input per building, the use of insulation for all types of building and planning layout for building orientation.

- The building code, must become to effect for the all types of the building not only for the multistory building and must make it mandatory for new construction to have wall and roof insulation. Doing this will be not only beneficial to the building owners but also to the Government in terms of power plant installation, maintenance, running cost and saving raw materials as well as reducing the air pollution.

- This study of the existing standard houses showed that the insulated roof and walls provided in the house contributes effectively in enhancing the thermal performance of the house. Therefore a appropriate legislation should be done by the Ministry of Housing in defining, for example applying energy conservation measures on the individual standard house.

- Although there are many insulating materials available on the market, only efficient and durable products should be used. Their performance and durability in existing building should be studied.

- The Government must subsidize the initial cost of insulation materials/systems mainly for consumers. This does not have to be direct cash, but rather in an indirect way for example on electricity bill for a number of years.

- Being the one to enforce, the government should be the first one to apply the insulation materials/systems to its projects.

- The government should encourage the private sector to invest in producing different type of efficient and low cost thermal insulation materials.

- In particular, since the Air conditioning (AC) units are responsible for more than 80% of the total energy consumption in the building, it would be essential to investigate high efficiency system. Government should encourage AC unit with higher coefficient of performance.

- Most of the population in Bahrain might not be aware of the concept of conservation of the energy, its effect on the individual and national economy and its impact on the local and global environment. Previous studies in this field found that different living patterns and styles of people occupying the same house could case a difference of 20% in energy consumption. Therefore, the development and implantation of comprehensive public information is needed.

- Training and educational programs on energy conservations including television and radio programs, presentation, demonstration and exhibits at schools, universities , government facilities, professional organization and other place where people gather are necessary in this matter.

- Further research efforts are still needed for a more detailed evaluation of other energy conservation strategies and further investigation on the range of local building materials.

- Initiation of research on the use of alternative energy resources and the development a new techniques to enhance efficient use of energy.

- Encourging the passive Solar and energy conservation measures. This lead to not merely savings in utility bills but also improvement of the quality of life inside our houses and around them.

Thermal insulation is the most important measure for conserving energy in buildings, but there are a number of other measures that play an important role in this regard too if taken into account during the construction of the building as follows:

- Windows are the weakest of the buildings envelop as with regard to heat transfer. Heat transfer through glass takes place by conduction as well as direct radiation. To reduce the radiation effect, reflective glass could be used. To reduce the conduction effect, double or triple glazing could be used.

- Selecting the optimum building orientation is of vital importance to its thermal performance. Designers should avoid placing large areas of glazing in the south-west, west and south east facades. Since these facades will be exposed to high intensities of direct solar radiation.

- The use of shading devices prevents direct sunshine on the building and results in the circulation of air around these devices, which release the absorbed heat, and prevents its radiation inside the building. Special attention should be given to shading of all windows and entrances.

- Designing a building with an internal yard around which the windows of the building are located, with internal or external corridors and proper orientation of openings can conserve energy as much as with using thermal insulation and double-glazing.

- White color absorbs 10-15% of the direct solar radiation, while dark colors absorbs 85-90% of the direct solar radiation. It is always recommended to use white colors for external surfaces of roofs and walls to reduce the heating effect of the direct solar radiation.

- Designing the proper lighting for each area separately and making sure to use the most efficient types, could save energy considerably.

- Air infiltration must be controlled since the amount of heat entering a building as a result of infiltration can often be greater

than the heat comes through the materials, therefore, all openings should be airtight.

- The higher the energy efficiency ratio (EER) of an air conditioner the lesser electricity it uses. When using air conditioner it should be noted that the air conditioner's capacity (shown on the unit) should not exceed the calculated required capacity by more than 30%.

- Setting the thermostat at reasonable temperature. In a study done by the University of Bahrain, we can save 8% energy by just increasing the thermostat setting from 22°C to 25°C.

Finally, further research efforts are still needed for a more detailed evaluation of the energy-10 conservation strategies and further investigations on the range of local building materials, the proportion of glazing on building facades, the effect of the external colors, the performance of shading devices, and building forms.

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APPENDICES

Appendix (A). Simulation result of both Standard house Types E & 3A

nergy-10 Energy Use/Cost Comparison Report May 11, 2006
roject: zayed town 4 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Project J4

escription:	Base Case (house type E)	Low-Energy Case
cheme Number:	1	2
ibrary Name:	ERCLIB	ERCLIB
imulation status, Thermal/DL	valid/NA	valid/NA
eather file:	BAHRAIN.ET1	BAHRAIN.ET1
loor Area, m²	274.2	274.2
urface Area, m²	606.8	606.8
olume, m³	919.6	919.6
otal Conduction UA, W/K	466.6	406.5
verage U-value, W/m²K	0.769	0.670
all Construction	8in cmu, R=2.5	8in cmu, R=2.5
oof Construction	flat, none, R=2.4	flat, none, R=2.4
loor type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
indow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
indow Shading	None	None
all total gross area, m²	333	333
oof total gross area, m²	137	137
round total gross area, m²	137	137
indow total gross area, m²	29	29
indows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
lazing name	single, U=6.30	single, U=6.30

perating parameters for zone 1

VAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ated Output, kW		
Heat	12	11
Sensible Cool	25	23
Total Cool	33	31
ated Air Flow,L/s	1508	1409
OOA,L/s	0	0
eating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
ooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
eat performance	eff=100	eff=100
ool performance	COP=2.6	COP=2.6
conomizer?	no	no
Type	NA	NA
uct Leaks, total %	2	2
onduction losses, total %	0	0
eak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
dded mass?	none	none
aylighting?	no	no
nfiltration, cm²	ELA=3071.4	ELA=3071.4

esults:	Base Case (house type E)	Low-Energy Case	% Change
nergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
imulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
nergy use, kWh	31348	29967	-4.41
nergy cost, $	815	779	-4.41
aved by daylighting, kWh	-	-	
otal Electric, kWh	31343	29962	-4.41
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	717	-27.65
Cooling, kWh	25012	24054	-3.83
Fan, kWh	3019	2871	-4.91
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	13.7	-5.66

ıeat, kWh	0	0	
:otal, kWh	0	0	
ınual Emissions			
:O2, kg	19107	18266	-4.41
3O2, kg	112	107	-4.41
NOx, kg	58	56	-4.41
ɔnstruction Costs	95051	93773	-1.34
ıfe-Cycle Cost	116230	114398	-1.58

Cost Summary Report

Scheme Name:	Base Case (house type E)	Low-Energy Case	Difference
Construction	95051.13	93773.43	1277.70
fixed	68582.35	68582.40	-0.05
EE strategies	0.00	0.00	0.00
HVAC installation	26468.78	25191.03	1277.74
Mortgage payment	0.00	0.00	0.00
HVAC replacement	3112.58	3112.58	0.00
Annual fuel	0.00	0.00	0.00
Annual electric	814.74	778.85	35.89
Annual maintenance	50.00	50.00	0.00

Life Cycle Cost Results	Base Case (hou	Low-Energy Case	NetPresentValue
capital	93063	91812	1251
property taxes	0	0	0
mortgage	0	0	0
utilities	13155	12574	581
maintenance	1017	1017	0
HVAC replacement	8995	8995	0
tax deductions	0	0	0
Life-Cycle Cost	116230	114398	1832

Internal Rate of Return, IRR,	NA%
Simple Payback, years	0.00
Benefit / Cost Ratio	9999.00

ancial Parameters

Year of Construction	2006
Building life, yr	30
Salvage value, % of original	7.00
Annual property tax, % of value	0.00
Property tax escalation rate, %	0.00
Fuel cost escalation rate, %	0.00
Electric cost escalation rate, %	0.00
Maintenance cost escalation rate, %	2.00
Building resale escalation rate, %	0.00
HVAC replacement cost escalation rate, %	3.00
HVAC replacement cycle	7
Discount rate, %	5.00
Mortgage?	no
mortgage term, yr	0
mortgage interest, %	8.00
down payment, %	100.00
Tax deductible?	
property taxes	no
loan interest	no
utilities	no
maintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

rgy-10 Energy Use/Cost Comparison Report May 11, 2006
ject: zayed333 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projects
33

cription:	Base Case house type 3A	Low-Energy Case
eme Number:	2	3
rary Name:	ARCHIVELIB	ARCHIVELIB
ulation status, Thermal/DL	valid/NA	valid/NA
ther file:	BAHRAIN.ET1	BAHRAIN.ET1
or Area, m²	197.2	197.2
face Area, m²	450.8	450.8
ume, m³	601.2	601.2
al Conduction UA, W/K	315.8	315.8
rage U-value, W/m²K	0.701	0.701
l Construction	8in cmu, R=2.5	8in cmu, R=2.5
f Construction	flat, none, R=2.5	flat, none, R=2.5
or type, insulation	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
dow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
dow Shading	None	None
ll total gross area, m²	254	254
f total gross area, m²	99	99
und total gross area, m²	99	99
dow total gross area, m²	25	25
dows (N/E/S/W:Roof)	1/2/3/5:0	1/2/3/5:0
zing name	single, U=6.30	single, U=6.30

erating parameters for zone 1

AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ed Output, kW		
Heat	8	8
Sensible Cool	22	22
Total Cool	29	29
ted Air Flow,L/s	1372	1372
OA,L/s	0	0
ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
ded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=2342.2	ELA=2342.2

sults:	Base Case house type 3A	Low-Energy Case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	25342	25342	0.00
ergy cost, $	659	659	0.00
ved by daylighting, kWh	-	-	
tal Electric, kWh	25338	25338	0.00
Internal Lights, kWh	1668	1668	0.00
External Lights, kWh	0	0	
Heating, kWh	609	609	0.00
Cooling, kWh	20518	20518	0.00
Fan, kWh	2542	2542	0.00
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	11.9	11.9	0.00

/ kWh			
eat, kWh	0	0	
otal, kWh	0	0	
nual Emissions			
02, kg	15447	15447	0.00
02, kg	91	91	0.00
Ox, kg	47	47	0.00
nstruction Costs	75398	71861	-4.69
fe-Cycle Cost	92863	89399	-3.73

ost Summary Report

cheme Name:	Base Case house type 3A	Low-Energy Case	Difference
onstruction	75398.45	71860.77	3537.68
fixed	49323.30	49323.30	0.00
E strategies	3537.68	0.00	3537.68
HVAC installation	22537.47	22537.47	0.00
ortgage payment	0.00	0.00	0.00
/AC replacement	2556.76	2556.76	0.00
nual fuel	0.00	0.00	0.00
nual electric	658.65	658.65	0.00
nual maintenance	50.00	50.00	0.00

ife Cycle Cost Results	Base Case hous	Low-Energy Case	NetPresentValue
apital	73821	70357	3464
roperty taxes	0	0	0
nortgage	0	0	0
tilities	10637	10637	0
naintenance	1017	1017	0
HVAC replacement	7388	7388	0
ax deductions	0	0	0
fe-Cycle Cost	92863	89399	3464

nternal Rate of Return, IRR,	NA%
mple Payback, years	0.00
nefit / Cost Ratio	9999.00

ncial Parameters

ar of Construction	2006
ilding life, yr	30
lvage value, % of original	7.00
nual property tax, % of value	0.00
operty tax escalation rate, %	0.00
el cost escalation rate, %	0.00
ectric cost escalation rate, %	0.00
intenance cost escalation rate, %	2.00
ilding resale escalation rate, %	0.00
AC replacement cost escalation rate, %	3.00
AC replacement cycle	7
scount rate, %	5.00
rtgage?	no
ortgage term, yr	0
ortgage interest, %	8.00
own payment, %	100.00
x deductible?	
roperty taxes	no
oan interest	no
tilities	no
aintenance	no
VAC upgrade	no
epreciation	no
traight line depreciation period, yr	31
ncremental tax bracket, %	0.00

Appendix (B). A sample of simulation result of
Application of Thermal Insulation to the
both Standard house Types E & 3A

rgy-10 Energy Use/Cost Comparison Report May 12, 2006
ject: zayed60 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projects
0

House type (E)

cription:	Reference Case	Low-Energy Case
eme Number:	1	2
rary Name:	ERCLIB	ERCLIB
ulation status, Thermal/DL	valid/NA	valid/NA
ther file:	BAHRAIN.ET1	BAHRAIN.ET1
or Area, m²	274.2	274.2
face Area, m²	606.8	606.8
ume, m³	919.6	919.6
al Conduction UA, W/K	466.6	428.8
rage U-value, W/m²K	0.769	0.707
l Construction	8in cmu, R=2.5	8in cmu, R=2.1
f Construction	flat, none, R=2.4	flat, none, R=2.4
or type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
dow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
dow Shading	None	None
l total gross area, m²	333	333
f total gross area, m²	137	137
und total gross area, m²	137	137
dow total gross area, m²	29	29
dows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
zing name	single, U=6.30	single, U=6.30

rating parameters for zone 1

AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ed Output, kW		
Heat	12	11
Sensible Cool	25	24
Total Cool	33	32
ed Air Flow,L/s	1508	1447
OA,L/s	0	0
ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
ded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=3071.4	ELA=3071.4

sults:	Reference Case	Low-Energy Case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	31348	30603	-2.38
ergy cost, $	815	795	-2.38
ved by daylighting, kWh	-	-	
tal Electric, kWh	31343	30598	-2.38
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	736	-25.73
Cooling, kWh	25012	24596	-1.66
Fan, kWh	3019	2945	-2.44
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	14.0	-3.52

ılw kWh	0	0	
heat, kWh	0	0	
total, kWh	0	0	
nnual Emissions			
CO2, kg	19107	18653	-2.38
SO2, kg	112	110	-2.38
NOx, kg	58	57	-2.38
onstruction Costs	95051	95065	0.01
ife-Cycle Cost	258323	253602	-1.83

ost Summary Report

cheme Name:	Reference Case	Low-Energy Case	Difference
onstruction	95051.17	95065.07	-13.90
fixed	68582.40	68582.40	0.00
EE strategies	0.00	813.50	-813.50
HVAC installation	26468.78	25669.17	799.60
ortgage payment	0.00	0.00	0.00
VAC replacement	19851.58	19251.88	599.70
nnual fuel	0.00	0.00	0.00
nnual electric	814.74	795.38	19.36
nnual maintenance	50.00	50.00	0.00

ife Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
capital	95051	95065	-14
property taxes	0	0	0
mortgage	0	0	0
utilities	24450	23850	600
maintenance	2028	2028	0
HVAC replacement	136794	132659	4135
tax deductions	0	0	0
ife-Cycle Cost	258323	253602	4721

nternal Rate of Return, IRR,	NA%
imple Payback, years	0.00
enefit / Cost Ratio	338.21

ncial Parameters

ear of Construction	2006
uilding life, yr	30
alvage value, % of original	0.00
nnual property tax, % of value	0.00
roperty tax escalation rate, %	0.00
uel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
aintenance cost escalation rate, %	2.00
uilding resale escalation rate, %	0.00
VAC replacement cost escalation rate, %	3.00
VAC replacement cycle	7
iscount rate, %	0.00
ortgage?	no
nortgage term, yr	0
nortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
roperty taxes	no
loan interest	no
utilities	no
naintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

nergy-10 Energy Use/Cost Comparison Report May 12, 2006
'roject: zayed22 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projec
)J22

House type (E)

'escription:	Reference Case	Low-Energy Case
cheme Number:	1	2
ibrary Name:	ERCLIB	ERCLIB
imulation status, Thermal/DL	valid/NA	valid/NA
eather file:	BAHRAIN.ET1	BAHRAIN.ET1
loor Area, m²	274.2	274.2
urface Area, m²	606.8	606.8
olume, m³	919.6	919.6
otal Conduction UA, W/K	466.6	405.9
verage U-value, W/m²K	0.769	0.669
all Construction	8in cmu, R=2.5	8in cmu, R=2.5
oof Construction	flat, none, R=2.4	flat, none, R=2.4
loor type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
indow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
indow Shading	None	None
all total gross area, m²	333	333
oof total gross area, m²	137	137
round total gross area, m²	137	137
indow total gross area, m²	29	29
indows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
lazing name	single, U=6.30	single, U=6.30

perating parameters for zone 1

VAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ated Output, kW		
Heat	12	11
Sensible Cool	25	23
Total Cool	33	31
ated Air Flow,L/s	1508	1407
OOA,L/s	0	0
eating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
ooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
eat performance	eff=100	eff=100
ool performance	COP=2.6	COP=2.6
conomizer?	no	no
Type	NA	NA
uct Leaks, total %	2	2
onduction losses, total %	0	0
eak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
dded mass?	none	none
aylighting?	no	no
nfiltration, cm²	ELA=3071.4	ELA=3071.4

esults:	Reference Case	Low-Energy Case	% Change
nergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
imulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
nergy use, kWh	31348	29937	-4.50
nergy cost, $	815	778	-4.50
aved by daylighting, kWh	-	-	
otal Electric, kWh	31343	29932	-4.50
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	715	-27.92
Cooling, kWh	25012	24030	-3.93
Fan, kWh	3019	2867	-5.04
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	13.7	-5.80

ıeat, kWh	0	0	
:otal, kWh	0	0	
ınual Emissions			
:O2, kg	19107	18247	-4.50
;O2, kg	112	107	-4.50
lOx, kg	58	56	-4.50
›nstruction Costs	126837	126343	-0.39
.fe-Cycle Cost	165275	162478	-1.69

ost Summary Report

cheme Name:	Reference Case	Low-Energy Case	Difference
onstruction	126836.78	126343.27	493.50
fixed	100368.00	100368.00	0.00
EE strategies	0.00	813.50	-813.50
HVAC installation	26468.78	25161.77	1307.00
ortgage payment	0.00	0.00	0.00
VAC replacement	19851.58	18871.33	980.25
nnual fuel	0.00	0.00	0.00
nnual electric	814.74	778.06	36.68
nnual maintenance	29.52	29.52	0.00

ife Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
capital	126837	126344	493
property taxes	0	0	0
mortgage	0	0	0
utilities	11891	11352	539
maintenance	438	438	0
HVAC replacement	57532	54689	2843
tax deductions	0	0	0
ife-Cycle Cost	196698	192823	3875

nternal Rate of Return, IRR,	NA%
imple Payback, years	0.00
enefit / Cost Ratio	9999.00

ncial Parameters

ear of Construction	2002
uilding life, yr	30
alvage value, % of original	0.00
nnual property tax, % of value	0.00
roperty tax escalation rate, %	0.00
uel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
aintenance cost escalation rate, %	0.00
uilding resale escalation rate, %	0.00
VAC replacement cost escalation rate, %	4.00
VAC replacement cycle	7
iscount rate, %	6.00
ortgage?	no
nortgage term, yr	0
nortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
roperty taxes	no
loan interest	no
utilities	no
naintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	31.00

nergy-10 Energy Use/Cost Comparison Report May 12, 2006
roject: zayed130 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projec
J130

House type (E)

escription:	Reference Case	Low-Energy Case
cheme Number:	1	2
ibrary Name:	ERCLIB	ERCLIB
imulation status, Thermal/DL	valid/NA	valid/NA
eather file:	BAHRAIN.ET1	BAHRAIN.ET1
loor Area, m²	274.2	274.2
urface Area, m²	606.8	606.8
olume, m³	919.6	919.6
otal Conduction UA, W/K	466.6	378.4
verage U-value, W/m²K	0.769	0.624
all Construction	8in cmu, R=2.5	8in cmu, R=2.5
oof Construction	flat, none, R=2.4	flat, none, R=4.7
loor type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
indow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
indow Shading	None	None
all total gross area, m²	333	333
oof total gross area, m²	137	137
round total gross area, m²	137	137
indow total gross area, m²	29	29
indows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
lazing name	single, U=6.30	single, U=6.30

perating parameters for zone 1

VAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ated Output, kW		
Heat	12	11
Sensible Cool	25	22
Total Cool	33	30
ated Air Flow,L/s	1508	1350
OA,L/s	0	0
eating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
ooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
eat performance	eff=100	eff=100
ool performance	COP=2.6	COP=2.6
conomizer?	no	no
Type	NA	NA
ict Leaks, total %	2	2
nduction losses, total %	0	0
eak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
lded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=3071.4	ELA=3071.4

sults:	Reference Case	Low-Energy Case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	31348	28710	-8.42
ergy cost, $	815	746	-8.42
ved by daylighting, kWh	-	-	
tal Electric, kWh	31343	28705	-8.42
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	683	-31.09
Cooling, kWh	25012	22977	-8.14
Fan, kWh	3019	2725	-9.75
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	13.2	-8.83

HW kWh	0	0	
heat, kWh	0	0	
total, kWh	0	0	
Annual Emissions			
CO2, kg	19107	17499	-8.42
SO2, kg	112	103	-8.42
NOx, kg	58	53	-8.42
Construction Costs	95051	93817	-1.30
Life-Cycle Cost	166583	159390	-4.32

ost Summary Report

cheme Name:	Reference Case	Low-Energy Case	Difference
onstruction	95051.17	93817.15	1234.03
fixed	68582.40	68582.40	0.00
EE strategies	0.00	813.50	-813.50
HVAC installation	26468.78	24421.25	2047.53
ortgage payment	0.00	0.00	0.00
VAC replacement	19851.58	18315.94	1535.64
nnual fuel	0.00	0.00	0.00
nnual electric	814.74	746.17	68.57
nnual maintenance	50.00	29.52	20.48

ife Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
capital	95051	93817	1234
property taxes	0	0	0
mortgage	0	0	0
utilities	13155	12041	1114
maintenance	1017	610	407
HVAC replacement	57360	52922	4438
tax deductions	0	0	0
ife-Cycle Cost	166583	159390	7193

nternal Rate of Return, IRR,	NA%
imple Payback, years	0.00
enefit / Cost Ratio	9999.00

ncial Parameters

ear of Construction	2006
uilding life, yr	30
alvage value, % of original	0.00
nnual property tax, % of value	0.00
roperty tax escalation rate, %	0.00
uel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
aintenance cost escalation rate, %	2.00
uilding resale escalation rate, %	0.00
VAC replacement cost escalation rate, %	3.00
VAC replacement cycle	7
iscount rate, %	5.00
ortgage?	no
nortgage term, yr	0
nortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
roperty taxes	no
loan interest	no
utilities	no
naintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
ncremental tax bracket, %	0.00

rgy-10 Energy Use/Cost Comparison Report May 12, 2006
ject: zayed167 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projects
67

House type (E.)

cription:	Reference Case	Low-Energy Case
eme Number:	1	2
rary Name:	ERCLIB	ERCLIB
ulation status, Thermal/DL	valid/NA	valid/NA
ther file:	BAHRAIN.ET1	BAHRAIN.ET1
or Area, m²	274.2	274.2
face Area, m²	606.8	606.8
ume, m³	919.6	919.6
al Conduction UA, W/K	466.6	379.0
rage U-value, W/m²K	0.769	0.625
l Construction	8in cmu, R=2.5	8in cmu, R=3.2
f Construction	flat, none, R=2.4	flat, none, R=2.4
or type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
dow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
dow Shading	None	None
l total gross area, m²	333	333
f total gross area, m²	137	137
und total gross area, m²	137	137
dow total gross area, m²	29	29
dows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
zing name	single, U=6.30	single, U=6.30

erating parameters for zone 1

AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ted Output, kW		
Heat	12	11
Sensible Cool	25	23
Total Cool	33	30
ted Air Flow,L/s	1508	1365
OA,L/s	0	0
ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
lded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=3071.4	ELA=3071.4

sults:	Reference Case	Low-Energy Case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	31348	29005	-7.47
ergy cost, $	815	754	-7.47
ved by daylighting, kWh	-	-	
tal Electric, kWh	31343	29000	-7.47
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	616	-37.89
Cooling, kWh	25012	23301	-6.84
Fan, kWh	3019	2764	-8.46
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	13.3	-8.09

ıeat, kWh	0	0	
:otal, kWh	0	0	
ınual Emissions			
:O2, kg	19107	17679	-7.47
3O2, kg	112	104	-7.47
NOx, kg	58	54	-7.47
ɔnstruction Costs	95051	94012	-1.09
ife-Cycle Cost	171218	165178	-3.53

ost Summary Report

cheme Name:	Reference Case	Low-Energy Case	Difference
onstruction	95051.17	94011.85	1039.32
fixed	68582.40	68582.40	0.00
EE strategies	0.00	813.50	-813.50
HVAC installation	26468.78	24615.95	1852.82
ortgage payment	0.00	0.00	0.00
VAC replacement	19851.58	18461.96	1389.62
nnual fuel	0.00	0.00	0.00
nnual electric	814.74	753.85	60.90
nnual maintenance	277.95	277.95	0.00

ife Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
capital	95051	94012	1039
property taxes	0	0	0
mortgage	0	0	0
utilities	13155	12170	985
maintenance	5652	5652	0
HVAC replacement	57360	53344	4016
tax deductions	0	0	0
ife-Cycle Cost	171218	165178	6040

nternal Rate of Return, IRR,	NA%
imple Payback, years	0.00
enefit / Cost Ratio	9999.00

ncial Parameters

ear of Construction	2006
uilding life, yr	30
alvage value, % of original	0.00
nnual property tax, % of value	0.00
roperty tax escalation rate, %	0.00
uel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
aintenance cost escalation rate, %	2.00
uilding resale escalation rate, %	0.00
VAC replacement cost escalation rate, %	3.00
VAC replacement cycle	7
iscount rate, %	5.00
ortgage?	no
mortgage term, yr	0
mortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
property taxes	no
loan interest	no
utilities	no
maintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

nergy-10 Energy Use/Cost Comparison Report May 12, 2006
roject: zayed380 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projec
J380

House type (3A)

escription:	Low-Energy Case	Low-Energy Case
cheme Number:	1	2
ibrary Name:	ARCHIVELIB	ARCHIVELIB
imulation status, Thermal/DL	valid/NA	valid/NA
eather file:	BAHRAIN.ET1	BAHRAIN.ET1
loor Area, m²	197.2	197.2
urface Area, m²	450.8	450.8
olume, m³	601.2	601.2
otal Conduction UA, W/K	694.0	418.0
verage U-value, W/m²K	1.539	0.927
all Construction	8in cmu, R=0.5	8in cmu, R=1.2
oof Construction	flat, none, R=2.3	flat, none, R=2.4
loor type, insulation	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
indow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
indow Shading	None	None
all total gross area, m²	254	254
oof total gross area, m²	99	99
round total gross area, m²	99	99
indow total gross area, m²	25	25
indows (N/E/S/W:Roof)	1/2/3/5:0	1/2/3/5:0
lazing name	single, U=6.30	single, U=6.30

perating parameters for zone 1

VAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ated Output, kW		
Heat	14	10
Sensible Cool	30	23
Total Cool	40	31
ated Air Flow,L/s	1990	1476
OOA,L/s	0	0
eating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
ooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
eat performance	eff=100	eff=100
ool performance	COP=2.6	COP=2.6
conomizer?	no	no
Type	NA	NA
uct Leaks, total %	2	2
onduction losses, total %	0	0
eak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
dded mass?	none	none
aylighting?	no	no
nfiltration, cm²	ELA=2342.2	ELA=2342.2

esults:	Low-Energy Case	Low-Energy Case	% Change
nergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
imulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
nergy use, kWh	35820	27864	-22.21
nergy cost, $	931	724	-22.21
aved by daylighting, kWh	-	-	
otal Electric, kWh	35814	27859	-22.21
Internal Lights, kWh	1668	1668	0.00
External Lights, kWh	0	0	
Heating, kWh	1303	573	-56.00
Cooling, kWh	29075	22794	-21.60
Fan, kWh	3768	2824	-25.06
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	16.0	12.7	-20.75

nw kWh	0	0	
heat, kWh	0	0	
total, kWh	0	0	
nnual Emissions			
CO2, kg	21833	16984	-22.21
SO2, kg	128	100	-22.21
NOx, kg	67	52	-22.21
onstruction Costs	102449	95909	-6.38
ife-Cycle Cost	155037	136718	-11.82

ost Summary Report

cheme Name:	Low-Energy Case	Low-Energy Case	Difference
onstruction	102449.12	95908.50	6540.62
fixed	68582.40	68582.40	0.00
EE strategies	3537.68	3469.12	68.56
HVAC installation	30329.04	23856.98	6472.06
ortgage payment	9399.00	8799.00	600.00
VAC replacement	22746.80	17892.70	4854.10
nnual fuel	0.00	0.00	0.00
nnual electric	930.97	724.18	206.79
nnual maintenance	218.46	218.46	0.00

ife Cycle Cost Results	Low-Energy Cas	Low-Energy Case	NetPresentValue
capital	20003	18725	1278
property taxes	7397	6924	473
mortgage	96762	90584	6178
utilities	42805	33288	9517
maintenance	7869	7869	0
HVAC replacement	39592	31144	8448
tax deductions	-59391	-51816	-7575
ife-Cycle Cost	155037	136718	18319

nternal Rate of Return, IRR,	NA%
imple Payback, years	0.00
enefit / Cost Ratio	3.42

ncial Parameters

ear of Construction	2002
uilding life, yr	60
alvage value, % of original	10.00
nnual property tax, % of value	0.20
roperty tax escalation rate, %	4.00
uel cost escalation rate, %	4.50
lectric cost escalation rate, %	5.00
aintenance cost escalation rate, %	4.00
uilding resale escalation rate, %	4.00
VAC replacement cost escalation rate, %	4.00
VAC replacement cycle	15
iscount rate, %	6.00
ortgage?	yes
mortgage term, yr	15
mortgage interest, %	8.00
down payment, %	20.00
ax deductible?	
property taxes	yes
loan interest	yes
utilities	yes
maintenance	yes
HVAC upgrade	yes
depreciation	yes
straight line depreciation period, yr	31
incremental tax bracket, %	31.00

nergy-10 Energy Use/Cost Comparison Report May 12, 2006
roject: zayed554 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projec
J554

House type (3A)

escription:	Low-Energy Case	Low-Energy Case
cheme Number:	1	2
ibrary Name:	ARCHIVELIB	ARCHIVELIB
imulation status, Thermal/DL	valid/NA	valid/NA
eather file:	BAHRAIN.ET1	BAHRAIN.ET1
loor Area, m²	197.2	197.2
urface Area, m²	450.8	450.8
olume, m³	601.2	601.2
otal Conduction UA, W/K	315.8	299.1
verage U-value, W/m²K	0.701	0.664
all Construction	8in cmu, R=2.5	8in cmu, R=2.5
oof Construction	flat, none, R=2.5	flat, none, R=5.9
loor type, insulation	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
indow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
indow Shading	None	None
all total gross area, m²	254	254
oof total gross area, m²	99	99
round total gross area, m²	99	99
indow total gross area, m²	25	25
indows (N/E/S/W:Roof)	1/2/3/5:0	1/2/3/5:0
lazing name	single, U=6.30	single, U=6.30

perating parameters for zone 1

VAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ated Output, kW		
Heat	8	8
Sensible Cool	22	21
Total Cool	29	28
ated Air Flow,L/s	1372	1309
OOA,L/s	0	0
eating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
ooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
eat performance	eff=100	eff=100
ool performance	COP=2.6	COP=2.6
conomizer?	no	no
Type	NA	NA
uct Leaks, total %	2	2
onduction losses, total %	0	0
eak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
dded mass?	none	none
aylighting?	no	no
nfiltration, cm²	ELA=2342.2	ELA=2342.2

esults:	Low-Energy Case	Low-Energy Case	% Change
nergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
imulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
nergy use, kWh	25342	24411	-3.68
nergy cost, $	659	634	-3.68
aved by daylighting, kWh	-	-	
otal Electric, kWh	25338	24407	-3.68
Internal Lights, kWh	1668	1668	0.00
External Lights, kWh	0	0	
Heating, kWh	609	559	-8.22
Cooling, kWh	20518	19751	-3.74
Fan, kWh	2542	2429	-4.48
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	11.9	11.6	-2.75

ν kWh	0	0	
ɐat, kWh	0	0	
ɔtal, kWh	0	0	
ıual Emissions			
ɔ2, kg	15447	14879	-3.68
ɔ2, kg	91	87	-3.68
ɔx, kg	47	45	-3.68
ıstruction Costs	94657	93814	-0.89
fe-Cycle Cost	158565	155639	-1.85

ost Summary Report

cheme Name:	Low-Energy Case	Low-Energy Case	Difference
onstruction	94656.97	93813.97	843.00
fixed	68582.40	68582.40	0.00
EE strategies	3537.68	3469.12	68.56
HVAC installation	22536.89	21762.45	774.44
ortgage payment	0.00	0.00	0.00
VAC replacement	16902.70	16321.80	580.90
nnual fuel	0.00	0.00	0.00
nnual electric	658.65	634.44	24.21
nnual maintenance	218.43	218.43	0.00

ife Cycle Cost Results	Low-Energy Cas	Low-Energy Case	NetPresentValue
capital	94657	93813	844
property taxes	0	0	0
mortgage	0	0	0
utilities	10637	10233	404
maintenance	4432	4432	0
HVAC replacement	48839	47161	1678
tax deductions	0	0	0
ife-Cycle Cost	158565	155639	2926

nternal Rate of Return, IRR,	NA%
imple Payback, years	0.00
enefit / Cost Ratio	9999.00

ncial Parameters

ear of Construction	2006
uilding life, yr	30
alvage value, % of original	0.00
nnual property tax, % of value	0.00
roperty tax escalation rate, %	0.00
uel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
aintenance cost escalation rate, %	2.00
uilding resale escalation rate, %	0.00
VAC replacement cost escalation rate, %	3.00
VAC replacement cycle	7
iscount rate, %	5.00
ortgage?	no
mortgage term, yr	0
mortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
property taxes	no
loan interest	no
utilities	no
maintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

rgy-10 Energy Use/Cost Comparison Report May 12, 2006
ject: zayed591 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projects
91

House type (3A)

cription:	Low-Energy Case	Low-Energy Case
eme Number:	1	2
rary Name:	ARCHIVELIB	ARCHIVELIB
ulation status, Thermal/DL	valid/NA	valid/NA
ther file:	BAHRAIN.ET1	BAHRAIN.ET1
or Area, m²	197.2	197.2
face Area, m²	450.8	450.8
ume, m³	601.2	601.2
al Conduction UA, W/K	694.0	314.2
rage U-value, W/m²K	1.539	0.697
l Construction	8in cmu, R=0.5	8in cmu, R=2.8
f Construction	flat, none, R=2.3	flat, none, R=2.4
or type, insulation	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
dow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
dow Shading	None	None
l total gross area, m²	254	254
f total gross area, m²	99	99
und total gross area, m²	99	99
dow total gross area, m²	25	25
dows (N/E/S/W:Roof)	1/2/3/5:0	1/2/3/5:0
zing name	single, U=6.30	single, U=6.30

erating parameters for zone 1

AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ted Output, kW		
Heat	14	8
Sensible Cool	30	22
Total Cool	40	29
ted Air Flow,L/s	1990	1361
OA,L/s	0	0
ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
ded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=2342.2	ELA=2342.2

sults:	Low-Energy Case	Low-Energy Case	% Change
nergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
imulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
nergy use, kWh	35820	25211	-29.62
nergy cost, $	931	655	-29.62
aved by daylighting, kWh	-	-	
otal Electric, kWh	35814	25207	-29.62
Internal Lights, kWh	1668	1668	0.00
External Lights, kWh	0	0	
Heating, kWh	1303	571	-56.17
Cooling, kWh	29075	20440	-29.70
Fan, kWh	3768	2528	-32.91
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	16.0	12.0	-25.42

HW kWh	0	0	
heat, kWh	0	0	
total, kWh	0	0	
nnual Emissions			
CO2, kg	21833	15367	-29.62
SO2, kg	128	90	-29.62
NOx, kg	67	47	-29.62
onstruction Costs	102449	94422	-7.83
ife-Cycle Cost	183628	153899	-16.19

Cost Summary Report

Scheme Name:	Low-Energy Case	Low-Energy Case	Difference
Construction	102449.12	94422.30	8026.82
fixed	68582.40	68582.40	0.00
EE strategies	3537.68	3469.12	68.56
HVAC installation	30329.04	22370.78	7958.26
Mortgage payment	0.00	0.00	0.00
HVAC replacement	22746.80	16778.10	5968.70
Annual fuel	0.00	0.00	0.00
Annual electric	930.97	655.24	275.73
Annual maintenance	21.23	21.23	0.00

Life Cycle Cost Results	Low-Energy Cas	Low-Energy Case	NetPresentValue
capital	102449	94422	8027
property taxes	0	0	0
mortgage	0	0	0
utilities	15027	10572	4455
maintenance	427	427	0
HVAC replacement	65725	48478	17247
tax deductions	0	0	0
Life-Cycle Cost	183628	153899	29729

Internal Rate of Return, IRR,	NA%
Simple Payback, years	0.00
Benefit / Cost Ratio	9999.00

Financial Parameters

Year of Construction	2006
Building life, yr	30
Salvage value, % of original	0.00
Annual property tax, % of value	0.00
Property tax escalation rate, %	0.00
Fuel cost escalation rate, %	0.00
Electric cost escalation rate, %	0.00
Maintenance cost escalation rate, %	2.00
Building resale escalation rate, %	0.00
HVAC replacement cost escalation rate, %	3.00
HVAC replacement cycle	7
Discount rate, %	5.00
Mortgage?	no
mortgage term, yr	0
mortgage interest, %	8.00
down payment, %	100.00
Tax deductible?	
property taxes	no
loan interest	no
utilities	no
maintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

Appendix (C). A sample of simulation result of Best house condition (Houses uses best roof, best walls, best insulation materials and optimum insulation wall & roof thickness)

ergy-10 Energy Use/Cost Comparison Report May 12, 2006
oject: Best case type E **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projects
2

scription:	Base Case house type 3A	Best Case
heme Number:	1	2
brary Name:	ARCHIVELIB	ARCHIVELIB
nulation status, Thermal/DL	valid/NA	valid/NA
ather file:	BAHRAIN.ET1	BAHRAIN.ET1
oor Area, m²	197.2	197.2
rface Area, m²	450.8	450.8
lume, m³	601.2	601.2
tal Conduction UA, W/K	315.8	192.0
erage U-value, W/m²K	0.701	0.426
ll Construction	8in cmu, R=2.5	8in cmu, R=500.0
of Construction	flat, none, R=2.5	flat, none, R=1000.0
oor type, insulation	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
ndow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
ndow Shading	None	None
ll total gross area, m²	254	254
of total gross area, m²	99	99
ound total gross area, m²	99	99
ndow total gross area, m²	25	25
ndows (N/E/S/W:Roof)	1/2/3/5:0	1/2/3/5:0
azing name	single, U=6.30	single, U=6.30

erating parameters for zone 1

AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ted Output, kW		
Heat	8	7
Sensible Cool	22	16
Total Cool	29	21
ted Air Flow,L/s	1372	954
OA,L/s	0	0
ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
lded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=2342.2	ELA=2342.2

sults:	Base Case house type 3A	Best Case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	25342	18866	-25.55
ergy cost, $	659	490	-25.55
ved by daylighting, kWh	-	-	
tal Electric, kWh	25338	18863	-25.55
Internal Lights, kWh	1668	1668	0.00
External Lights, kWh	0	0	
Heating, kWh	609	611	0.41
Cooling, kWh	20518	14826	-27.74
Fan, kWh	2542	1757	-30.88
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	11.9	9.4	-21.55

w kWh	0	0	
eat, kWh	0	0	
otal, kWh	0	0	
nual Emissions			
O2, kg	15447	11500	-25.55
O2, kg	91	68	-25.55
Ox, kg	47	35	-25.55
nstruction Costs	32879	30776	-6.40
fe-Cycle Cost	60080	51216	-14.75

›st Summary Report

:heme Name:	Base Case house type 3A	Best Case	Difference
›nstruction	32879.07	30776.33	2102.74
:ixed	6804.50	10000.00	-3195.50
:E strategies	3537.68	3469.12	68.56
!VAC installation	22536.89	17307.21	5229.68
›rtgage payment	0.00	0.00	0.00
'AC replacement	0.00	0.00	0.00
ınual fuel	0.00	0.00	0.00
ınual electric	658.65	490.34	168.31
ınual maintenance	21.23	21.23	0.00

.fe Cycle Cost Results	Base Case hous	Best Case	NetPresentValue
:apital	32880	30776	2104
›roperty taxes	0	0	0
ıortgage	0	0	0
ıtilities	19770	14700	5070
ıaintenance	630	630	0
:VAC replacement	0	0	0
ax deductions	0	0	0
fe-Cycle Cost	53280	46106	7174

ternal Rate of Return, IRR,	NA%
mple Payback, years	0.00
nefit / Cost Ratio	9999.00

cial Parameters

ar of Construction	2006
ilding life, yr	30
lvage value, % of original	0.00
nual property tax, % of value	0.00
operty tax escalation rate, %	0.00
el cost escalation rate, %	0.00
ectric cost escalation rate, %	0.00
intenance cost escalation rate, %	0.00
ilding resale escalation rate, %	0.00
AC replacement cost escalation rate, %	0.00
AC replacement cycle	4.00
scount rate, %	10
rtgage?	0.00
ortgage term, yr	no
ortgage interest, %	0
own payment, %	8.00
x deductible?	100.00
roperty taxes	
oan interest	no
tilities	no
aintenance	no
VAC upgrade	no
epreciation	no
traight line depreciation period, yr	no
ncremental tax bracket, %	31
	0.00

Energy-10 Energy Use/Cost Comparison Report May 12, 2006
Project: zayed118 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projec
)J118

House type (E)

Description:	Reference Case	Low-Energy Case
Scheme Number:	1	2
Library Name:	ERCLIB	ERCLIB
Simulation status, Thermal/DL	valid/NA	valid/NA
Weather file:	BAHRAIN.ET1	BAHRAIN.ET1
Floor Area, m²	274.2	274.2
Surface Area, m²	606.8	606.8
Volume, m³	919.6	919.6
Total Conduction UA, W/K	466.6	361.6
Average U-value, W/m²K	0.769	0.596
Wall Construction	8in cmu, R=2.5	8in cmu, R=2.9
Roof Construction	flat, none, R=2.4	flat, none, R=4.8
Floor type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
Window Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
Window Shading	None	None
Wall total gross area, m²	333	333
Roof total gross area, m²	137	137
Ground total gross area, m²	137	137
Window total gross area, m²	29	29
Windows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
Glazing name	single, U=6.30	single, U=6.30

Operating parameters for zone 1

HVAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
Rated Output, kW		
Heat	12	10
Sensible Cool	25	22
Total Cool	33	29
Rated Air Flow,L/s	1508	1325
OOA,L/s	0	0
Heating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
Cooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
Heat performance	eff=100	eff=100
Cool performance	COP=2.6	COP=2.6
Economizer?	no	no
Type	NA	NA
Duct Leaks, total %	2	2
Conduction losses, total %	0	0
Peak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
Added mass?	none	none
Daylighting?	no	no
Infiltration, cm²	ELA=3071.4	ELA=3071.4

Results:

Energy cost	Reference Case	Low-Energy Case	% Change
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kWh	31348	28104	-10.35
Energy cost, $	815	730	-10.35
Saved by daylighting, kWh	-	-	
Total Electric, kWh	31343	28099	-10.35
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	629	-36.60
Cooling, kWh	25012	22492	-10.08
Fan, kWh	3019	2659	-11.94
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	13.0	-10.19

ıeat, kWh	0	0	
:otal, kWh	0	0	
ınual Emissions			
:O2, kg	19107	17130	-10.35
;O2, kg	112	101	-10.35
NOx, kg	58	52	-10.35
›nstruction Costs	95051	18833618	19714.19
.fe-Cycle Cost	169230	18509363	10837.40

ost Summary Report

cheme Name:	Reference Case	Low-Energy Case	Difference
onstruction	95051.17	18833619.33	-18738568.15
fixed	68582.40	18808706.92	-18740124.52
EE strategies	0.00	813.50	-813.50
HVAC installation	26468.78	24098.91	2369.87
ortgage payment	0.00	0.00	0.00
VAC replacement	19851.58	18074.18	1777.40
nnual fuel	0.00	0.00	0.00
nnual electric	814.74	730.43	84.31
nnual maintenance	277.95	277.95	-0.00

ife Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
capital	93063	18439705	-18346642
property taxes	0	0	0
mortgage	0	0	0
utilities	13155	11783	1372
maintenance	5652	5652	0
HVAC replacement	57360	52223	5137
tax deductions	0	0	0
ife-Cycle Cost	169230	18509363	-18340133

nternal Rate of Return, IRR,	-8.094%
imple Payback, years	0.00
enefit / Cost Ratio	0.00

ncial Parameters

ear of Construction	2006
uilding life, yr	30
alvage value, % of original	7.00
nnual property tax, % of value	0.00
roperty tax escalation rate, %	0.00
uel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
aintenance cost escalation rate, %	2.00
uilding resale escalation rate, %	0.00
VAC replacement cost escalation rate, %	3.00
VAC replacement cycle	7
iscount rate, %	5.00
ortgage?	no
mortgage term, yr	0
mortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
property taxes	no
loan interest	no
utilities	no
maintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

rgy-10 Energy Use/Cost Comparison Report May 12, 2006

ject: zayed119 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projects
19

ouse type (E)

cription:	Reference Case	Low-Energy Case
eme Number:	1	2
rary Name:	ERCLIB	ERCLIB
ulation status, Thermal/DL	valid/NA	valid/NA
ther file:	BAHRAIN.ET1	BAHRAIN.ET1
or Area, m²	274.2	274.2
face Area, m²	606.8	606.8
ume, m³	919.6	919.6
al Conduction UA, W/K	466.6	370.7
rage U-value, W/m²K	0.769	0.611
l Construction	8in cmu, R=2.5	8in cmu, R=2.6
f Construction	flat, none, R=2.4	flat, none, R=4.8
or type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
dow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
dow Shading	None	None
l total gross area, m²	333	333
f total gross area, m²	137	137
und total gross area, m²	137	137
dow total gross area, m²	29	29
dows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
zing name	single, U=6.30	single, U=6.30

erating parameters for zone 1

AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ted Output, kW		
Heat	12	11
Sensible Cool	25	22
Total Cool	33	30
ted Air Flow,L/s	1508	1338
OA,L/s	0	0
ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
lded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=3071.4	ELA=3071.4

sults:	Reference Case	Low-Energy Case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	31348	28429	-9.31
ergy cost, $	815	739	-9.31
ved by daylighting, kWh	-	-	
tal Electric, kWh	31343	28425	-9.31
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	664	-33.05
Cooling, kWh	25012	22747	-9.06
Fan, kWh	3019	2694	-10.77
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	13.1	-9.46

kWh			
ıt, kWh	0	0	
:al, kWh	0	0	
ıal Emissions			
², kg	19107	17328	-9.31
², kg	112	102	-9.31
‹, kg	58	53	-9.31
ɜtruction Costs	95051	93663	-1.46
ɜ-Cycle Cost	173468	162082	-6.56

ost Summary Report

cheme Name:	Reference Case	Low-Energy Case	Difference
onstruction	95051.17	93662.99	1388.18
ixed	68582.40	68582.40	0.00
E strategies	0.00	813.50	-813.50
VAC installation	26468.78	24267.09	2201.68
rtgage payment	0.00	0.00	0.00
AC replacement	19851.58	18200.32	1651.26
nual fuel	0.00	0.00	0.00
nual electric	814.74	738.89	75.86
nual maintenance	277.95	50.00	227.95

.fe Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
apital	95051	93663	1388
roperty taxes	0	0	0
ortgage	0	0	0
tilities	16570	15025	1545
aintenance	4487	807	3680
VAC replacement	57360	52587	4773
ax deductions	0	0	0
.fe-Cycle Cost	173468	162082	11386

ternal Rate of Return, IRR,	NA%
mple Payback, years	0.00
nefit / Cost Ratio	9999.00

ncial Parameters

ar of Construction	2006
ilding life, yr	30
lvage value, % of original	0.00
nual property tax, % of value	0.00
operty tax escalation rate, %	0.00
el cost escalation rate, %	0.00
ectric cost escalation rate, %	2.00
intenance cost escalation rate, %	0.00
ilding resale escalation rate, %	0.00
AC replacement cost escalation rate, %	3.00
AC replacement cycle	7
scount rate, %	5.00
rtgage?	no
ortgage term, yr	0
ortgage interest, %	8.00
own payment, %	100.00
x deductible?	
roperty taxes	no
oan interest	no
tilities	no
aintenance	no
VAC upgrade	no
epreciation	no
traight line depreciation period, yr	31
ncremental tax bracket, %	0.00

ıergy-10 Energy Use/Cost Comparison Report May 12, 2006
:oject: zayed222 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Project
J222

House type (E)

:escription:	Base Case	Insulated base case
:heme Number:	1	2
.brary Name:	ERCLIB	ERCLIB
.mulation status, Thermal/DL	valid/NA	valid/NA
:ather file:	BAHRAIN.ET1	BAHRAIN.ET1
.oor Area, m²	274.2	274.2
ırface Area, m²	606.8	606.8
)lume, m³	919.6	919.6
)tal Conduction UA, W/K	466.6	323.0
'erage U-value, W/m²K	0.769	0.532
ıll Construction	8in cmu, R=2.5	8in cmu, R=4.0
)of Construction	flat, none, R=2.4	flat, none, R=7.1
.oor type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
.ndow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
.ndow Shading	None	None
ıll total gross area, m²	333	333
)of total gross area, m²	137	137
'ound total gross area, m²	137	137
.ndow total gross area, m²	29	29
.ndows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
.azing name	single, U=6.30	single, U=6.30

)erating parameters for zone 1

'AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
.ted Output, kW		
Heat	12	10
Sensible Cool	25	21
Total Cool	33	28
.ted Air Flow,L/s	1508	1257
)OA,L/s	0	0
.ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
'oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
ded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=3071.4	ELA=3071.4

sults:	Base Case	Insulated base case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	31348	26754	-14.65
ergy cost, $	815	695	-14.65
ved by daylighting, kWh	-	-	
tal Electric, kWh	31343	26750	-14.65
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	559	-43.59
Cooling, kWh	25012	21365	-14.58
Fan, kWh	3019	2506	-17.00
Hot water, kWh	0	0	
ınregulated/process loads	0	0	
Peak Electric, kW	14.5	12.5	-14.06

w kWh	0	0	
eat, kWh	0	0	
otal, kWh	0	0	
nual Emissions			
O2, kg	19107	16307	-14.65
O2, kg	112	96	-14.65
Ox, kg	58	50	-14.65
nstruction Costs	95051	92618	-2.56
fe-Cycle Cost	122853	159809	30.08

t Summary Report

eme Name:	Base Case	Insulated base case	Difference
struction	95051.17	92617.75	2433.42
xed	68582.40	68582.40	0.00
strategies	0.00	813.50	-813.50
AC installation	26468.78	23221.85	3246.92
tgage payment	0.00	0.00	0.00
C replacement	3112.58	17416.40	-14303.82
ual fuel	0.00	0.00	0.00
ual electric	814.74	695.35	119.39
ual maintenance	277.95	277.95	0.00

e Cycle Cost Results	Base Case	Insulated base	NetPresentValue
pital	95051	92618	2433
operty taxes	0	0	0
rtgage	0	0	0
ilities	13155	11218	1937
intenance	5652	5652	0
/AC replacement	8995	50321	-41326
x deductions	0	0	0
e-Cycle Cost	122853	159809	-36956

ernal Rate of Return, IRR,	NA%
mple Payback, years	0.00
nefit / Cost Ratio	0.11

cial Parameters

ar of Construction	2006
ilding life, yr	30
lvage value, % of original	0.00
nual property tax, % of value	0.00
operty tax escalation rate, %	0.00
el cost escalation rate, %	0.00
ectric cost escalation rate, %	0.00
intenance cost escalation rate, %	2.00
ilding resale escalation rate, %	0.00
AC replacement cost escalation rate, %	3.00
AC replacement cycle	7
scount rate, %	5.00
rtgage?	no
ortgage term, yr	0
ortgage interest, %	8.00
own payment, %	100.00
x deductible?	
roperty taxes	no
oan interest	no
tilities	no
aintenance	no
VAC upgrade	no
epreciation	no
traight line depreciation period, yr	31
ncremental tax bracket, %	0.00

ergy-10 Energy Use/Cost Comparison Report May 12, 2006
oject: zayed318 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Project
318

house type (E)

scription:	Reference Case	Low-Energy Case
heme Number:	1	2
brary Name:	ERCLIB	ERCLIB
mulation status, Thermal/DL	valid/NA	valid/NA
ather file:	BAHRAIN.ET1	BAHRAIN.ET1
oor Area, m²	274.2	274.2
rface Area, m²	606.8	606.8
lume, m³	919.6	919.6
tal Conduction UA, W/K	466.6	355.2
erage U-value, W/m²K	0.769	0.585
ll Construction	8in cmu, R=2.5	8in cmu, R=3.0
of Construction	flat, none, R=2.4	flat, none, R=5.1
oor type, insulation	Slab on Grade, Reff=1.8	Slab on Grade, Reff=8.0
ndow Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
ndow Shading	None	None
ll total gross area, m²	333	333
of total gross area, m²	137	137
ound total gross area, m²	137	137
ndow total gross area, m²	29	29
ndows (N/E/S/W:Roof)	6/0/5/2:0	6/0/5/2:0
azing name	single, U=6.30	single, U=6.30

erating parameters for zone 1

AC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ted Output, kW		
Heat	12	10
Sensible Cool	25	22
Total Cool	33	29
ted Air Flow,L/s	1508	1313
OA,L/s	0	0
ating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
oling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
at performance	eff=100	eff=100
ol performance	COP=2.6	COP=2.6
onomizer?	no	no
Type	NA	NA
ct Leaks, total %	2	2
nduction losses, total %	0	0
ak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
ded mass?	none	none
ylighting?	no	no
filtration, cm²	ELA=3071.4	ELA=3071.4

sults:	Reference Case	Low-Energy Case	% Change
ergy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
mulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
ergy use, kWh	31348	27880	-11.06
ergy cost, $	815	725	-11.06
ved by daylighting, kWh	-	-	
tal Electric, kWh	31343	27875	-11.06
Internal Lights, kWh	2320	2320	0.00
External Lights, kWh	0	0	
Heating, kWh	991	617	-37.81
Cooling, kWh	25012	22305	-10.82
Fan, kWh	3019	2633	-12.79
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	14.5	12.9	-10.80

ıw kWh	0	0	
heat, kWh	0	0	
total, kWh	0	0	
ınnual Emissions			
CO2, kg	19107	16993	-11.06
SO2, kg	112	100	-11.06
NOx, kg	58	52	-11.06
:onstruction Costs	95051	93349	-1.79
ıife-Cycle Cost	171747	163140	-5.01

ost Summary Report

cheme Name:	Reference Case	Low-Energy Case	Difference
onstruction	95051.17	93349.18	1702.00
ixed	68582.40	68582.40	0.00
E strategies	0.00	813.50	-813.50
VAC installation	26468.78	23953.28	2515.50
rtgage payment	0.00	0.00	0.00
AC replacement	19851.60	17965.00	1886.60
nual fuel	0.00	0.00	0.00
nual electric	814.74	724.60	90.15
nual maintenance	303.77	303.77	0.00

ife Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
apital	95051	93349	1702
roperty taxes	0	0	0
ortgage	0	0	0
tilities	13155	11702	1453
aintenance	6181	6181	0
VAC replacement	57360	51908	5452
ax deductions	0	0	0
fe-Cycle Cost	171747	163140	8607

ternal Rate of Return, IRR,	NA%
mple Payback, years	0.00
nefit / Cost Ratio	9999.00

cial Parameters	
ar of Construction	2006
ilding life, yr	30
lvage value, % of original	0.00
nual property tax, % of value	0.00
operty tax escalation rate, %	0.00
el cost escalation rate, %	0.00
ectric cost escalation rate, %	0.00
intenance cost escalation rate, %	2.00
ilding resale escalation rate, %	0.00
AC replacement cost escalation rate, %	3.00
AC replacement cycle	7
scount rate, %	5.00
rtgage?	no
ortgage term, yr	0
ortgage interest, %	8.00
own payment, %	100.00
x deductible?	
roperty taxes	no
oan interest	no
tilities	no
aintenance	no
VAC upgrade	no
epreciation	no
traight line depreciation period, yr	31
ncremental tax bracket, %	0.00

Energy-10 Energy Use/Cost Comparison Report May 12, 2006
Project: zayed438 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Projec
DJ438

House type (3A)

Description:	Low-Energy Case	Low-Energy Case
Scheme Number:	1	2
Library Name:	ARCHIVELIB	ARCHIVELIB
Simulation status, Thermal/DL	valid/NA	valid/NA
Weather file:	BAHRAIN.ET1	BAHRAIN.ET1
Floor Area, m²	197.2	197.2
Surface Area, m²	450.8	450.8
Volume, m³	601.2	601.2
Total Conduction UA, W/K	694.0	321.3
Average U-value, W/m²K	1.539	0.713
Wall Construction	8in cmu, R=0.5	8in cmu, R=2.1
Roof Construction	flat, none, R=2.3	flat, none, R=4.1
Floor type, insulation	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
Window Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
Window Shading	None	None
Wall total gross area, m²	254	254
Roof total gross area, m²	99	99
Ground total gross area, m²	99	99
Window total gross area, m²	25	25
Windows (N/E/S/W:Roof)	1/2/3/5:0	1/2/3/5:0
Glazing name	single, U=6.30	single, U=6.30

Operating parameters for zone 1

HVAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
Rated Output, kW		
Heat	14	8
Sensible Cool	30	21
Total Cool	40	28
Rated Air Flow,L/s	1990	1333
MOOA,L/s	0	0
Heating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
Cooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
Heat performance	eff=100	eff=100
Cool performance	COP=2.6	COP=2.6
Economizer?	no	no
Type	NA	NA
Duct Leaks, total %	2	2
Conduction losses, total %	0	0
Peak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
Added mass?	none	none
Daylighting?	no	no
Infiltration, cm²	ELA=2342.2	ELA=2342.2

Results:	Low-Energy Case	Low-Energy Case	% Change
Energy cost			
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kWh	35820	24826	-30.69
Energy cost, $	931	645	-30.69
Saved by daylighting, kWh	-	-	
Total Electric, kWh	35814	24822	-30.69
Internal Lights, kWh	1668	1668	0.00
External Lights, kWh	0	0	
Heating, kWh	1303	421	-67.66
Cooling, kWh	29075	20257	-30.33
Fan, kWh	3768	2475	-34.32
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	16.0	11.8	-26.61

[illegible] kWh	0	0	
heat, kWh	0	0	
total, kWh	0	0	
nnual Emissions			
CO2, kg	21833	15132	-30.69
SO2, kg	128	89	-30.69
NOx, kg	67	46	-30.69
onstruction Costs	102449	94121	-8.13
ife-Cycle Cost	187633	156788	-16.44

ost Summary Report

cheme Name:	Low-Energy Case	Low-Energy Case	Difference
onstruction	102449.12	94120.55	8328.57
ixed	68582.40	68582.40	0.00
E strategies	3537.68	3469.12	68.56
VAC installation	30329.04	22069.03	8260.01
ortgage payment	0.00	0.00	0.00
AC replacement	22746.80	16551.80	6195.00
nual fuel	0.00	0.00	0.00
nual electric	930.97	645.23	285.74
nual maintenance	218.46	218.46	0.00

ife Cycle Cost Results	Low-Energy Cas	Low-Energy Case	NetPresentValue
apital	102449	94120	8329
roperty taxes	0	0	0
ortgage	0	0	0
tilities	15027	10411	4616
aintenance	4432	4432	0
VAC replacement	65725	47825	17900
tax deductions	0	0	0
ife-Cycle Cost	187633	156788	30845

nternal Rate of Return, IRR,	NA%
imple Payback, years	0.00
enefit / Cost Ratio	9999.00

ncial Parameters

ear of Construction	2006
uilding life, yr	30
alvage value, % of original	0.00
nnual property tax, % of value	0.00
roperty tax escalation rate, %	0.00
uel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
aintenance cost escalation rate, %	2.00
uilding resale escalation rate, %	0.00
VAC replacement cost escalation rate, %	3.00
VAC replacement cycle	7
iscount rate, %	5.00
ortgage?	no
mortgage term, yr	0
mortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
property taxes	no
loan interest	no
utilities	no
maintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

?C(3A)

:	Low-Energy Case 1	Low-Energy Case 2
er:	ARCHIVELIB	ARCHIVELIB
e:	valid/NA	valid/NA
status, Thermal/DL	BAHRAIN.ET1	BAHRAIN.ET1
e:	197.2	197.2
m²	450.8	450.8
a, m²	601.2	601.2
	694.0	275.8
ıction UA, W/K	1.539	0.612
alue, W/m²K	8in cmu, R=0.5	8in cmu, R=3.3
uction	flat, none, R=2.3	flat, none, R=6.4
uction	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
insulation	4060 single, alum, U=6.81	4060 single, alum, U=6.81
struction	None	None
ding	254	254
gross area, m²	99	99
gross area, m²	99	99
al gross area, m²	25	25
al gross area, m²	1/2/3/5:0	1/2/3/5:0
/E/S/W:Roof)	single, U=6.30	single, U=6.30
ne		

parameters for zone 1

m	DX Cooling with Elect Furn	DX Cooling with Elect Furn
ut, kW	14	8
	30	20
Cool	40	27
ol	1990	1256
Flow,L/s	0	0
	21.1 °C	21.1 °C
ermostat	no setback	no setback
	23.9 °C	23.9 °C
ermostat	no setup	no setup
	eff=100	eff=100
rmance	COP=2.6	COP=2.6
rmance	no	no
?	NA	NA
	2	2
, total %	0	0
losses, total %		
;W/m²		
Lights	2.15	2.15
Lights	0.00	0.00
er	0.00	0.00
Plug loads)	0.00	0.00
s?	none	none
ıg?	no	no
ion, cm²	ELA=2342.2	ELA=2342.2

st	Low-Energy Case	Low-Energy Case	% Change
	0.000	0.000	
	0.026	0.026	
	0.000	0.000	
n dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
e, kWh	35820	23363	-34.78
st, $	931	607	-34.78
daylighting, kWh	-	-	
ctric, kWh	35814	23359	-34.78
l Lights, kWh	1668	1668	0.00
l Lights, kWh	0	0	
, kWh	1303	352	-72.99
, kWh	29075	19033	-34.54
h	3768	2306	-38.80
er, kWh	0	0	
ated/process loads	0	0	
ectric, kW	16.0	11.3	-29.41

ıw kWh	0	0	
heat, kWh	0	0	
total, kWh	0	0	
ınnual Emissions			
CO2, kg	21833	14241	-34.78
SO2, kg	128	84	-34.78
NOx, kg	67	43	-34.78
:onstruction Costs	102449	93139	-9.09
ıife-Cycle Cost	187633	153066	-18.42

›st Summary Report

:heme Name:	Low-Energy Case	Low-Energy Case	Difference
›nstruction	102449.12	93138.98	9310.14
:ixed	68582.40	68582.40	0.00
:E strategies	3537.68	3469.12	68.56
HVAC installation	30329.04	21087.46	9241.58
›rtgage payment	0.00	0.00	0.00
/AC replacement	22746.80	15815.60	6931.20
ınual fuel	0.00	0.00	0.00
ınual electric	930.97	607.22	323.75
ınual maintenance	218.46	218.46	0.00

ıfe Cycle Cost Results	Low-Energy Cas	Low-Energy Case	NetPresentValue
:apital	102449	93138	9311
›roperty taxes	0	0	0
ıortgage	0	0	0
ıtilities	15027	9798	5229
ıaintenance	4432	4432	0
HVAC replacement	65725	45698	20027
:ax deductions	0	0	0
ıfe-Cycle Cost	187633	153066	34567

ıternal Rate of Return, IRR,	NA%
ımple Payback, years	0.00
enefit / Cost Ratio	9999.00

ıcial Parameters

ear of Construction	2006
ıilding life, yr	30
ılvage value, % of original	0.00
ınual property tax, % of value	0.00
:operty tax escalation rate, %	0.00
ıel cost escalation rate, %	0.00
lectric cost escalation rate, %	0.00
ıaintenance cost escalation rate, %	2.00
ıilding resale escalation rate, %	0.00
/AC replacement cost escalation rate, %	3.00
/AC replacement cycle	7
iscount rate, %	5.00
›rtgage?	no
ıortgage term, yr	0
ıortgage interest, %	8.00
down payment, %	100.00
ax deductible?	
›roperty taxes	no
loan interest	no
ıtilities	no
ıaintenance	no
HVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

Energy-10 Energy Use/Cost Comparison Report May 12, 2006
Project: zayed638 **Project Directory:** C:\Program Files\Energy-10\Version 1.8\Project
ZJ638

House type (3A)

Description:	Base Case	Insulated Base Case
Scheme Number:	1	2
Library Name:	ARCHIVELIB	ARCHIVELIB
Simulation status, Thermal/DL	valid/NA	valid/NA
Weather file:	BAHRAIN.ET1	BAHRAIN.ET1
Floor Area, m²	197.2	197.2
Surface Area, m²	450.8	450.8
Volume, m³	601.2	601.2
Total Conduction UA, W/K	315.8	266.3
Average U-value, W/m²K	0.701	0.591
Wall Construction	8in cmu, R=2.5	8in cmu, R=3.7
Roof Construction	flat, none, R=2.5	flat, none, R=7.2
Floor type, insulation	Slab on Grade, Reff=6.8	Slab on Grade, Reff=6.8
Window Construction	4060 single, alum, U=6.81	4060 single, alum, U=6.81
Window Shading	None	None
Wall total gross area, m²	254	254
Roof total gross area, m²	99	99
Ground total gross area, m²	99	99
Window total gross area, m²	25	25
Windows (N/E/S/W:Roof)	1/2/3/5:0	1/2/3/5:0
Glazing name	single, U=6.30	single, U=6.30

Operating parameters for zone 1

HVAC system	DX Cooling with Elect Furn	DX Cooling with Elect Furn
Rated Output, kW		
Heat	8	7
Sensible Cool	22	20
Total Cool	29	27
Rated Air Flow,L/s	1372	1239
OOA,L/s	0	0
Heating thermostat	21.1 °C	21.1 °C
Setback	no setback	no setback
Cooling thermostat	23.9 °C	23.9 °C
Setup	no setup	no setup
Heat performance	eff=100	eff=100
Cool performance	COP=2.6	COP=2.6
Economizer?	no	no
Type	NA	NA
Duct Leaks, total %	2	2
Conduction losses, total %	0	0
Peak Gains;W/m²		
Internal Lights	2.15	2.15
External Lights	0.00	0.00
Hot Water	0.00	0.00
Other (Plug loads)	0.00	0.00
Added mass?	none	none
Daylighting?	no	no
Infiltration, cm²	ELA=2342.2	ELA=2342.2

Results:

Energy cost	Base Case	Insulated Base Case	% Change
$/kWh	0.000	0.000	
$/kWh	0.026	0.026	
$/kW	0.000	0.000	
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec	
Energy use, kWh	25342	23059	-9.01
Energy cost, $	659	599	-9.01
Saved by daylighting, kWh	-	-	
Total Electric, kWh	25338	23055	-9.01
Internal Lights, kWh	1668	1668	0.00
External Lights, kWh	0	0	
Heating, kWh	609	339	-44.32
Cooling, kWh	20518	18777	-8.49
Fan, kWh	2542	2271	-10.68
Hot water, kWh	0	0	
unregulated/process loads	0	0	
Peak Electric, kW	11.9	11.2	-6.13

...eat, kWh	0	0	
...otal, kWh	0	0	
...nual Emissions			
...O2, kg	15447	14055	-9.01
...O2, kg	91	83	-9.01
...Ox, kg	47	43	-9.01
...nstruction Costs	94657	92919	-1.84
...ife-Cycle Cost	158565	152241	-3.99

t Summary Report

eme Name:	Base Case	Insulated Base Case	Difference
.struction	94656.97	92918.88	1738.09
xed	68582.40	68582.40	0.00
; strategies	3537.68	3469.12	68.56
'AC installation	22536.89	20867.36	1669.53
·tgage payment	0.00	0.00	0.00
ıC replacement	16902.70	15650.50	1252.20
ıual fuel	0.00	0.00	0.00
ıual electric	658.65	599.32	59.33
ıual maintenance	218.43	218.43	0.00

:e Cycle Cost Results	Base Case	Insulated Base	NetPresentValue
ıpital	94657	92918	1739
:operty taxes	0	0	0
ɔrtgage	0	0	0
:ilities	10637	9669	968
ıintenance	4432	4432	0
/AC replacement	48839	45222	3617
ax deductions	0	0	0
fe-Cycle Cost	158565	152241	6324

ternal Rate of Return, IRR,	NA%
mple Payback, years	0.00
nefit / Cost Ratio	9999.00

cial Parameters

ar of Construction	2006
ilding life, yr	30
lvage value, % of original	0.00
nual property tax, % of value	0.00
operty tax escalation rate, %	0.00
el cost escalation rate, %	0.00
ectric cost escalation rate, %	0.00
intenance cost escalation rate, %	2.00
ilding resale escalation rate, %	0.00
'AC replacement cost escalation rate, %	3.00
'AC replacement cycle	7
.scount rate, %	5.00
·rtgage?	no
ıortgage term, yr	0
ıortgage interest, %	8.00
lown payment, %	100.00
ıx deductible?	
ɔroperty taxes	no
.oan interest	no
ıtilities	no
ıaintenance	no
ıVAC upgrade	no
depreciation	no
straight line depreciation period, yr	31
incremental tax bracket, %	0.00

Appendix (D)

- Ministerial Order no.8 of 1999 with respect to Building Thermal Insulation Regulation.

- Summary of Bahrain Electricity Statistical data.

MINISTERIAL ORDER NO. 8 OF 1999 WITH RESPECT TO BUILDING THERMAL INSULATION REGULATION

Chapter One

Definitions

Article (1)

In the application of the provisions of this Order, thermal insulation means the use of materials having thermal insulation properties so as to help reduce the conduction and transfer of heat from outside a building to its inside in summer and from its inside to its outside in winter.

Schedule No.(1) which is attached to this Order details the technical and engineering glossary required for the implementation of thermal insulation, the defined meanings thereof and the equations indicating the manner of applying its requirements.

Chapter Two

Scope of Application and Requirements of Thermal Insulation of Buildings

Article (2)

Thermal insulation shall be used in all public and private buildings that require airconditioning equipment according to their engineering designs whether such buildings are government offices, commercial or industrial premises, houses, apartment blocks or otherwise.

Article (3)

Use of thermal insulation shall take place according to the requirements, specifications, materials and engineering methods indicated in Schedules (2), (3), (4) and (5), which are attached to this Order in respect of the surfaces and walls of all the buildings that are subject to the provisions thereof whether in respect to the newly constructed buildings or these that are rebuilt after demolition or in respect of the buildings added to the existing ones.

Article (4)

One of the appropriate engineering methods indicated in the attached Schedule (5) shall be followed upon using thermal insulation for

surfaces and walls of all the buildings subject to the provisions of this Order. In case of a desire to use a different insulation method, it shall be imperative to obtain the approval of the concerned authorities specified by the Technical and Engineering Affairs Directorate at the Central Municipal Council, provided that such approval shall be in writing and given before such use.

Article (5)

Building plans submitted with applications for building permits filed with the Municipalities shall conform with the requirements for implementing thermal insulation in buildings as indicated in this Order and the Schedules attached thereto and shall include the duly completed forms indicated in the attached Schedule (6), provided that such plans shall be accompanied by the approval of the concerned authority at the Ministry of Electricity and Water to the use of the thermal insulation method and materials to be used in the building including the type of the exterior window glass therein.

In the cases of using thermal insulation, it shall be prohibited to approve any plans that do not include the requirements referred to in the preceding paragraph or include requirements not compatible therewith.

Article (6)

Temporary facilities and minor additions to existing buildings the area of which does not exceed 70 (seventy) square metres shall be exempted from application of the provisions of this Order.

Chapter Three

General Provisions

Article (7)

The Technical and Engineering Affairs Directorate at the Municipalities Affairs (Central Municipal Council) may in co-ordination with the authorities concerned with implementing the provisions of this Order amend the necessary requirements, specifications, materials and methods of using thermal insulation indicated in the attached Schedules.

Such amendments shall not be valid and effective except upon the approval thereof by the Minister of Housing, Municipalities and Environment.

Article (8)

The Technical and Engineering Affairs Directorate at the Municipalities Affairs (Central Municipal Council) shall develop the necessary

mechanism for ensuring the implementation of the provisions of this Order from the Technical point of view in co-ordination with the officers concerned with thermal insulation at the Ministry of Electricity and Water and the other concerned authorities. The concerned officers at the Municipalities shall ensure applying the decisions adopted in this respect.

A building owner who uses insulation in his building shall not be permitted to connect services to the building save after proving his implementation of all the necessary requirements in this respect according to the provisions of this Order according to a report or certificate issued by the authority to be determined by the aforesaid Directorate or as provided for in the mechanism referred to above.

Article (9)

The application of the provisions of this Order shall commence from the effective date thereof to government buildings and investment commercial and industrial buildings that are more than four storeys high.

An order of the Minister of Housing, Municipalities and Environment shall determine the kinds of buildings and facilities to which this Order shall apply in future and the effective date in respect thereof.

Article (10)

Every violation of the provisions of this Order shall be punishable by the penalty indicated in Article 23 of Legislative Decree No.13 of 1977 with respect to the promulgation of the Law of Constructional Organisation of Buildings.

Article (11)

The Central Municipal Council's Director General shall implement this Order, which shall come into effect six months after the date of its publication in the Official Gazette.

Khalid bin Abdulla Al Khalifa,
Minister of Housing, Municipalities & Environment

Issued on: 1st Rabie'e Al Awal, 1420 Hijra,
Corresponding to: 15th June,1999

SCHEDULE (1)

TECHNICAL & ENGINEERING TERMS WITH RESPECT TO THE USE OF THERMAL INSULATION AND MEASUREMENTS REQUIRED THEREFOR

(First): <u>The following terms shall have the meanings assigned against each:</u>

(1) **Thermal Conductivity**:

It is the average time for the transfer of a thermal unit through an area unit of a homogenous material in a vertical direction on its surface as a result of the difference of one temperature degree between the two surfaces of the material. It is a measure of the material's heat conductivity.

(2) **Thermal Specific Resistance (Thermal Density)**:

It is a measure of the material's ability to resist the transfer of heat through it.

(3) **Thermal Resistance (R)**:

It is the average temperature of the difference between the heat of the two surfaces of the material resulting in the transfer of a thermal unit through an area unit of the thickness of the material whose resistance is to be measured.

(4) **Total Thermal Resistance (R_T)**:

It is the total thermal resistance of all the components/materials comprised in a section of the building's wall or surface plus the resistance of the air adjacent to the outside surface and resistance of the layer of air adjacent to the outside surface.

(5) **Heat Transfer Coefficient (U)**:

It is the average time for the transfer of a thermal unit through an area unit of the components of materials comprised in a section of construction starting from the hot surface and ending at the cooler surface.

(Second): <u>Measurements Necessary for Thermal Insulation:</u>

The coefficients and resistances mentioned in the (First) Section shall be measured according to the following equations taking into

consideration the meanings of symbols comprised therein and indicated as follows:

(a) The symbols indicated in the following equations shall mean the words and expressions against each:

W = Watt
m = Meter
m^2 = Square meter
K = Kelvin
Btu = British thermal unit
in = Inch
hr = Hour
ft = Foot
ft^2 = Square foot
F = Fahrenheit

(b) The coefficients and resistances indicated in the above (First) Section of this Schedule shall be measured according to the following equations:

1. Thermal Conductivity (λ or K) $= \frac{\text{Btu. In}}{\text{hr. ft}^2\text{. F}}$ or $\frac{\text{W}}{\text{m. K}}$

2. Thermal specific resistance (thermal density) (and r):

It calculated by the reciprocal of the thermal conductivity, i.e.

$\frac{\text{m. K}}{\text{W}}$ or $\frac{\text{hr. ft}^2\text{. F}}{\text{Btu. in}}$

3. Thermal Resistance (R) shall be measured by

$\frac{\text{K. m}^2}{\text{W}}$ or $\frac{\text{ft}^2\text{. hr. F}}{\text{Btu.}}$

It is calculated by multiplying the material's thickness (L) by thermal resistance (r) of the same material, i.e. R = L x r.

It should be noted that the higher the thermal resistance of a material is, the better it is in terms of thermal insulation.

4. Total Thermal Resistance (R_T):
RT = R1 + R2 + ...+ Ri + Ro

Where Ri means the resistance of the layer of air adjacent to the inside surface.

And Ro the resistance of the layer of air adjacent to the outside surface.

5. Heat Transfer Coefficient (U):

It is the reciprocal of the total thermal resistance (R_T) i.e.

$$U = \frac{1}{R_T}$$

It is measured in W/m^2 k or Btu/ft^2 hr.f

It should be noted that the lower the U value is, the better the surface or wall will be in terms of thermal insulation.

SCHEDULE (2)
BUILDING THERMAL INSULATION REQUIREMENTS

In the use of thermal insulation, the following conditions and requirements shall be complied with:

(1) The Heat Transfer Coefficient in airconditioned buildings in which insulation materials are used shall not be more than 0.6 watts per square metre for roofs surfaces degrees centigrade and not more than 0.75 watts per square metre degrees centigrade for walls.

(2) The Heat Transfer Coefficient applicable to surfaces indicated in the preceding paragraph shall be applied to false ceilings especially upon fixing the insulation material thereupon.

(3) If the building roof is of a trusses type on an insulated cardboard surface, mechanical ventilation must be provided for the space between the roof and the cardboard ceiling.

(4) Insulated glass must be used in all the windows of buildings with a height of more than three storeys or where the glass area in their facade is between 10% to 20% of the area of their facade.

However, for buildings with a glass area of more than 20% of their facade area, insulated and double glazed glass must be used for all their outside windows.

جـدول Table 14.06

وحدات الطاقة الكهربائية المستهلكة حسب القطاع والشهر ومعدل استهلاك الفرد الشهري ـ ألف كيلووات/ساعة
(2003 ـ 2002)

Electric Units Consumed By Sector and Month, Monthly Per Capita Consumption - ,000 kW/hour - (2002 & 2003)

Month	معدل استهلاك الفرد في القطاع المنزلي (كيلووات/ساعة) Per Capita Consumption in Domestic Sector (kW/hr)	إجمالي الوحدات المستهلكة Total Units Consumed	Sector القطاع				الشـــهـــر
			منزلي Domestic	تجاري Commercial	صناعي Industrial	زراعي Agricultural	
2003							
Jan	241	352,898,971	163,864,874	113,613,924	73,308,655	2,111,518	يناير
Feb	209	348,265,119	142,729,376	98,781,204	105,265,784	1,488,755	فبراير
Mar	209	336,489,947	142,919,801	93,932,025	98,046,650	1,591,471	مارس
Apr	207	340,267,183	141,726,579	99,092,203	97,375,681	2,072,720	ابريل
May	368	482,717,776	252,312,136	121,543,555	106,492,468	2,369,617	مايو
Jun	509	789,998,378	350,092,267	332,346,220	104,242,777	3,317,114	يونية
Jul	652	855,478,556	449,288,248	199,516,531	202,828,893	3,844,884	يولية
Aug	691	793,895,491	477,093,413	199,570,118	112,618,132	4,613,828	أغسطس
Sep	732	839,357,714	506,785,689	219,021,625	109,014,651	4,535,749	سبتمبر
Oct	673	798,561,610	467,254,446	213,080,505	114,547,353	3,679,306	أكتوبر
Nov	559	712,267,169	388,926,799	197,379,340	122,493,406	3,467,624	نوفمبر
Dec	368	520,734,412	256,629,349	150,276,636	112,692,271	1,136,156	ديسمبر
Total	**5,424**	**7,170,932,326**	**3,739,622,977**	**2,038,153,886**	**1,358,926,721**	**34,228,742**	**الجملة**
2004							
Jan	242	412,238,320	168,965,147	119,236,195	121,280,177	2,756,801	يناير
Feb	230	375,585,045	160,806,127	110,737,443	102,079,180	1,962,295	فبراير
Mar	211	360,969,228	147,930,829	107,789,054	103,456,172	1,793,173	مارس
Apr	224	384,053,237	157,426,446	124,610,204	100,055,635	1,960,952	ابريل
May	310	474,595,296	218,455,399	156,497,223	97,257,323	2,385,351	مايو
Jun	492	617,850,501	347,464,254	161,366,031	105,769,345	3,250,871	يونية
Jul	647	775,073,744	457,869,576	199,553,813	113,722,024	3,928,331	يولية
Aug	762	885,865,730	539,726,598	224,476,794	116,938,894	4,723,444	أغسطس
Sep	746	918,663,642	530,045,030	250,296,300	134,663,079	3,659,233	سبتمبر
Oct	692	843,455,111	492,672,513	229,993,859	116,539,342	4,249,397	أكتوبر
Nov	580	729,816,230	413,350,700	198,858,009	114,102,331	3,505,190	نوفمبر
Dec	420	743,254,857	299,951,029	174,014,915	266,602,882	2,686,031	ديسمبر
Total	**5,564**	**7,521,420,941**	**3,934,663,648**	**2,057,429,840**	**1,492,466,384**	**36,861,069**	**الجملة**