The Effect of Using Advanced Insulation Material on Indoor Temperature

Dissertation Presented for the degree of

MSc in Environmental design of Building

To the

British University in Dubai

Supervisor

Prof. Bassam Abu-Hijleh

By:

Sahar Arbabioon

Student ID: 20050067

Feb 2009

Abstract

Since UAE's urban development started two decades ago, the constructions have been influenced by international high technology. As a result, the advanced developments are very different from the local traditional housing which has been built according to the climate. The traditional building materials and components, such masonry and brick walls, have a great capacity to insulate the heat therefore the best possible thermal comfort is achieved during the summer. On the other hand, the modern materials as well as highly glazed surfaces have a little capacity to isolate the heat which causes uncomfortable high temperature during the summer.

The purpose of this study was to introduce advanced heat and moisture insulation for UAE hot and humid climate. Studying different type of insulation material such as Phase Change Material, Styropor, Styrodur c, Neopor, Micronal PCM, and EIFS class PB wall and finding the effects of humidity on their thermal storage and their latent heat. The advanced heat and moisture recommended insulation material in this research was Class PB-EIFS panel. EIFS, Exterior Insulation Finish Systems, has been presented in order to reveal the effect of the thickness and the color of the exterior wall which creates more comfort in the interior temperature.

Although this material seems more expensive than the normal insulations, but in the real terms a fully glazed building has more initial cost for exterior finishes. By selecting an existing fully glazed building in UAE and applying EIFS with different thickness and colors. The results Ecotect Simulations showed that Class PB EIFS with 290 mm Thickness on beige color exterior finish, not only reduces the annual energy by 10 %, also there

was significant of 60% saving on initial cost by removing the glass façade on construction cost. As result the initial cost of buying this EIFS material could be covered in the early years of usage by reducing the annual energy consumption.

ACKNOWLEDGMENTS

I would like first to thanks God and the entire universe that supported me to accomplish my work.

My sincere appreciation to my family for their supports and encouragements, which guide to all my successes.

Also special thanks to my advisor Professor Bassam Abu-Hijleh for all his time and knowledge that he shared with me along his guidance.

My sincere appreciation to my ever best instructors of my life, professor John Alexander Smith and Dr Fatima Taghi for all their help and supports which lead me to this stage of my life.

My regards to BASF company special Engineer Gassan, who has accepted me to interview with him and kindly shared all the information that I needed for my paper.

Special thanks to my kind classmate Omar Helmy for teaching me simulation software also special thanks to Fawwaz Hammad for sharing data regarding the Case study building in Abu Dhabi.

Finally, my great regards and thanks to my best friends Golnaz and Ehsan and Yasmin for supporting me to achieve my goal.

Dedication

I would like to dedicate this research to my beloved parents Ali Arbabioon and Parvin Amini, who their moral supports have guided me to all my achievement.

TABLE OF CONTENTS: **Page No**

Page No

Chapter Seven

Chapter Eight

Chapter Nine

List of Figures

LIST OF TABLES **Page No**

NOMENCLATURE

K	Thermal conductivity [W/(m.K)]
ΔQ	Quantity of heat (W)
Δt	Time duration for heat transferring (s)
ΔT	Temperature difference of conducting surface (°C)
R_{hs}	Thermal resistance ($m^2 \cdot K/W$)
P_{th}	Thermal power, heat flow (Watts)
R_s	Thermal resistance of the heat source (°K/W)
RH	Relative Humidity
U value	Heat Transfer Coefficient [W/(m^2.K)]
SR	Solar Radiation

CHAPTER 1

1. Introduction

1.1 Background to the Research

“Building is one of the oldest and most basic and at the same time most innovative activities in human history. A roof over one's head, protection, safety, privacy – these are all basic human needs.”(Marcinowski, 2007). References to Marcinowski (2007), Human beings always have been creative to build a pleasant indoor air conditions to adapt to the external climate situation. Building material has been one of the vital issues which help human to survive in different climate. The traditional building materials and components have a large thermal inertia or, in the other words, have a large sensible heat storage capacity, therefore these material provide the natural cooling system for the building’s interior (Ahmad, Bontemps , Salle’e, and Quenard, 2006).

Based on Santmouris and Asimkopoulos (2001), 6.7% of the total world energy is consuming for cooling and heating of the building. On the other hand 2.35% of this energy can be saved by sustainable design of the building. Especially in hot climate, cooling the space needs double of the energy in comparison to heating in cold climate. As a result, finding the right material according to the local climate can make enormous change on saving world energy.

Furthermore, Ahmad, Bontemps, Salle’e, and Quenard (2006) state the recent statistics on energy consumption shows; the building industry with 28% of total energy consumption is the world’s major consumer of energy. This percentage increases to the total of 45% in Western Countries mainly in France since people tend to consistently use heating and cooling systems in order to achieve indoor comfortable temperature. The thermal comfort is greatly associated with people’s psychological sensitivity to hot and cold temperature.

Pasupathy and Velraj (2008), believe searching for new materials and renewable energy sources have been the Scientist major mission for many years. Developing energy storage devices is as important as developing new sources of energy. Potential ability of thermal energy storage system in saving energy can decrease the negative impact of environment on non-renewable energy use. Therefore, the best solution to rebalance the inequality between the supply and demand of energy can be achieved through the usage of thermal energy storage system.

Choosing the right material for different climate would help to save the energy, according to Marcinowski (2007). Also, Marcinowski (2007) discusses that 85 percent of energy consumption is during the occupation phase of the house and construction phase consumes 15percent of the total energy load. So the envelop of the building can play a significant role on saving energy. For instance, having a right thermal insulation can save the energy up to 20 percent, which can be an extraordinary reduction in long term.

Pasupathy and Velraj (2008), discuss about the envelope of the building which is the most important factor for the range of the energy consumption and the comfort temperature in the room. Also, from the natural heavy clay to the high tech phase change material the only concern is to achieve the lowest level of energy consumption as well as the pleasant mean-temperature (Velraj and Pasupathy, 2008). Reference to the same source, in these days the main concern is to build energy efficient buildings with the light weight construction, not only the construction technique, but also chemistry helps a lot to create the new type of thermal insulation. Furthermore, increasing demands for air conditioning in hot climate country like UAE resulted in higher fuel energy consumption in last decade.

To reduce the amount of energy in buildings, Santmouris and Asimkopoulos (2001), believe, architects can apply the passive cooling strategies on the new high rise buildings. For example, selecting the right thermal insulation can reduce the heat transmission thorough the buildings envelop. In addition, light color of the exterior wall can control the solar radiation of the building's envelope which consequently can decrease the solar heat gain of the structure (Santmouris and Asimkopoulos, 2001).

Since the major electrical energy consumption is due to the space cooling in hot climate country people tried to examine different material with high thermal capacity. As Khudhair and Farid (2004), mentions in their research Phase Change Material (PCM) could be an efficient thermal storage because of the high latent heat capacity, where PCM absorb or release the energy to change the face from solid to liquid or reverse. For example the latent heat of PCM such as calcium chloride hex hydrate is 193 kJ/kg, on the other hand the sensible heat of the concrete is 1.0 kJ/kg K (Khudhair and Farid, 2004). As Ahmad, Bontemps, Salle'e, and Quenard (2006) mention in their research, the first publication about Phase change material has been done in 1940; from that time people start implement this material for storing and recovering solar energy. Since 1980 Phase change material has been use as thermal storage in the building, and has been inserted in to different material such as concrete, plaster and gypsum board. This material can be installed as part of the structure which can help to reduce the weight of the building at the same time (Khudhair and Farid, 2004).

According to Heinz and Streicher (2001), the concept of Phase Change Material is; a material with a high heat of fusion. PCM is melting and solidifying at certain temperatures, so PCM will be able to store or release large amounts of energy, during phase changes. Using PCM has similar function as the old massive structure in traditional housing to decrease the heat gain from the wall or to increase the thermal storage. The latent heat of phase change material is the main characteristic of PCM for storing thermal energy; the heat is stored during the phase change state of liquid to solid.

Schossig et al. (2005) have done a field investigation on real model simulation on an existing building in order to achieve an optimum thermal comfort on modern lightweight constructions and they have been trying to incorporate phase change materials known as Macro-capsules PCMs in to one room construction. Direct immersion process used to be the common methods to apply the PCMs in to the building's structure. However, due to their several disadvantages, this method failed and a need for an alternative option was raised. An advance technique involves the integration of micro-encapsulated PCMs in to the building structure. An advance method of encapsulated PCMs has overcome the drawbacks and limitations of earlier methods. In previous techniques (direct immersion process) PCMs are not encapsulated, therefore there is a higher risk of chemical interaction between PCMs and building materials which may change the original properties of these materials. In addition PCM leakage may occur over the following years of usage. Another main draw back of the macro-capsules is that they are sensitive to any type of destruction or any penetration to the building structure such as drilling and nailing. Further more incorporating Macro-capsules in to the building system is an expensive process since it requires large amount of time and work. Finally, Macro-capsules PCMs such as paraffin may not efficiently transfer the heat during the solidification process; consequently the heat transfer rate is low. On the other hand, Micro-encapsulated PCM is extremely small in size (few micro meters in diameter) and since it is enclosed in a capsule, micro encapsulated PCM can easily integrate with building materials with out any possibility of chemical reaction or leakage. Another advantage of micro encapsulated PCM is that the amount of time and energy required to integrate the PCM in to building materials are far less than Macro – capsules. Also, destruction to the building structure does not have any

effect on Micro-encapsulated PCM because of its extreme small size. Finally, due to the fact that Micro-encapsulated PCM are small in size but large in quantity, i.e. have a large surface area to volume ratio, their ability to transfer the heat is significant, consequently the heat transfer rate is high between capsules molecules in side the unit wall (Schossing et, al. 2005). Following are some evidences of different investigation on the usage of Phase Change Materials.

Refer to Schossing et al. (2005), after three weeks investigation on two test rooms with a lightweight construction one with PCM and the other with typical insulation they have found out that the room with PCM has 4K temperature difference compared to a typical room.

Shilei et al. (2005) did a simulation in China on Real models room with PCM gypsum wall, and they found out that the in the hottest day the maximum temperature difference was 2.95 C compared to the room with typical wall.

Reference to Medina et al. (2007), on their field investigation model houses; one with structural insulated panels (SIPs) contains Phase change material other with regular polystyrene insulation. The final simulation results showed that the PCMSIP had 5C lower temperature than the typical insulated model house.

Stritih (2003) presented paraffin fins as PCM to store the solar heat also investigated the influence of the distance between the Phase Change Material fines to transfer the heat inside the wall. Finally according to Alawadhi (2008) researches on Athienitis Investigation on PCM gypsum panels the investigation results showed that by applying PCM panels as exterior envelope the maximum reduction on indoor temperature could be 4 C.

The first aim of this paper was to propose the PCM as sustainable material for UAE construction to decrees the solar gain in this hot and humid weather condition. After studying different type of PCM and reviewing previous investigation by other people also communicating with PCM factories, the long period of time with high temperature during the summer day with high humidity can effect on phase change material functions heat conductivity and latent heat.
As result the topic had been converted to finding the suitable sustainable insulation material with high thermal and humidity resistant for UAE hot and humid climate. By studying different type of insulation material such as Styropor, Styrodur c, Neopor, and Micronal PCM and determining the advantages and disadvantages of using this material in UAE construction by communicating with different construction companies, and according to Engineer Gassan from BASF, Class PB-EIFS heat and moisture insulation material could be a sustainable thermal insulation material with high moisture barrier for UAE climate. EIFS is an Exterior Insulation and Finish System which is for insulating the exterior envelope. The system is based on adhered technique which is consisting of “an insulation panel and adhesive, polystyrene board, a base coat and reinforcing mesh and finish coat” (BASF,”Senerflex Classic PB Wall System, Senerflex Channeled Adhesive Design”, 2006).

Reference Senergy, in the article; “company on its Exterior Insulation & Finish System”, EIFS can be applied to the existing structure with any base to increase the insulation level and decrease the construction cost and improve the exterior envelope presentation. The other reimbursements of EIFS are being energy efficient also being flexible with any design for exterior of the building.

Based on BASF publications in article, “Commercial Wall Systems, Design Freedom for Distinctive and Enduring Buildings”, one of the remarkable examples of EIFS project is Bahamas’s Atlantis Resort Which had been clad with 425,000 square feet of EIFS. “ In September 1999, the 155mph winds of Hurricane Floyd ripped through the Bahamas, toppling 30-foot trees and ripping roofs from the homes”, but the Atlantis Resort remained untouched.

According to Schmidt (2008), EIFs had been used in all around the world as a sustainable energy efficient insulation material for all type of the construction, in low rise and high rise, commercial and residential. In Table1.1 have been cited some example of project which had been made of EIFS systems. Furthermore BASF recently had done one mock up villa in festival City in Dubai to simulate the effect of using this system on low rise construction in hot and humid climate condition.

No	Project name / Type	Location
1	Office Building	Vancouver, BC
2	Hospital ,Celebration Health	Orlando
3	Baptist church	Texas
4	Multi Family Housing Condominium	Atlanta
5	Single family Residential	Virginia Beach
6	Retail Center & Renovation Town& Country Center	Columbus
7	Urban Center ,The gate way	Salt Lake City
8	Dolphin and Swan Hotels	Orlando
9	Marriott	Phoenix
10	Arizona State University	Arizona
11	Atlantis Hotel	Bahamas
12	Robinson’s Station Rosa	Philippines
13	NCCC Mall	Davao City, Philippines
13	British Embassy Villa	Abu Dhabi

Table 1.1 Project which used Class PB EFIS(Schmidt, 2008)

Based on the above researches, EIFS Insulation System is the advance thermal and humidity barrier that had been chosen for this dissertation. The main part of this paper is covering the investigation on applying Class PB-EIFS insulation on an existing building in UAE and estimating the cooling and heating load of the building after applying this material and estimating the annual energy saving and construction cost estimation.

1.2. Aim and Objectives

The aim of this study is to study the effect of using advanced insulation material in U.A.E construction. This material must be a high thermal and humidity barrier insulation.

Since by keeping the heat and moisture out from the indoor atmosphere, the HVAC usage would decrease and there could be a significant reduction on energy usage of the building. This will reduce the building demand on material and energy. In order to accomplish the aim of this research the following objectives are required to be investigated:

1. Understanding the main concept of thermal and humidity insulation from the beginning of building construction
2. Analyzing the existing insulation material in the market
3. Recommend a sustainable moisture and heat insulation material
4. Evaluating the proposed material
5. Simulating the cooling and heating load of a building with or without the proposed material
6. Estimate the anticipate energy saving by using the proposed material.
7. Evaluate the financial implications of using the proposed material and estimating the saving on initial cost.

CHAPTER 2

2.Research Methodology

2.1 Backgroud to methodology of the research:

In order to conduct an investigation, there are different type of research methodology, such as, physical modeling investigation, field investigation and computer simulation.

Although the physical modeling can create more accurate results which are more close to real condition, this method needs too much time and facilities, also it is costly.

Field investigation with weather tool instrument is another research method which has been used in this research, to investigate the effect of the traditional thermal mass walls on the interior temperature in Bastakiya area in Dubai.

Other investigation method is interview which is the qualitative method and the purpose is to reach to a deeper understanding and description of a subject.

Interview technique was one of the appropriate methods to received long term feedback from the professionals who were experienced in insulation material field, and were capable of choosing the suitable material for building insulation.

Furthermore literature review was an alternative and valuable method to collect other researcher Ideas and Investigations on the same subject and comparing their results to come up with the accurate solution to select the right material.

Furthermore the key method to investigate the selected material on this research was the computer simulation. Since we do not have facilities to build the real model and there is not enough time to build a model and examine the different situations, computer simulation is more reasonable to use. Also computer simulation highly controls different conditions, and provides reliability and repeatability. Furthermore computer simulation can remove noise from data which is out of control in real physical model. Refer to different investigations about insulation material researchers had chosen the computer simulation; for example Feist (2006), have used Building Simulation Program DYNBIL, to examine EIFS and other insulation material on different building around the world. Also BASF and LUWOGE had used the computer simulation to estimate the energy consumption for three-liter house project (BASF Publications in article “The 3-Liter House”. Furthermore refer to Schmidt (2008), presentation, he had used the Doftherm program to estimated the U value of the thermal insulation with different thickness and effect of the thermal insulation on energy saving.

2.2 Scope of this research

As mentioned in introduction section, this research has been started by the Idea of using Phase change Material in UAE construction sector. After five months of communications with PCM manufactures and investigation on the PCM criteria, it was found out that this material cannot function properly by itself as a passive method, which means using the PCM in the wall to protect the interior from solar gain. Some companies like Phase Change Material Products LTD in their latest product publication introduced the Ecopac Tile ™ as PCM panels on suspended ceiling next to the air channel to keep the interior cold, but these panels are customized for exterior wall which could not act as passive thermal mass to keep the heat out in UAE climate condition.

On the other hand by Communicating with BASF chemical company, I found out that there are some other new materials with high thermal and humidity barrier. These new materials can be tailor made according to the building U-value target. During this time, I found some other materials which contain PCM that I presented them on the following chapter. Furthermore, I have done some comparisons between the concrete massive structures and the EIFS thermal insulation walls. The main aim is to reach the human comfort inside the building by using lighter material such as EIFS exterior insulation wall with high thermal resistant. The structure of this research paper consists of the following stages:

a) Conducting some interviews with companies regarding their latest insulation material.

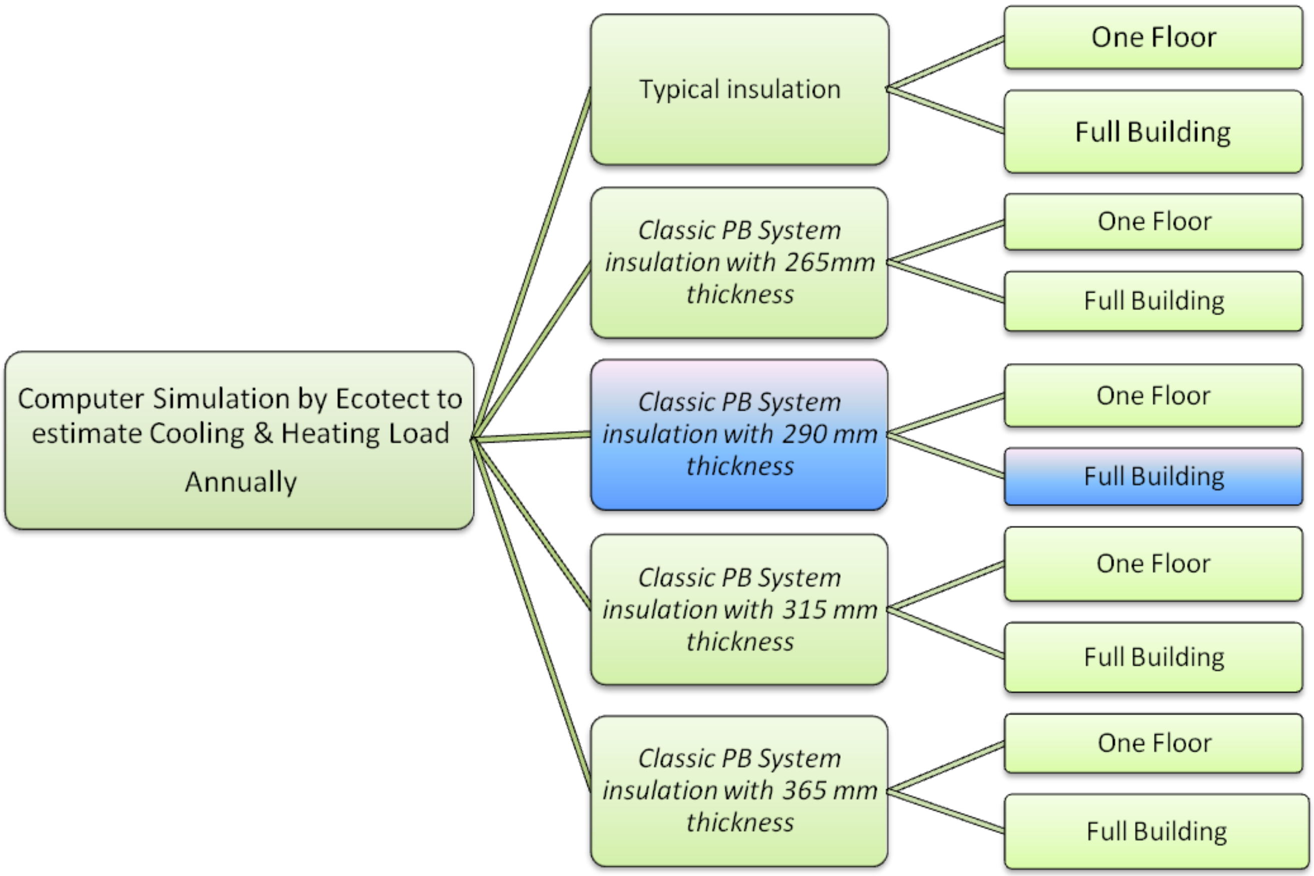
b) Site investigation in Bastakiya Area for collecting some weather Data and investigating by weather instruments to find the effect of traditional massive structure on indoor temperature.

c) Selecting an existing building with estimated cooling load, and energy consumption.

d) Applying the new material with different thickness and color by Ecotect.

e) Run different simulation on cooling and heating load of the building, starting from one floor then the whole building (annually ad monthly), first with different thickness. To find the effect of the thickness on envelope heat resistant.
f) Present the result with some tables and diagrams.
g) Make some comparison between the results.
h) Select the most efficient thickness and apply different color to find the effect of the exterior color on solar gain.
i) Select the right color and compare the annual cooling and heating load result with typical wall.

j) Presenting the energy saving load within one year and estimate the



financial saving on future.

Fig 2.1 Scope of this research

United Arab Emirates known as UAE, is situated in Southwest Asia on the Arabian Peninsula between latitudes 22.0° and 26.5° N and between 51° and 56.5° E.UAE consists of seven states that bonded together in 1972.UAE covers 83,600 square kilometers in total, and Abu Dhabi, the largest state, covers about 80% of UAE. Abu Dhabi is the UAE's capital city. (Ministry of Energy , United Arab Emirates, 2006)

2.3.1Abu Dhabi climate and Location

Abu Dhabi is an island five miles wide and nine miles long which is located in Persian Gulf area. UAE has border with Saudi Arabia on the south and west as well as a border with Oman on the east and north. The climate of the UAE is hot with high temperature and high evaporation rates. Sunny blue sky is mostly the case during the year but the country is likely to expect infrequent rainfall of less than 100 mm/yr average. During the summer the temperature reaches the highest of 48°C. On the other hand, the lowest temperature is 10°C in January. As a result, the most favorable temperature is during the winter with the maximum of 24°C in the daytime and minimum of 13°c during the night. "Weather in United Arab Emirates",2008)

2.3.2 Dubai climate and Location

Reference to Realityana website (2008), Dubai is located on the southern shore of the Persian Gulf. It has an area of some 3,900 square kilometers. Outside the city itself, the emirate is sparsely inhabited and characterized by desert vegetation.

Dubai is consists of two parts; Deira and Bur Dubai, separated by a creek Flowing inland from the Persian Gulf.

Dubai has a sub-tropical, arid climate, and sunny blue skies and high temperatures can be expected most of the year. Rainfall is infrequent and irregular, falling mainly in winter November to March .Temperatures range is from a low of around 10º C to a high of 48º C in summer. The mean daily maximum is 24º C in January, rising to 41º C in July. During the winter there are occasional sandstorms (the wind is known as shemal) when the sand is whipped up of the desert, furthermore it has a hot Climate with a high intensity of direct solar radiation (South Travel web site, ”Weather in United Arab Emirates”,2008) .

Figure 2.2 UEA Image (Google Earth)

CHAPTER 3

3. Background to Heat Transfer in Building

3.1. Thermal conductivity (K value)

Schmidt (2008) explains thermal conductivity is the rate of heat flow through the material Perpendicular to the surface of 1sqm area of the material. The unit of measurement is [W/ (m.K)].

"What is called the k-value of construction materials in the US is called λ-value in Europe" (Wikipedia the free encyclopedia, "Thermal Conductivity").

$$k = \frac{\Delta Q}{A \times \Delta t} \times \frac{x}{\Delta T}$$

Value	Description
K	Thermal conductivity
ΔQ	Quantity of heat
A	Total cross sectional area of conducting surface
Δt	Time duration for heat transferring
x	Thickness of conducting surface
ΔT	Δ*T* is temperature difference of conducting surface

Table 3.1 Thermal conductivity (K value) (Wikipedia)

- Some example of the substrate materials (k value):

Substrates	K Value
AAC block	0.134
Hollow concrete block	1.173
Solid concrete block	1.273
Concrete block with polystyrene inserts	0.235
Reinforced concrete	1.850

Concrete building	1.730
Light weight concrete	0.840

Table 3.2 Substrates Thermal conductivity (K value) (Schmidt 2008)

3.2. Thermal resistance (R value)

"Is the resistance to heat transfer through a material by conduction"(Schmidt, 2008).

The unit measurement is [(m²·K/W)]

$$R_{hs} = \frac{\Delta T}{P_{th}} - R_s$$

Value	Description	
R_{hs}	Thermal resistance	(m²·K/W)
P_{th}	Thermal power (heat flow)	Watts
R_s	Thermal resistance of the heat source	°C/W
ΔT	ΔT is temperature difference of conducting surface	°C

Table 3.3 Thermal resistance (R value) (Wikipedia)

3.3. Overall Heat Transfer Coefficient (U value)

The rate of the heat goes through material called U value with units of W/m^2 °C. Less heat can grow through the Material with the low U value number (Sustainable Energy Ireland (SEI)in article "what is a U value").

3.4. Types of Phase Change Material:

Two most common types of phase change material are organic and inorganic.

3.4.1. Organic: paraffin is one of the examples of organic compounds.

- ✓ advantage
- o Chemically stable

- Non-corrosive
- No supper cooling, which mean for crystallization they do not need to be
- Cooled to the freezing level.
- Can be matched with building material
- High latent heat
- Recyclable (Bruno ,2004),

✓ Disadvantage

- Expensive
- Low latent heat/ low density
- Flammable

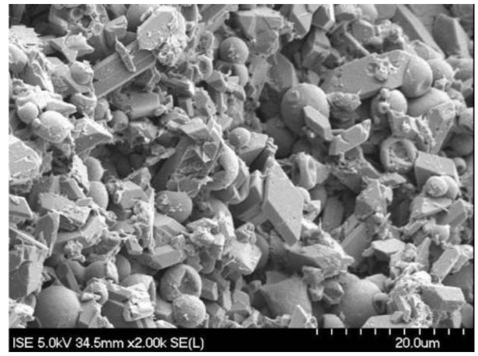


Figure 3.1 The PCM micro-capsules (Gschwander and Schossig)

3.4.2. Salt Hydrates are mixed of salt and water.

✓ Advantage:

- High latent heat of fusion/Density
- Cheap in price
- Non Flammable. (PCM Limited, 2007)

✓ Disadvantage:

- Additives material is essential for long term use
- Corrosive to some material like metal
- Needs super cooling

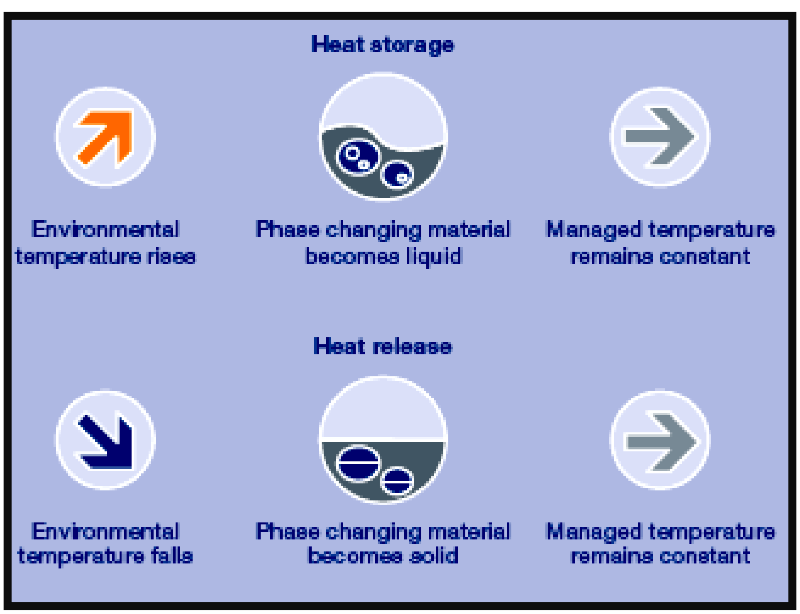


Figure 3.2 How phase changing materials work (BASF Publications," Foams-Styroper /peripor (EPS)")

3.4.3. Latent heat of Phase Change Material

Velraj and Pasupathy stated, Latent heat storage was the main research topic at the time of energy crises during 1970-1980's. latent heat phase is the Heat absorbed or released as a result of phase change of the material molecules. Also, Elert (2008), believes the temperature and the kinetic energy will not change during a phase change so energy stored in the bonds between the atoms will release during this state. For instance, during the water evaporation, latent heat increases by water molecules. The temperature of the water itself will not change because this heat will be used to break the hydrogen bond between the water molecules during the evaporations state. This heat will stay hidden in the water molecule and it can be free just during the condensation which will transfer to the sensible heat (The Physical Environment, 2008).

According to Bruno (2004), PCM do not function like traditional thermal storage method because in PCM energy is stored and released in stable temperature. Unlike the traditional thermal storage, PCM can be use in active and passive method. In the passive cooling method PCM can be injected by encapsulation method in to the concrete wall and gypsum board which can be used in flooring and ceiling to enhance the thermal storage of the building. Controlling the thermal storage capacity can have an effect on the air temperature with a pleasant mean temperature for desire period of time.

In addition Urtel (2006) says, "This is the same effect which is so welcome on sweltering hot days when the ice cubes in a drink absorb large amounts of heat when melting, effectively keeping the drink cool for a long time."

CHAPTER 4

4.0 Thermal management from old time to modern date.

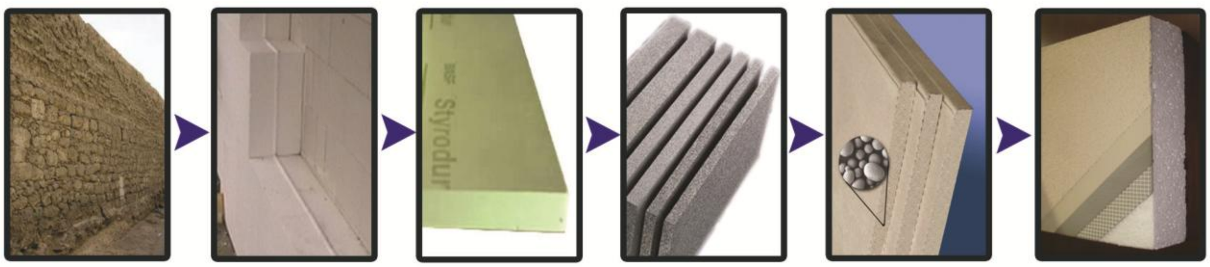


Figure 4.1 Thermal Management from Traditional Clay to Class

Santmouris and Asimkopoulos (2001) state that different parameters can have effects on the thermal behavior of the building, some can be controlled by human and some not. For instance, climatological is one of the factors which are not under the human control. On the other hand, design of the structure with the right material can lead the thermal behavior to a pleasant environment. Solar radiation and high temperature are main issues for the buildings in hot climate countries, which can be resolved with right material for that region. Traditional architecture has some talented solutions to use the right materials according to local climate. Massive structure made of clay and coral stone with light color on the exterior walls is a nice example of harmonization with the region climate.

Moreover due to the same source, some materials like brick and concrete have high thermal mass capacity, so they are able to absorb and store the hot and cold weather. The strategy of this thermal mass is to keep the heat during the day as long as possible, and then release it to the exterior environment during the evening time when the weather temperature has been cooled down (Santmouris and Asimkopoulos, 2001).

According to the Simon Swan cited by Mostaedi (2002), high thermal construction materials such as brick can be economical and ecological for the architecture style of harsh climate in desert area; also the right material can serve the pleasant indoor temperature.

For instance Bastakiya area is one of the traditional housing compounds in Dubai which has been designed according to the hot and humid climate of the region. All the houses have thick walls of 45cm-60cm wide. These massive walls act like thermal insulation, to keep the solar heat out from the interior.

Massive walls contain the bellow criteria:

- Corel stone (porous nature)
- Sarooj; comprised of sand, clay, egg whites, lime, goat hair, and ash.
- Covered with plaster.
- Low thermal conductivity material.

Figure 4.2 Bastakiya Area

Givoni (1998) mentions, Today, the combination of modern high tech insulation materials with inspiration of passive cooling system, make architects able to reach the pleasant indoor temperature, by providing natural cooling system during hot days of the year and reducing the wastage of energy for air conditioning system.

4.1 Case study on traditional houses

Bastakiya area with traditional massive walls construction

This site is located near the British Embassy next to the Maktum Bridge. Most of the buildings in this area are designed with traditional architecture with massive walls. According to the site investigation on September 2005 by BUID students, to investigate the weather temperature in the site Weather Instrument was used. According to the Weather Instrument's result, outside temperature was showing 30C, inside 25C at the same time. So the outcome data proves the effects of massive structure on the indoor temperature; for instance coral wall has been used as massive structure to keep the heat out during the hot summer. Since the design of the building has been changed, the massive walls cannot be a good solution for thermal insulation in high rise buildings. As a result, manufactures have come up with new lighter thermal insulation material every decade to create the pleasant indoor temperature.

4.2 Styrodur C

Styrodur C is extruded polystyrene hard foam. This material is thermal insulation which can make the indoor atmosphere healthy and comfortable to live. Styrodur C green polystyrene foam is environmental healthy insulation material to use for the building envelop, because it is free of ozone-depleting CFC, HCFC, and HFC. . Styrodur C can be used for wall, and ceiling and flooring at the same time to get better result for insulation.

Figure 4.3 Styrodur C installations (BASF, "reconstruction and refurbishment")

BASF in “Customer Success Story, At BASF, we don’t make custom-designed or affordable homes. We make them more energy efficient” expresses on some Styrodur C’s advantages such as:

- Reducing the energy consumption because of high thermal insulation
- Easy to install
- Short construction period
- Low moisture abortion

property	Tope 2500C	Type 2800C
Length Width mm	1250x600	1250x 600
Density kg/m3	28	30
Thermal Conductivity [W/m.K] Thermal Resistance [m2K/W]	22 mm thickness = 0,032 22 mm thickness = 0,65	22 mm thickness = 0,032 22 mm thickness = 0,65
Thermal Conductivity [W/m.K] Thermal Resistance [m2K/W]	60 mm thickness = 0,034 60 mm thickness = 1.8	22 mm thickness = 0,034 22 mm thickness = 1.8

Table 4.1 Styrodur c variety and criteria (BASF, “Customer Success Story, At BASF, we don’t make custom-designed or affordable homes. We make them more energy efficient”, and “Technical date and assistance data for dimensioning”)

Furthermore, BASF in a publication, “Technical date and assistance data for dimensioning” explains, the moisture can have an effect on thermal conductivity of Styrodur c, which can be the disadvantage of using it in UAE weather, because the humidity in summer is above 70%. According to the data bellow data, per 1% of moisture, thermal conductivity will increases by 2.3 %. As a result, Styrodur has to be installed with moisture barrier to keep its thermal conductivity value. This can be disadvantage for using it in Dubai with such high humidity during the year especially in summer time.

Moisture content vol.%	Thermal conductivity in W/m.K
4%	0.035
6%	0.037
8%	0.038
10%	0.039
12%	0.040

Table 4.2 Moisture affect on Styrodur C's thermal conductivity (BASF, "Technical date and assistance data for dimensioning")

4.3 Styropor®

"Styropor®, an expandable polystyrene (EPS) was invented by BASF in 1952 and today is a classic among the raw materials employed for cost-effective construction as well as efficient and reliable packaging".(BASF, "Foams-Styroper /peripor (EPS)).

Figure 4.4 Styropor® installations(Refe: www.lrzmuenchen.de/~Passivhaus/images/d5.jpg)

Figure 4.5 Styropor® installations (Ref:www.kreisel.ua/technologies/thermal_insulation/_images/technologie/tech_2_05.jpg)

4.4 Neopor®

Neopor® is expandable polystyrene contain 6%wt pentane (C_5H_{12}), which is an organic complex (BASF, 2008a). Neopor® is an insulation panel which is coming in silver gray color, it contains spherical black beads (BASF, 2008b). Also, some other characteristics of Neopor which BASF states on the published issue; "Neopor, Innovation in Insulation" is as follows: Neopor panels are thinner than the rest of the insulation panels but they have better insulation result. Neopor can reflect the radiation of the sun, so this characteristic make Neopor better thermal insulation material. These panels are also excellent sound impact insulation, so they can be a good choice for building next to the high ways. Neopor insulation panel can be 20% thinner than Styropor panel with the same thermal insulation.

Figure 4.6 Neopor® installations (BASF, Pictures)

4.5 Micronal PCM

Urtel (2006) discusses, micronal PCM is a smart boards containing of phase change material microencapsulated on paraffin wax. These smart boards can act as thermal insulation, since they can store the latent heat during the phase change of the encapsulate paraffin wax. "During this phase transition, a large amount of thermal energy (known as latent heat) is consumed without the temperature of the material itself changing".

24-26 C˚ is a nice temperature for interior; the wax in Micronal PCM is usually melting at the point to keep the indoor temperature pleasant. Melting temperature for the contained wax is 23C˚ or 26C˚. As one can see on the bellow figure, “The Micronal® PCM microcapsules in SmartBoardTM are embedded in a carrier matrix of gypsum” (Urtel, 2006).

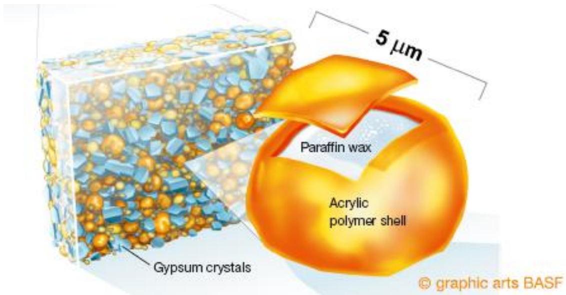


Figure 4.7 The Micronal® PCM microcapsules (Urtel, 2006)

Also, Urtel (2006), explains about the Micronal PCM gypsum wall board which SmartBoardTM is only 1.5centimeters thickness contains three kilograms PCM per square meter. According to the simulation, 1.5centimeters Micronal PCM gypsum wall board SmartBoard^{TM} has same heat capacity as brick wall with 12 cm thickness.

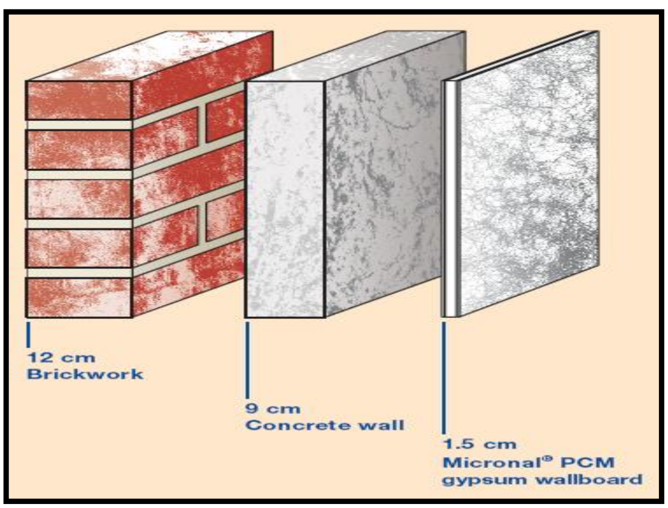


Figure 4.8 The Micronal® PCM thickness comparison with other materials (BASF, “Foams-Styroper /peripor (EPS)”)

"The cooling effect of about 3 to 4C˚ achievable with BASF's innovative PCM products is almost equivalent to that provided by conventional air conditioning systems which are usually designed to create a temperature difference of 6C˚"(Urtel, 2006). Although the Micronal PCM gypsum wall board SmartBoard™ Are environmentally friendly and easy to use but it cannot function in UAE environment, because 4 degree temperature change cannot achieve the thermal comfort in summer time when the temperature rise to 48C˚. As a result, according to my discussion with one of the BASF chemical group engineer, PCM cannot function in this harsh climate, which the comfort temperature is around half the outdoor temperature. Therefore 4 degree difference cannot help to achieve the pleasant indoor temperature during the summer time.

4.6 Class PB-EIFS

Class PB-EIFS is the best product that has been suggested for UAE hot and humid weather from different companies such as BASF, because as it will be presented on the following chapter, this material can keep the heat and moisture out from interior even during the summer days. EIFS is Exterior Insulation and Finish System developed in Europe. It can be tailor made by different insulation solution, such as different types of weather barrier, and humidity barrier.

Original option

- Class PB EIFS

Tailored options

- Class PM EIFS
- Water Managed PB EIFS
- One-Coat Stucco
- ICF surfacing Systems
- Cement-Board Stucco

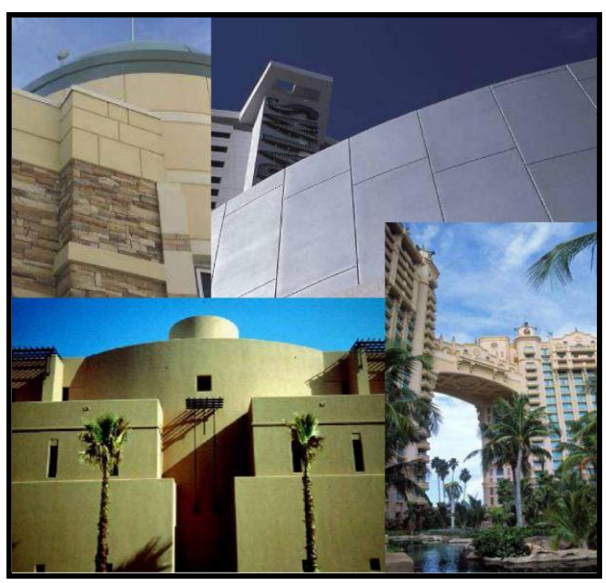


Figure 4.9 Class PB EIFS samples work (Schmidt, 2008)

4.6.1. Class PB-EIFS installation benefit:

- Design flexibility: it can be shaped and cut to any type of design and scales.
- Variety of texture
- Variety of color selection
- Energy saving
- High speed of construction
- Crack resistance.(14)
- Dirt and mildew resistance.(33)
- Reduce the weight on facades.(36)
- Reduce the U value.(36)

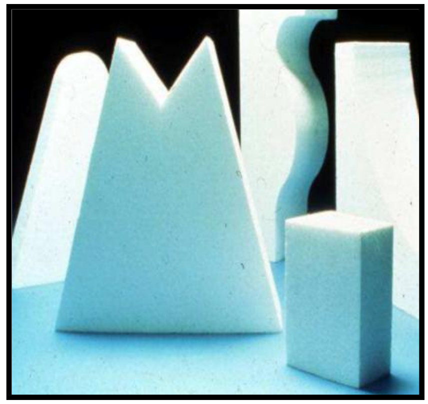


Figure4.10. EIFS Design flexibility (Schmidt, 2008)

4.6.2. Class PB-EIFS Mechanism

Based on the report from National Research Council Canada (2005), this cladding wall structure includes the following mechanisms:

1. Substrate; such as masonry, brick, concrete, cement, gypsum board.
2. WPB coating, Water Penetration Barrier. “Senershield” is a polymer –based, fiber-reinforced wet mix coating with Portland cement on site.
3. Adhesive coating; adhesive products are using for bonding the WPB to the insulation board.
4. Insulation board; The Expanded polystyrene-foam.
5. Reinforcing Mesh; “is alkaliresistant, glass-fiber reinforcing fabric, and has minimum 142 g/m2 nominal weight, used with the adhesive/base coat. The mesh is white and is available in rolls that are 965 mm wide and 45.7 m long. Starter mesh for rendering surface articulations and terminations is available in rolls that are 229 mm wide”.
6. Finish coating system, is the acrylic based finish coat, which is coming in different colors and textures.

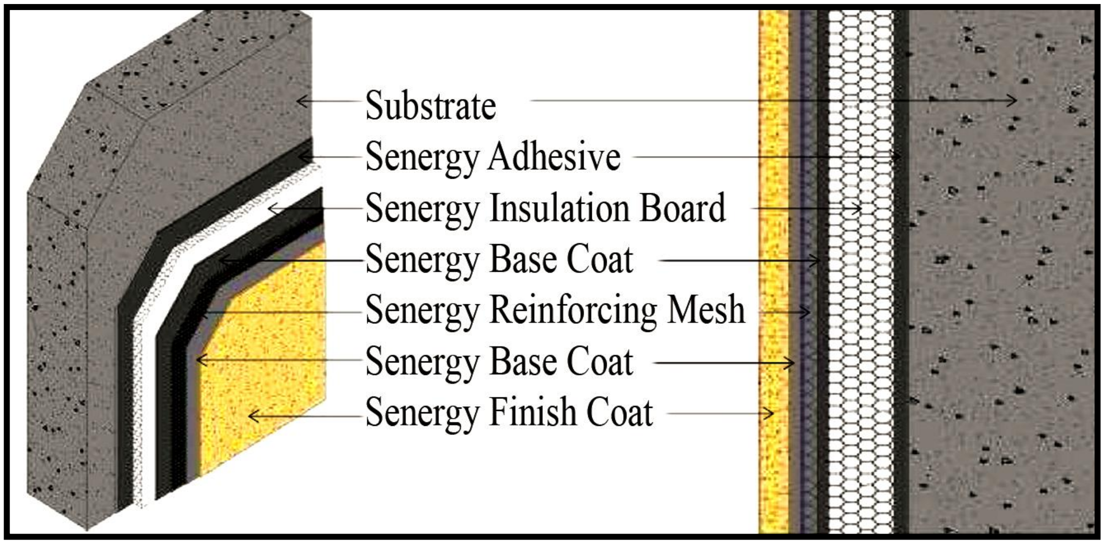


Figure4.11- Class PB-EIFS Mechanism (Schmidt, 2008)

4.6.3. Class PB-EIFS Finish coating system variety

FINE Texture; 100% acrylic polymer/ ready mixed and available in different colors.
SAHARA; 100% acrylic polymer/ ready mixed, and available in different colors and custom made colors /"pebble" appearance.
TEXTURE; 100% acrylic polymer , ready mixed/free-formed textured including stipple and skip-trowel.
BELGIAN LACE; 100% acrylic polymer / ready mixed/ available in different colors/ "worm-holed" texture.
CLASSIC; 100% acrylic polymer/ ready mixed, and available in different colors and custom made colors.
COARSE; 100% acrylic polymer/ ready mixed/ and available in different colors. The "worm-holed" look can be circular, random, vertical or horizontal."

Table4.3- Class PB-EIFS Finish coating system variety (National Research Council Canada, (2005))

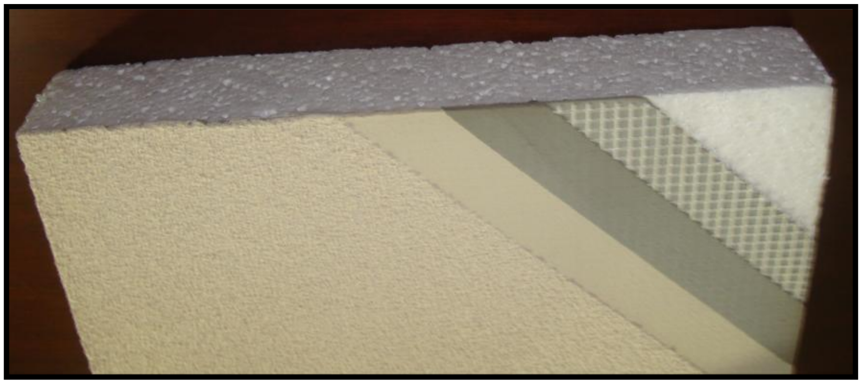


Figure4.12 Class PB-EIFS Finish coating real sample.(BASF)

4.6.4. Class PB-EIFS Senerflex Finishes Benefits:

Features	Benefits
100% acrylic polymer-based chemistry	Provides long-term durability and weather resistance
Integral color	Reduces maintenance and recoating
Weather resistant	Repels water and resists wind-driven rain
Seals existing, non-moving hairline cracks	Protects
Breathable	Does not blister, peel or flake
Abrasion resistant	Durable
Factory mixed	Ready to use, no additives to mix
Water based	Safe, non-toxic, clean up easily with soap and water
High UV resistance	Resist fading

Table4.4- Class PB-EIFS Senerflex Finishes Benefits (National Research Council Canada, (2005))

4.6.5 Class PB-EIFS wall System design Architectural Elements

According to the published report from Wall System Design, to Carter Water construction, Senergy has been designed some architectural element from the same material to be attached to the PB-EIFS wall, which has same benefits as they save construction time and easy to attached to the EIFS wall surface, can be recycled also same as EIFs they are free of CFC, HCFC & HFC pollution which make them more environmental friendly and sustainable.

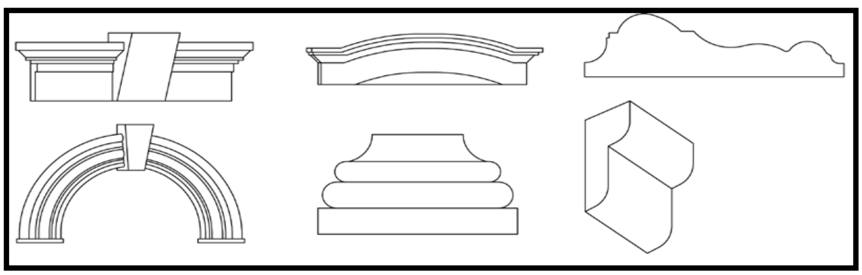


Figure4.13- Class PB-EIFS wall System design Architectural Elements (“Senergy® E.I.F.S”, Wall System Design)

4.6.6. System Design Option

All of the bellow mechanisms can be tailor made and mix together for Senerflex Classic PB to make it more efficient on the environment and minimize the energy consumption of the building.

- **Senturion** TM **I, II, III** ; installing for light commercial construction, in areas that there is no high wind blowing.
- **Senerflex**® **Channeled Adhesive Design**; installing in area that moisture barrier is main consideration.
- **Senerflex**® **Adhered Mat Design**; when there is needed to release the humidity from the structure’s walls.
- **Senergy**® **Cement-Board Stucco** TM **1000;** is contains high moisture management, 100% acrylic polymer with fiber glass reinforced mesh for the exterior cement board walls.”

Table4.5EIFS System Design Option(BASF, “Commercial Wall Systems, Design Freedom for Distinctive and Enduring Buildings”

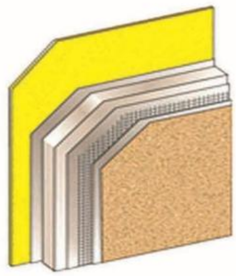
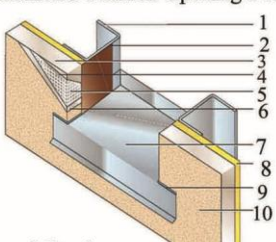
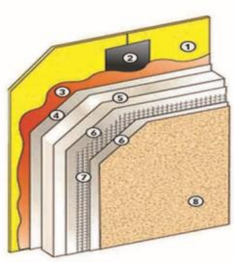
System	Features	Benefits
Senerflex® Classic PB Wall System 	-For exterior walls in new and retrofit commercial and institutional construction where exterior insulation and higher wind loads are design considerations. -use in high-rise and low-rise. -Adhesive attachment -Unlimited colors, textures and architectural details. -reinforced base coats -100% Acrylic finish coats	-Achieves high wind-load capacity -Support design freedom, create details that would be impossible or cost prohibitive with other claddings -Reduces energy costs -Reduces energy costs Produce a weather-resistant barrier, -provide crack resistance -Resist fading and abrasion, -offer options for added dirt/mildew resistance
Senerflex® Flashed Opening Design  1-Framing 2-Applicable Secondary Moisture Protection Barrier 3-Senerflex Insulation Board 4-Senergy Base Coat 5-Senergy Reinforcing Mesh 6-Senergy Base Coat 7-Pan Flashing 8-Acceptable Sheathing 9-Sealant 10-Senergy Finish Coa	-For exterior walls in commercial and institutional construction when local source drainage is required or desired at windows, doors and other wall penetrations. -Integrated flashing and weather barrier system -Unlimited colors, textures and architectural details -100% Acrylic finish coats	-Drains incidental moisture to the exterior at its point of entry -Support design freedom, create details that would be impossible or cost prohibitive with other claddings -Reduces energy costs Produce a weather-resistant barrier, provide crack resistance. Resist fading and abrasion, offer options for added dirt/mildew resistance
Senerflex® Secondary Weather Barrier Design  1. Applicable Sheathing 2. Approved Joint Reinforcement 3. Senergy Adhesive 4. Senershield™ or Senershield-R 5. Senerflex Insulation Board 6. Senergy Base Coat 7. Senergy Reinforcing Mesh 8. Senergy Finish Coat	-Class PB EIFS incorporating a secondary air/weather barrier -Unlimited colors, textures and architectural details Exterior insulation -100% Acrylic, reinforced base coats -100% Acrylic finish coats	-Protects the sheathing, guards against incidental moisture intrusion and air infiltration -Support design freedom, create details that would be impossible or cost prohibitive with other claddings. -Reduces energy costs Produce a weather-resistant barrier, -provide crack resistance -Resist fading and abrasion, -offer options for added dirt/mildew resistance

Table4.6- Classic PB System Design with different features for hot and humid climate (http://www.senergy.cc/pages/wall%20systems)

4.6.7. EIFS Class PB panels criteria

EIFS panels can be assembled next to each other, and act like monolithic blanket of insulation on the building envelop, this foam contains of these main elements; 1) Polyisocyanurate, 2) Expanded polystyrene, 3) Extruded polystyrene

1) "Polyisocyanurate or polyiso is a thermosetting type of plastic, closed-cell foam that contains a low-conductivity gas (usually hydrochlorofluorocarbons or HCFC) in its cells. The high thermal resistance of the gas gives polyisocyanurate insulation materials an R-value typically around R-7 to R-8 per inch" (US Department of Energy, 2008).
2) "Extruded polystyrene has a well established reputation for long-term reliability and superior resistance to the elemental forces of nature: time, water, cold, heat, and pressure."(Diversifoam, "What Is Extruded Polystyrene Insulation (XEPS))
3) Expanded polystyrene foam is usually white color and has high thermal insulation (Wikipedia, "Polystyrene").

EIFS Class PB Act as thermal and humidity insulation material and it can decrease cooling and heating load as a result, there will be significant reduction on the HVAC consumption. The bellow tables present Class PB with reinforced concrete with different thickness of expanded polystyrene board. As a result, one can see the effect of the thickness on R value and U value of the unit.

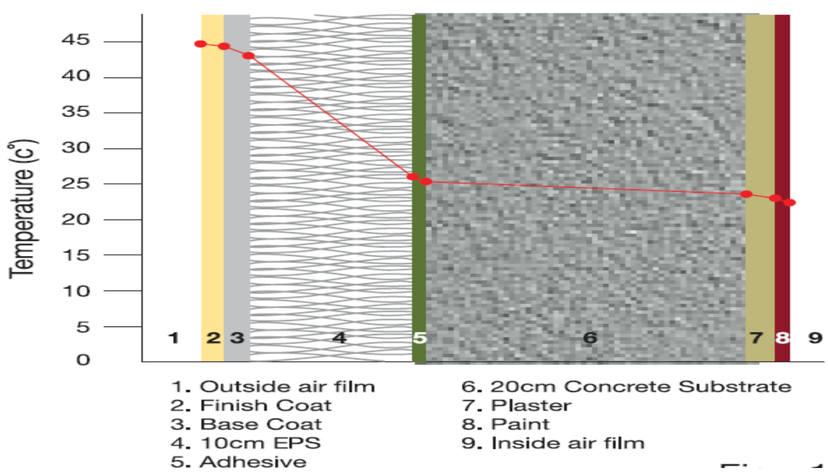


Fig 4.14-.The temperature gradient through the wall and how the wall remains cool (BASF, "Exterior insulation & Finish System")

Material	Thickness m	K value W/(m.K)	R value (m^2·K/W)
Internal standers surface resistance			0.120
Internal plaster	0.010	0.720	0.014
Reinforce concrete	0.200	1.850	0.014
Expanded polystyrene board(20-22 Kg/m_2)	0.050	0.035	1.429
Senergy External Plaster with mesh	0.005	0.100	0.050
External Standard surface resistance			0.044
Total thickness	0.265		
Total R value			1.7646
Overall Heat Transfer Coefficient U value W/(m_2.k)			0.567

Table4.7 Classic PB System insulation with 265mm thickness (Schmidt, 2008)

Material	Thickness m	K value W/(m.K)	R value (m^2·K/W)
Internal standers surface resistance			0.120
Internal plaster	0.010	0.720	0.014
Reinforce concrete	0.200	1.850	0.014
Expanded polystyrene board(20-22 Kg/m_2)	0.075	0.035	2.143
Senergy External Plaster with mesh	0.005	0.100	0.050
External Standard surface resistance			0.044
Total thickness	0.290		
Total R value			2.4789
Overall Heat Transfer Coefficient U value W/(m_2.k)			0.403

Table4.8 Classic PB System insulation with 290 mm thickness (Schmidt, 2008)

Material	Thickness m	K value W/(m.K)	R value ($m^2 \cdot K/W$)
Internal standers surface resistance			0.120
Internal plaster	0.010	0.720	0.014
Reinforce concrete	0.200	1.850	0.014
Expanded polystyrene board(20-22 Kg/m_{2})	0.100	0.035	2.857
Senergy External Plaster with mesh	0.005	0.100	0.050
External Standard surface resistance			0.044
Total thickness	0.315		
Total R value			3.1931
Overall Heat Transfer Coefficient U value W/(m_{2}.k)			0.313

Table4.9 Classic PB System insulation with 315 mm thickness (Schmidt, 2008)

After studying all the above mentioned materials and communicating with their manufactures such as Senergy, BAFS, EPS Company, Elastogran, the only material which BASF advised is Class PB-EIFS, which has been manufactured by Senergy Company. Refer to tables 4.7, 4.8, and 4.9 the thickness of the expanded polystyrene board can be tailor made according to achieve the desire U value of the building. The following chapters will cover some simulations to examine the effect of Class PB-EIFS material on heating and cooling load of the existing building and comparing the energy consumption result with the typical insulation material.

CHAPTER 5

5.0 Description of building used for case study.

This building is located in Al Reem Island in Abu Dhabi. It is commercial and residential. This tower contains of the following areas:

- Ground floor lobby area
- 23 floors of residential
- 8 floor commercial
- Car park area and the services on the basement -2 levels
- Roof deck swimming pool

Exterior finishes:

Exiting material for this building is summarized on the following part:

Double glazed curtain wall with 24mm double glazed with 5mm tinted glass+ 12 air space with 6 mm thickness clear low E glass. The characteristic of the glazed envelope comprises of the following:

- 55% Light transmittance
- 11% Light reflection out side
- 14% light reflection in side
- 24% solar energy transmission
- 7% solar energy reflection out
- 0.35 Solar heat gain coefficient
- Block walls from the inside

Figure5.1-Case study building perspective.

As one can see the existing envelope has been designed fully glazed which can be the disadvantage for such climate. On the following parts are consisting of different simulation on the existing envelope and the proposed exterior EIFS walls with different thicknesses then comparing the results to find the best reasonable solution for protecting the envelope from solar gain.

6.0. Simulation and Analyses;

The simulation in this chapter has been done by Ecotect program according to the following arrangement with different scenarios:

Stage one:

Estimating the cooling/ heating load of the building with the existing typical insulation and exterior envelope annually.

a) Running the simulation for one floor.
b) Running the simulation for whole tower.

Stage two:

Applying Class PB-EIFS with reinforced concrete with several thicknesses (265,315 and 365 mm) and comparing the results with typical insulation.

a) Running the simulation for one floor.
b) Running the simulation for whole tower.

Stage three:

After collecting all the data from the above simulations, and comparing the results of the total heating and cooling load of the building, the most reasonable thickness was chosen according to the comparison outcome.

Stage four:

In this stage, the selected thickness was simulated with different colors, to investigate the effects of the envelop color on the heating and cooling loads.

Stage five:

After collecting the results obtained from the Ecotect simulations, there has been some comparison between the outcomes. Theses comparisons have been done by Excel program to create reliable tables and graphical charts.

Stage Six:

The focus of this stage is on financial comparison before and after applying the proposed insulation material. This comparison had been done according to the following scenarios based on cost estimation between the typical insulation with the existing envelope and Class PB-EIFS with reinforced concrete 290 mm thickness:

a) Cost of the Building construction cost
b) Cost of the annual cooling and heating load of the building to estimate the possible future investment and saving.

6.1. Estimating the cooling/ heating load with the existing envelope, annually (One floor):

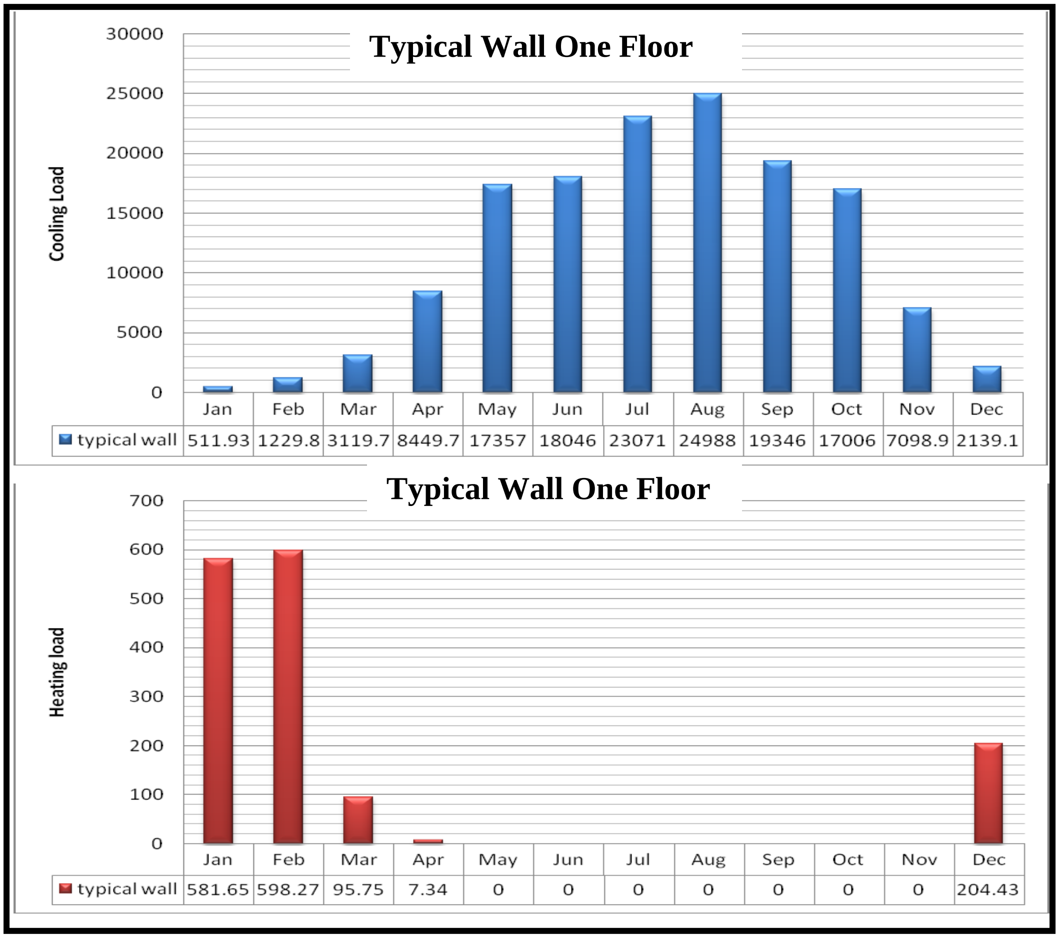


Figure6.1- cooling/ heating load with the existing typical insulation (One Floor)

According to the Ecotect simulation the Max Heating load for one floor is estimated 31.61 kW at 08:00 on 14th February and the Max Cooling is 112.36 kW at 16:00 on 19th June. Furthermore, the total cooling load for one floor has been estimated 142363.44 kWh, which means 111.33 per M². Also total heating load for one floor has been estimated 1855.94 kWh which means 1.45 per M².

All the above Heating and cooling load estimations has been done for the first floor of the building which would be changed on the higher floors according to the sun angel and temperature difference.

6.2. Estimating the cooling/ heating load with the existing envelope, annually (Full Building)

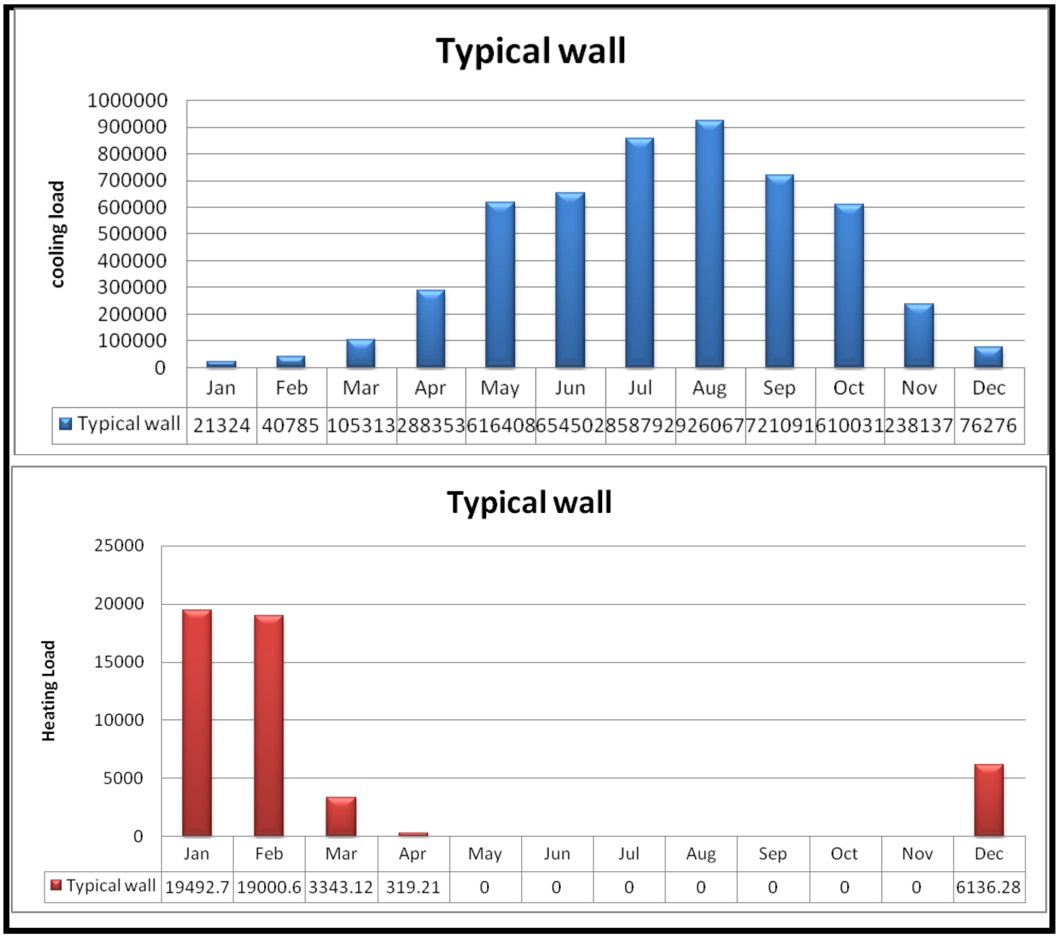


Figure6.2- cooling/ heating load with the existing typical insulation (Full Building)

The bellow Data of monthly cooling / heating load has been estimated by Ecotect for the full building with the exisiting typical concrete block wall :

- Max Cooling load: 3851.35 kW at 16:00 on 19th June.
- Max Heating load: 820.26 kW at 08:00 on 14th February.
- Total Cooling load: 5157079.04 kWh.
- Total Heating Load: 48291.89 kWh.

6.3. Simulation for the cooling load of Class PB-EIFS with different thicknesses (one floor)

I. Typical concrete block wall+ insulation.

- Max Cooling load: 112.36 kW at 16:00 on 19th June.
- Total cooling per year: 142363.44 kWh.

II. Class PB-EIFS, 265mm wall thickness.

- Max Cooling load: 106.43 kW at 16:00 on 19th June.
- Total cooling per year: 130469.86 kWh

III. Class PB-EIFS, 290 mm wall thickness

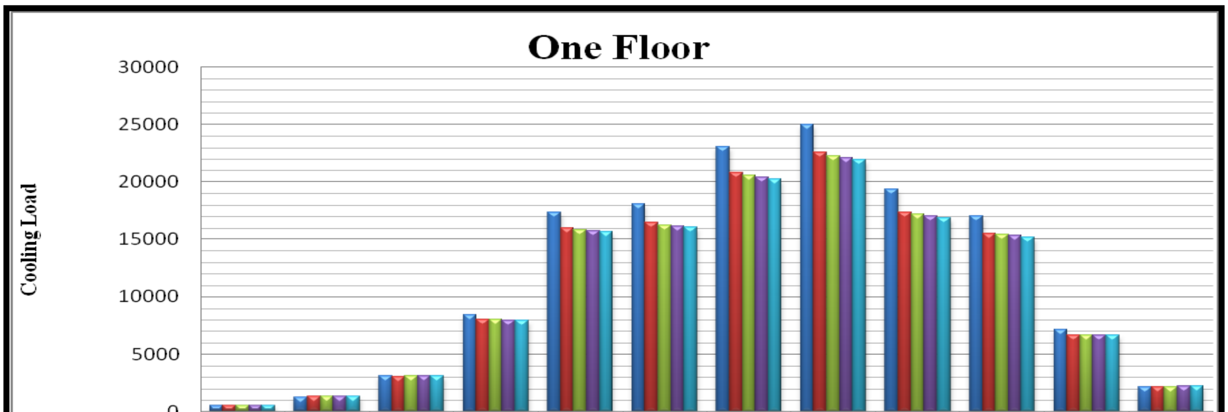
- Max Cooling load: 105.40 kW at 16:00 on 19th June.
- Total Cooling Load per year: 129262.29 kWh

IV. Class PB-EIFS, 315 mm wall thickness.

- Max Cooling load: 104.84 kW at 16:00 on 19th June.
- Total Cooling Load per year: 128606.05 kWh

V. Class PB-EIFS, 365 mm wall thickness.

- Max Cooling load: 104.34 kW at 16:00 on 19th June.
- Total Cooling Load per year: 127740.5 kWh



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
typical wall	511.93	1229.8	3119.67	8449.7	17356.7	18046.4	23071.4	24988	19345.9	17006	7098.94	2139.12
265 thickness	556.56	1320.34	3070.32	8036.19	15968.9	16422.4	20814.8	22547.9	17365.4	15531.2	6679.24	2156.64
290 thickness	560.81	1322.73	3092.06	7994.03	15816.1	16247.5	20567	22277.6	17163.7	15385.5	6655.73	2179.47
315 thickness	565.43	1326.12	3094.88	7970.5	15732.3	16151.6	20431	22129.2	17053.1	15305.6	6641.87	2204.47
365 thickness	570.71	1331.19	3099.83	7943.41	15626	16021.3	20244.4	21929.2	16898.3	15202.4	6635.39	2238.41

Figure6.3- Comparing cooling load of Class PB-EIFS with reinforced concrete with different thickness

6.4 Simulation for the Heating load of Class PB-EIFS with different thickness (one floor).

I. Typical concrete block wall+ insulation.

- Max Heating load: 31.61 kW at 08:00 on 14th February.
- Total Heating load per year: 1855.94 kWh.

II. Class PB-EIFS, 265mm wall thickness.

- Max Heating load: 28.79 kWh at 08:00 on 14th February.
- Total Heating load per year: 1564.55 kWh

III. Class PB-EIFS, 290 mm wall thickness

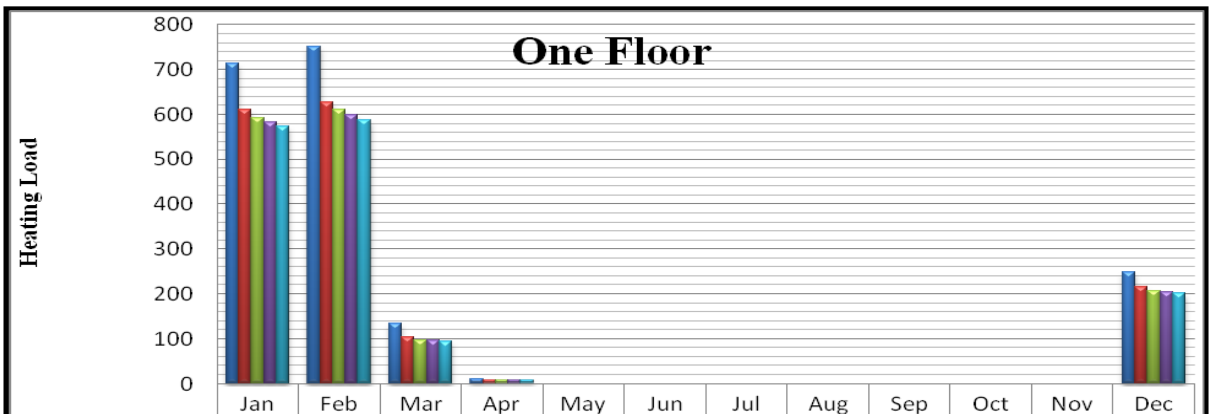
- Max Heating load: 28.41 kW at 08:00 on 14th February
- Total Heating load per year: 1512.98 kWh

IV. Class PB-EIFS, 315 mm wall thickness.

- Max Heating load: 28.20 kW at 08:00 on 14th February.
- Total Heating load per year: 1487.44 kWh

V. Class PB-EIFS, 365 mm wall thickness.

- Max Heating load: 27.96 kW at 08:00 on 14th February.
- Total Heating load per year: 1461.99 kWh



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
typical wall	712.16	749.57	133.88	10.97	0	0	0	0	0	0	0	249.37
265 thickness	610.89	626.79	103.82	8.12	0	0	0	0	0	0	0	214.93
290 thickness	590.79	609.4	97.89	7.62	0	0	0	0	0	0	0	207.28
315 thickness	581.65	598.27	95.75	7.34	0	0	0	0	0	0	0	204.43
365 thickness	572.01	587.58	93.79	7.09	0	0	0	0	0	0	0	201.52

Figure6.4- Comparing cooling load of Class PB-EIFS with reinforced concrete with different thickness

6.5. Simulating the cooling load of Class PB-EIFS with different thickness (full building).

I. Typical concrete block wall+ insulation

- Max Cooling load: 3851.35 kW at 16:00 on 19th June.
- Total cooling load per year: 5157079.04 kWh.

II. Class PB-EIFS, 265mm wall thickness

- Max Cooling load: 3664.53 kW at 16:00 on 19th June
- Total cooling load per year: 4790486.02 kWh.

III. Class PB-EIFS, 290 mm wall thickness

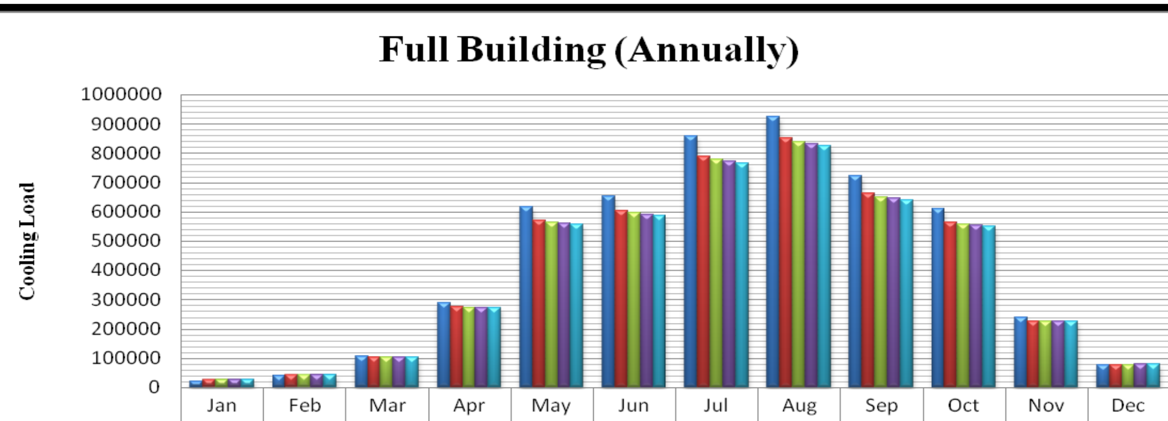
- Max Cooling load: 3632.17 kW at 16:00 on 19th June
- Total cooling load per year: 4734459.9 kWh.

IV. Class PB-EIFS, 315 mm wall thickness

- Max Cooling load: 3614.43 kW at 16:00 on 19th June
- Total cooling load per year: 4702326.27 kWh.

V. Class PB-EIFS, 365 mm wall thickness

- Max Cooling load: 3598.59 kW at 16:00 on 19th June
- Total cooling load per year: 4673603.58 kWh.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Typical wall	21324.1	40785.1	105313	288353	616408	654502	858792	926067	721091	610031	238137	76276
Thickness 265	26087.8	42333.3	103135	273739	571022	603513	790197	852001	661295	564653	225467	77042.5
Thickness 290	27297.3	42841.7	103331	272322	564177	595063	778050	839014	651261	558009	225308	77787.1
Thickness 315	27418.1	42941	103357	271451	560392	590416	771378	831813	645672	554385	224971	78132.8
Thickness365	27521.3	42999	103353	270599	557034	586279	765435	825457	640781	551042	224747	78357

Figure6.5- Comparing cooling load of Class PB-EIFS with reinforced concrete with different thickness

6.6. Simulating the heating load of Class PB-EIFS with different thickness (full building).

I. Typical concrete block wall+ insulation

- Max Heating load: 820.26 kW at 08:00 on 14th February
- Total Heating load per year: 48291.89 kWh.

II. Class PB-EIFS, 265mm wall thickness

- Max Heating load: 746.99 kW at 08:00 on 14th February
- Total Heating load per year: 43616.34 kWh.

III. Class PB-EIFS, 290 mm wall thickness

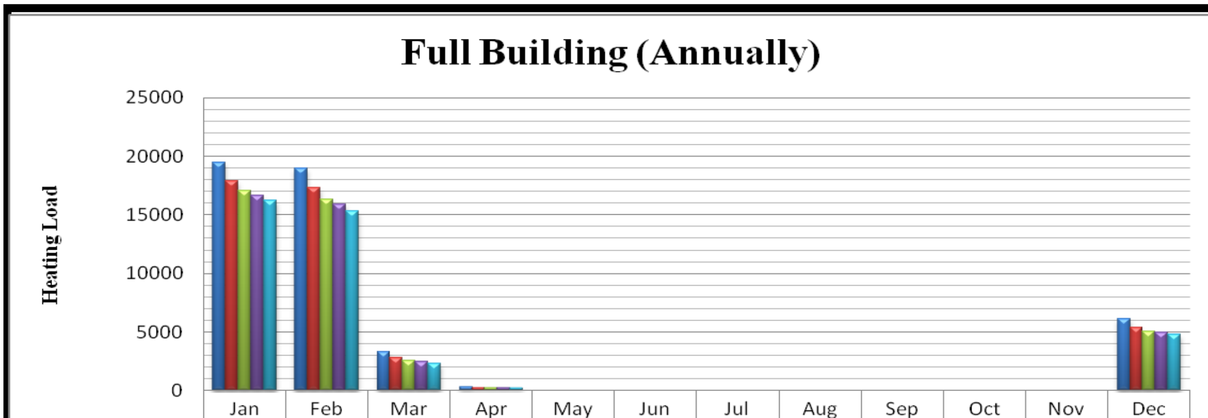
- Max Heating load: 729.53 kW at 08:00 on 14th February
- Total Heating load per year: 41291.19 kWh.

IV. Class PB-EIFS, 315 mm wall thickness

- Max Heating load: 720.00 kW at 08:00 on 14th February
- Total Heating load per year: 40140.74 kWh.

V. Class PB-EIFS, 365 mm wall thickness

- Max Heating load: 711.55 kW at 08:00 on 14th February
- Total Heating load per year: 38843.4 kWh.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Typical wall	19492.7	19000.6	3343.12	319.21	0	0	0	0	0	0	0	6136.28
Thickness 265	17880.9	17321.8	2786.38	259.58	0	0	0	0	0	0	0	5367.71
Thickness 290	17051.5	16347.5	2568.89	240.81	0	0	0	0	0	0	0	5082.43
Thickness 315	16603.1	15916.8	2459.61	230.58	0	0	0	0	0	0	0	4930.74
Thickness365	16196.8	15331	2333.78	221.53	0	0	0	0	0	0	0	4760.33

Figure6.6- Comparing Heating load of Class PB-EIFS with reinforced concrete with different thickness

CHAPTER 7

7.0 Class PB-EIFS 290mm simulation with different color.

7.1. Simulating the cooling load of 290 mm Class PB-EIFS with different colors (Full Building).

I. White

- Max Cooling load: 3631.72 kW at 16:00 on 19th June
- Total cooling load per year: 4731981.31 kWh

II. Light Beige

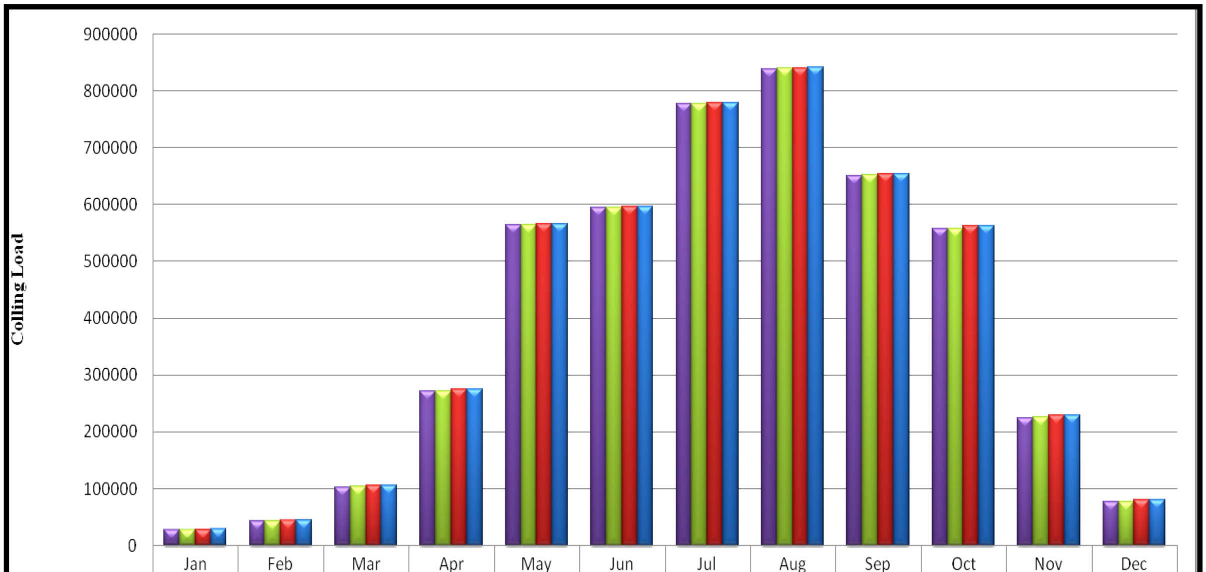
- Max Cooling load: 3632.17 kW at 16:00 on 19th June
- Total cooling load per year: 4734459.9 kWh

III. Red-brown

- Max Cooling load: 3637.38 kW at 16:00 on 19th June
- Total cooling load per year: 4759016.45 kWh

IV. Black

- Max Cooling load: 3638.06 kW at 16:00 on 19th June
- Total cooling load per year: 4762501.12 kWh



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
white wall	27277.29	42806.48	103206.55	272168.54	564043.52	594981.76	777966.08	838882.94	651060.54	557684.74	224692.14	77211.13
light beige wall	27297.27	42841.66	103330.66	272321.5	564176.9	595062.66	778049.79	839014.08	651261.25	558008.83	225308.38	77787.07
Red-Brown Wall	28762.3	44100.36	105200.38	274281.22	565753.22	596019.14	779036.42	840563.33	653624.06	561831.87	229412.3	80432.03
Black wall	28926.21	44280.71	105451.46	274484.13	565958.14	596143.1	779164.16	840763.46	653930.05	562326.53	229915.68	81157.72

Figure7.1- Cooling load of 290 mm Class PB-EIFS insulation wall thickness with different colors

7.2. Simulating the heating load of 290 mm Class PB-EIFS with different colors (full building)

I. White

Max Heating load: 729.54 kW at 08:00 on 14th February

Total Heating load per year: 41348.01

II. Light Beige

Max Heating: 729.53 kW at 08:00 on 14th February

Total Heating load per year: 41291.19

III. Red-brown

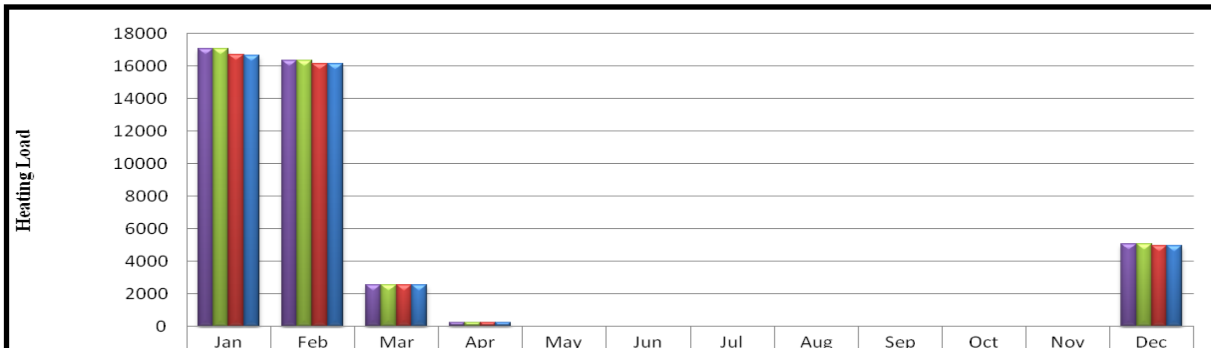
Max Heating load: 729.44 kW at 08:00 on 14th February

Total Heating load per year: 40649.4

IV. Black

Max Heating load: 729.42 kW at 08:00 on 14th February

Total Heating load per year: 40570.7



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
white wall	17081.77	16362.94	2571.32	240.83	0	0	0	0	0	0	0	5091.14
light beige wall	17051.54	16347.52	2568.89	240.81	0	0	0	0	0	0	0	5082.43
Red-Brown Wall	16711.36	16165.5	2542.7	240.59	0	0	0	0	0	0	0	4989.26
Black wall	16670.85	16141.92	2539.64	240.56	0	0	0	0	0	0	0	4977.73

Figure7.2-Heating load of 290 mm Class PB-EIFS insulation wall thickness with different colors

7.3 Results Comparison of Class PB with different colors

According to the Ecotect simulations the light color walls decrease the cooling load during the summer; on the other hand, the darker color wall decrease the heating load during the winter time. Both colors have their own benefits, but the saving on cooling load is the major issue for hot and humid climate. As a result, we have to choose an efficient color between white and light beige; although the white color save more energy during the summer but using the beige color have more advantages such as:

- Fewer glares during the summer time
- Remain clean after some years, since there is too much sand on the air which can easily affect the white color surfaces.
- Less heating load compare to the white color during the winter.

According to above advantages and simulations, the beige color can be a good choice for the exterior paint of this case study. Figure 8.1 shows the sum of cooling load with the wall thickness of 290 which present the comparison between the different applied colors on the exterior.

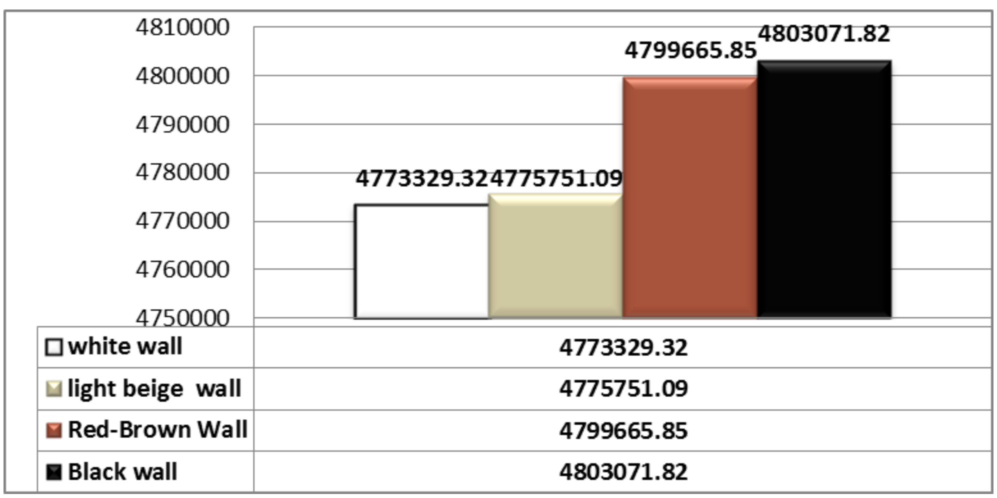


Figure7.3-Heating + Cooling Load 290 Thickness wall (Full Building)

7.4 Results comparison of heating and cooling load annually:

According to the simulation results; 290mm Class PB-EIFS wall has a reasonable energy consumption compare to the other thicknesses, although the thicker wall saves significant amount of energy but they cost more and waste more space and add more weight load on structure. Figure 8.2 demonstrates the enormous energy consumption difference between the typical existing envelope and the other thickness of Class PB-EIFS insulation, which in 290 thickness the amount of energy saving is 429619.8 kWh per year. According to the Figure 8.3, 290 mm Class PB-EIFS exterior wall insulation can make reduction of 14.50% from the heating load and 8.19% from the cooling load, which can be a significant energy saving in the long term.

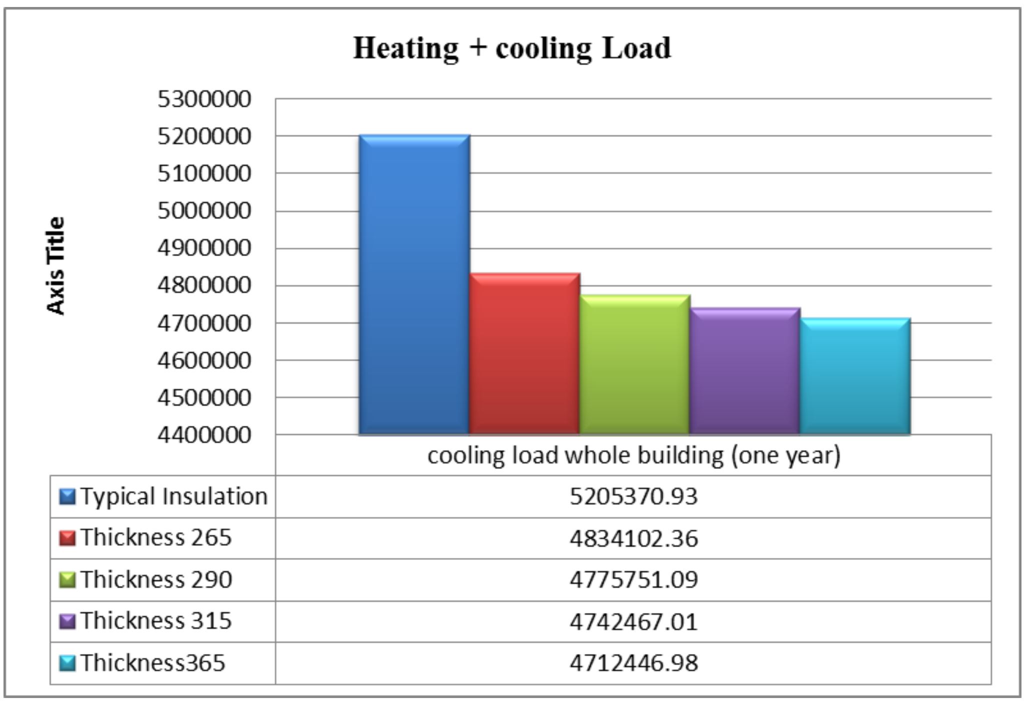


Figure7.4- Comparing Total Heating load + Cooling Load (kWh)

As it is shows in figure 8.3, the reduction cooling load in different thicknesses are almost at the same level with the minor differences, which compare to the their cost and space wastages, so the 290 mm class PB is the most reasonable choice to employ.

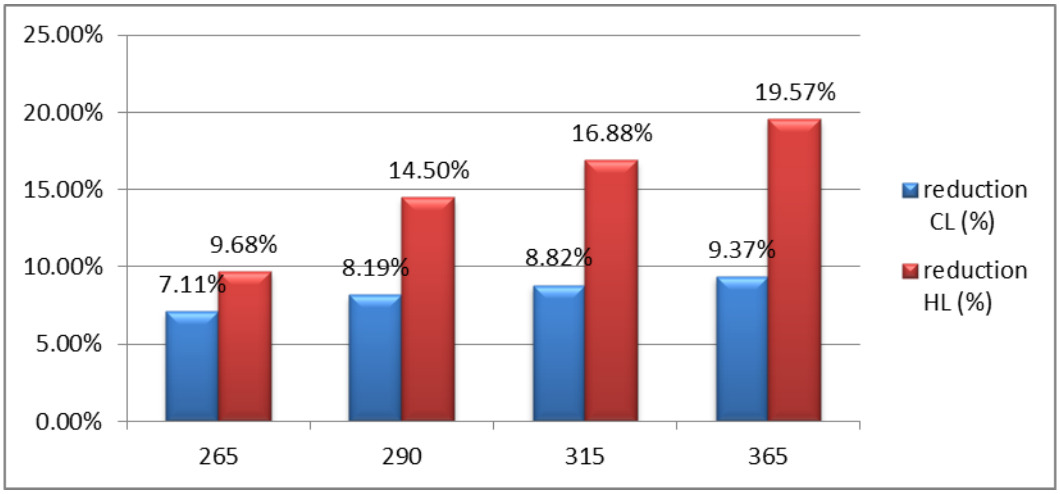


Figure7.5- Comparing Heating load and cooling load Percent Reduction

Type	Heating Load (kW)	Cooling Load (kW)	Saving on Cooling load (kW)	Saving on Heating load (kW)
Thickness 365mm	38843.4	4673603.58	483,475	9448.49
Thickness 315mm	40140.74	4702326.27	454,753	8151.15
Thickness 290mm	41291.19	4734459.9	422,619	7000.7
Thickness 265mm	43616.34	4790486.02	366,593	4675.55
Typical wall	48291.89	5157079.04		

Table7.1- Comparing Heating load and cooling load Saving

8. Cost Estimations

8.1 Saving on operate cost

Reference to the Tabreed web site the cost for cooling load is equal by 0.24 AED per kW. Since the cooling cost is provided separately by Tabreed, and heating cost was not available by them, in this study the calculations were just about the major energy consumption which was the cooling loads. According to the Ecotect simulation and some calculations Figure 8.1 presents the cost of annual cooling load consumption with all different thickness PB class wall.

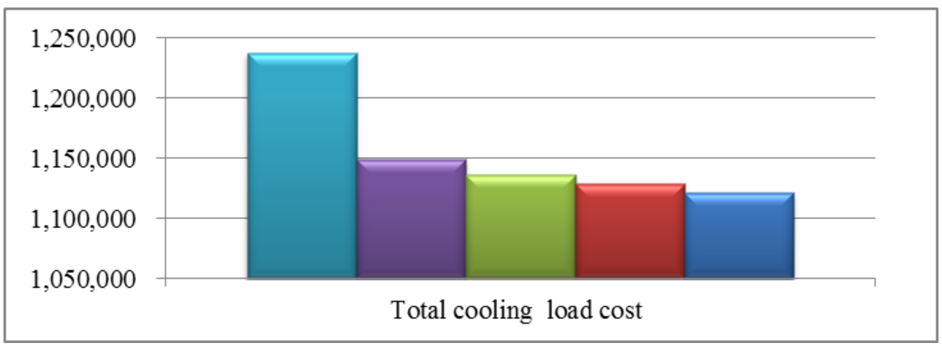


Figure8.1- Cooling Cost Estimation (Full Building)

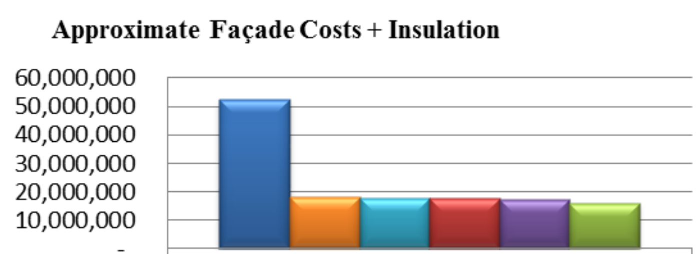
Type EIFS Class PB	Annual Cooling Load kW	Price per kWh	Total Cooling Price AED	Annual saving(A) AED
Thickness 365mm	4673604	0.24	1,121,665	116,034
Thickness 315mm	4702326	0.24	1,128,558	109,141
Thickness 290mm	4734460	0.24	1,136,270	101,429
Thickness 265mm	4790486	0.24	1,149,717	87,982
Existing Typical wall	5157079	0.24	1,237,699	----

Table 8.1 Annual saving cost

As it shown in Table 8.1, the Total Cooling Price (Annual Cooling Load multiple to Price per kWh) the typical wall had been estimated AED 1,237,699 and the proposed 290Class PB wall had been estimated AED 1,136,270 the difference of cost was AED 101,429 per year. This means 8.19% reduction on cooling load.

8.2 Saving in Initial Construction Cost:

According to the Figure5.1 case study building perspective, the original design for the building was fully glaze envelope. The first proposal was to remove the glazed façade and to replace with classic PB wall which can be applied with different color. This act does not only decree the solar gain but also decreases the construction cost and structure weight load. According to discussion with Engineer Yasmin from Masdar Abu Dhabi Future Energy Company (December 2008), the cost estimation for the glazed façade had been estimated AED 52,365,000 for this building. In the same case by applying the class PB wall insulation 290mm the cost can be reduced to AED 17,761,120.(Ref Appendix C) The difference was about 34,603,880 which could be a significant saving on the first stage of construction by changing the envelope of the building. Figure 8.5 shows the related cost for different envelopes with different thickness and materials.



	AED Total Cost
Fully glazed curtain wall	52,365,000
EIFS PB Exterior finish 365mm	18,406,292
EIFS PB Exterior finish 315mm	17,981,065
EIFS PB Exterior finish 290mm	17,761,120
EIFS PB Exterior finish 265mm	17,541,175
Typical insulation + paint exterior finish	16,148,190

Figure8.2- Construction Cost estimation

Table 8.2 demonestrates that by changing the building façade from glazing to EISF class PB 290, 66% reduction in intial cost will be resulted. Other possible initial savings could be HVAC equiepment, electrical substances, and structure weight reduction which consequently lead to reduction in fundation load which would reduce the material, time and labor costs.

8.3 Present- worth factor:

Refrence to H.Thuesen, Fabrycky(2005), and G.Thuesen Present value of the money has to be count up front to investigate the posible saving on future. Financial issue on future is one of the important factor which can incourage the building owner to think about the sustable material which can deduct from the future expences. "The equal_payment capital-recovery factor may be solved by P as a Present worth factor"(H.Thuesen, Fabrycky, and G.Thuesen, 2005):

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

(A) is a Annual Cost which had been estimated from heating and cooling load of the building which had been smulated by ecotect and convert the unit to the UAE currency.(AED).

(i) is Annula Interst Rate, the avrage interest rate in UAE bank has been estimated 8%.

(n) is the number of the years, which had been estimated for 20 years in this project.

The sample calculation of 290 thicknesses follows which presents how other calculation had been done:

$$P = 101{,}429\left[\frac{(1+0.08)^{20} - 1}{0.08(1+0.08)^{20}}\right]$$

$$P = 101{,}429 \text{x } 9.818$$

$$P = 995822.9$$

8.3.1 Present- worth factor for 290 Thickness with different color:

Refer to Table 8.2 the highest preset worth factor belongs to the Class PB with white color exterior, but since there is so many dust on the air, the white color would need more maintance in future, also high solar radiantion reflected on the white surface can generate more glare durring the summer sunny days. So the light beige color could be the best option for furture mainatance, also the present worth factor diffrence between White Color and Light Beige was just AED 5,841 which was the resouanable cost compare to the maintance cost of white color façade.

290mm different colors	Cooling Load	Price per kWh	total Price	Annual Saving AED	P(A) AED
White	4,731,981	0.24	1,135,676	102,023	1,001,667
Light Beige	4,734,460	0.24	1,136,270	101,429	995,826
Red Brown	4,759,016	0.24	1,142,164	95,535	937,963
Black Wall	4,762,501	0.24	1,143,000	94,699	929,752

Table 8.2- Present- worth factor for 290 Thickness with different color

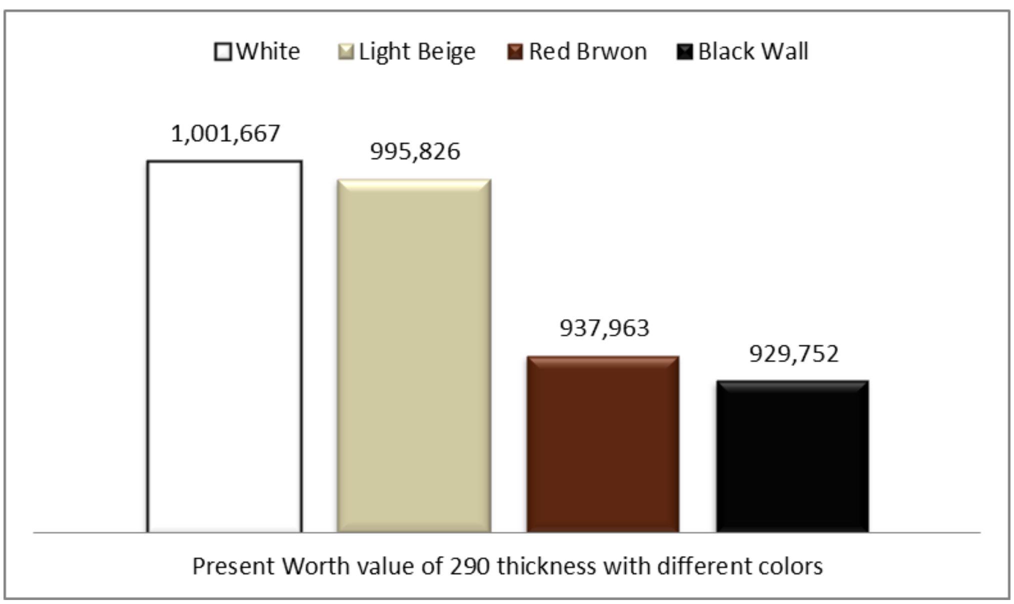


Figure8.3- Present- worth factor for 290 Thickness with different color

8.3.2 Present- worth factor for Different Thichnesses

Refer to Table 8.3 the Total Present saving value in 20 years for Class PB 365 thicknesses was the lowest compare to the other thicknesses, although the annual saving was more but the total present value saving in 20 years was less than others. On the other hand the thinner wall such as 265 mm had the highest saving amount of money but less annual energy saving. Since the thicker wall cost more money in advance for construction and less present value of the money, so to have reasonable saving on capital and energy also to be closer to the standard wall thickness with higher U value 290mm could be a suitable type for this building.

Type	Annual Cooling Load kW	Price per kWh	Total Price AED	Annual saving(A) AED	$\left[\frac{(1+0.08)^{20}-1}{0.08(1+0.08)^{20}}\right]$ Present- worth factor	Present- worth AED
Thickness 365	4673604	0.24	1,121,665	116,034	9.818	1,139,222
Thickness 315	4702326	0.24	1,128,558	109,141	9.818	1,071,544
Thickness 290	4734460	0.24	1,136,270	101,429	9.818	995,826
Thickness 265	4790486	0.24	1,149,717	87,982	9.818	863,810
Typical wall	5157079	0.24	1,237,699	----		

Table 8.3- Present- worth factor for Different Thichnesses

Follows is the explanaition of Table 8.3:

- Data for Column Annual Cooling Load obtained from Ecotect Simulation.
- Also, Price per kWh gotten from Tabreed website which is AED 0.24 per kWh.
- The Total Price is the result of Annual Cooling Load multiple to Price per kWh.

- In the column Annual Saving (A) in AED, the results are obtained from subtraction of total price in different Thicknesses with Typical wall.

Table 8.4 shows a clear reason for choosing 290 thickness. As it is shown by replacing the glaze façade to the Class PB EIFS, the (P) Saving on Construction increases from thicker to thiner thicknesses but, P(A) Annual Cooling Load Saving reduces from thicker to thiner thicknesses. The Total Present Worth Factor wich is the sum of Saving on cunstruction and Annual Cooling Load Saving, for 290 thickness is much greater than 365 and 315 thicknesses, so it is reasonable to employ the 290 thickness rather than those other two thickness. In case of choosing between 290 and 265 thickness, 290 is reasonable because the Total Present Worth Factor for 265 thickness is just 0.24% greater than 290 thickness which is not a big difference, but as the matter of global energy saving, in 290 amount of energy saving is 13.2% greater than 265 thickness.

Type	(P) Saving on Construction AED	P(A) Annual Cooling load Saving	(P) Total Present worth factor AED
Thickness365	33,958,708	1,139,222	35,097,930
Thickness 315	34,383,935	1,071,544	35,455,479
Thickness 290	34,603,880	995,826	35,599,706
Thickness 265	34,823,825	863,810	35,687,635
Ref: Typical existing wall 52,365,000 AED expense			

Table 8.4- Total Present- worth factor for Different Thichnesses

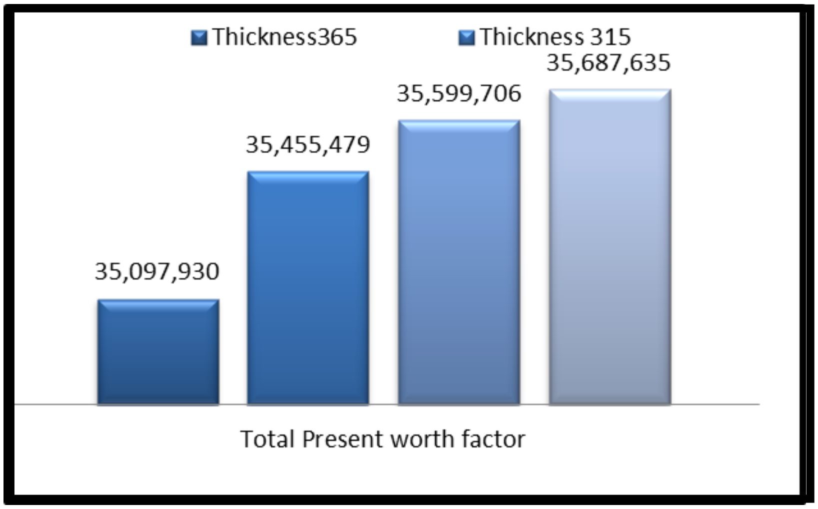


Figure8.4- Total Present- worth factor for Different Thichnesses

9. Conclusions and recommendations

9.1 Conclusions:

Since the time united Arab Emirates started to develop less than a half century, with magnificent high speed construction and development. UAE had been affected by high tech construction with completely different style of its own traditional housing. The face of the city has been changed from low rise traditional houses with wind towers and massive walls to high rise fully glazed buildings. Although this change may look nice and modern but this type of building design has conflict with local climate. In such hot and humid weather, fully glazed buildings use huge amount of energy to keep the heat out and cool the interior, on the other hand, the efficient insulated wall can save the huge amount of energy.

This Thesis is about choosing the right material for building envelope in U.A.E, to use less energy inside the building and to make the city more environmental friendly. For instance, UAE climate is hot and humid so the envelop of the building used to be constructed of massive walls with minimum 50 cm thickness to keep the heat out. On the other hand, now a day, most of the buildings are highly glazed which is not sustainable for such hot climate.

Fully glaze buildings with high thermal gain during the summer, with high HVAC consumption and energy wastage, became a challenge for environmental researchers to find a right insulation to protect the building form solar gain during the hot summer days. The main concern of this dissertation was to convince Construction Company to use the right exterior envelope with efficient insulation material, to minimize the initial cost and energy consumption. This research had been started by idea of using Phase Change Material on exterior envelope as thermal insulation material. After doing so many researches and studies and communication by different PCM manufactures, the final data proved that high humidity and long hot summer days could have negative effects on PCM thermal storage system. As result by communicating with BASF The Chemical Company, class PB EIFS became the focal insulation material on this research paper. By applying BP wall with different thickness and colors on the existing building and collecting the data from Ecotect simulation, class PB EIFs with 290mm thickness beige color had the best score on energy efficiency and initial cost estimation.
In case of cooling load the grate reduction of 10% on annual cooling load. Regarding the initial cost by removing the glass envelope there was significant saving of 66% on initial construction cost. Certainly by removing the weight of the glass partition from the structure load, there would be reduction on foundation material, construction time and number of labors. All these factors could encourage the building’s owners to think about the right and light insulation material for the exterior of their building to save the energy and initial cost of construction. The saving from the reduction on foundation material was not imbedded in this study, but will certainly strengthen the findings of this study. In view of the fact that by providing the right type of exterior wall insulation, such EIFS panels, one can have pleasant temperature inside. As a result HVAC usage

will be minimized, so the annual Electricity bill amount will be cut off considerably. Moreover, construction time and expenses will be less if one uses the prefabricated panel. As a result of using prefabricated panels, significant cost saving can be achieved from the first day of the construction.

Finally building the environmentally friendly structures not only help financially but also help the future generation global energy.

9.2. Recommendation for Future study

The Following factors are important and should be considered in future studies:

a. More investigation on effect of using EIFS Class PB insulation material on structure weigh load.
b. Estimating the required foundation reduction
c. Estimation the time and material saving
d. Effect of using EIFS Class PB as an efficient thermal and humidity insulation on HVAC Load.
e. Estimating the reduction of HVAC equipment, which could save significant cost and space in the first stage of construction.
f. The life operate analyzes of the building in terms of embedded energy and total CO_2 emissions.

REFERENCES

"Abu Dhabi Int'l United Arab Emirates: Climate, Global Warming, and Daylight Charts and Data", World Climate [Online]. Available from: http://www.climate-charts.com/Locations/u/UE41217.php [Accessed: 12-08-2008].
"Abu Dhabi", Wikipedia the free encyclopedia [Online]. Available from: http://en.wikipedia.org/wiki/Abu_Dhabi [Accessed: 12-08-2008].

ACSAD, (2003), "Inventory Study and Regional Database on Sustainable Vegetation Cover Management in West Asia (TN2)", The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) [Online]. Available from: http://www.unep.org.bh/Publications/Natural%20Resources%20Final/Summary.pdf [Accessed: 23-11-2008].

Ahmad. M, Bontenmps. A, Salle'e. H, Quenard. D (2006), "Experimental investigation and computer simulation of thermal behaviour of wallboards containing a phase change material", Energy and Buildings [Online]. Vol 38, 2006, pp: 357-366. Available from: www.sciencedirect.com [Accessed: 25-08-2008].

Ahmad. M, Bontenmps. A, Salle'e. H, Quenard. D (2006), "Thermal testing and numerical simulation of a prototype cell using light wallboards coupling vacuum isolation panels and phase change material", Energy and Buildings [Online]. Vol 38, 2006, pp: 673-681. Available from: www.sciencedirect.com [Accessed: 25-08-2008].

Alawadhi. E (2008), "Thermal Analysis of a Building Brick Containing Phase Change Material", Energy and Buildings [Online]. Vol 40, 2008, pp: 351-357. Available from: www.sciencedirect.com [Accessed: 25-08-2008].

BASF, "Customer Success Story, At BASF, we don't make custom-designed or affordable homes. We make them more energy efficient", BASF Publications [Online]. Available from: www.basf.com/usa [Accessed: 04-09-2008].

BASF, "Technical date and assistance data for dimensioning", BASF Publications, Available from: Sahar Arbabioon upon request [Accessed: 03-09-2008].

BASF, "Reconstruction and Refurbishment", BASF Publications, Available from: Sahar Arbabioon upon request [Accessed: 03-09-2008].

BASF, (2005), “Intelligent Temperature Management in an Extremely Lightweight Approach”, BASF Publications. Available from: Sahar Arbabioon upon request [Accessed: 03-09-2008].

BASF, “Foams-Styroper /peripor (EPS)”, BASF the Chemical Company [Online]. Available from: http://www.plasticsportal.net/wa/plasticsEU/portal/show/content/products/foams/styropor_peripor [Accessed: 06-09-2008].

BASF, (2008a), “Neopor® Expandable polystyrene Product Series”, BAFS Publications [Online]. Available from: http://iwww.plasticsportal.com/products/PDF/NeoporS2_2008.pdf [Accessed: 06-09-2008].

BASF, (2008b), “Neopor®”, BASF Publications [Online]. Available from: http://www.plasticsportal.net/wa/plasticsEU~en_GB/function/conversions:/publish/common/upload/foams/Neopor_TM.pdf [Accessed: 06-09-2008].

BASF, “Neopore ® Innovation in Insulation”, BASF Publications. Available from: Sahar Arbabioon upon request.

BASF, Picture, BASF Publications [Online]. Available from: http://www.corporate.basf.com/basfcorp/copsfiles/pressefotodb/4071_neopor-anwendung2---application2_03d.jpg [Accessed: 10-09-2008].

BASF, “Senerflex® Classic PB Wall System”, BASF [Online]. Available from: http://www.senergy.cc/pages/wall%20systems/classic_pb.html [Accessed: 10-09-2008].

BASF, “Commercial Wall Systems, Design Freedom for Distinctive and Enduring Buildings”, BASF Publications. Available from: Sahar Arbabioon upon request [Accessed: 03-09-2008].

BASF, “Built with Confidence”, BASF The Chemical Company [Online]. Available from: http://www.senergy.cc/pages/wall%20systems/class_pb.html [Accessed: 23-09-2008].

BASF, “Built with Confidence”, BASF The Chemical Company [Online]. Available from: http://www.senergy.cc/pages/wall%20systems/flashed_opening.html [Accessed: 15-10-2008].

BASF, "Built with Confidence", BASF The Chemical Company [Online]. Available from: http://www.senergy.cc/pages/wall%20systems/classic_pb.html [Accessed: 15-10-2008].

BASF, "Built with Confidence", BASF The Chemical Company [Online]. Available from: http://www.senergy.cc/pages/wall%20systems/swb.html [Accessed: 15-10-2008].

BASF, "Senerflex® Flashed Opening Design", BASF The Chemical Company [Online]. Available from: http://www.senergy.basf.com/documents/system%20guides/1022477_Flashed_Opening.pdf [Accessed: 16-10-2008].

BASF, "Exterior insulation & Finish System", BASF Publications [Online]. Available from: www.basf-cc.ae/SiteCollectionDocuments/Brochures/EIFS%20brochure.pdf [Accessed: 27-01-2009].

Bruno. F (2004), "Using Phase Change Materials (PCMs) for Space Heating and Cooling in Buildings", AIRAH performance enhanced buildings environmentally sustainable design conference, 2004 Available from: http://www.airah.org.au/downloads/2005-03-02.pdf [Accessed: 23-08-2008].

"Commercial Wall System, Design freedom for distinctive and enduring Buildings", Senergy [Online]. Available from: www.awci.org/buyersguide/files/senergy.pdf [Accessed: 29-01-2009].

"Dubai At a Glance" Realityana [Online]. Available from: http://www.realtyna.com/dubai_real_estate/dubai-at-a-glance.html [Accessed: 12-08-2008].

"Ecopac TILE, Phase Change Material, Thermal Energy Storage Systems", Phase Change Material Products Limited [Online]. Available from: www.pcmpoducts.net [Accessed: 27-01-2009].

Elert. G (2008), "Latent Heat", The Physics Hypertexbook [Online], Available from: http://hypertexbook.com [Accessed: 25-10-2008].

Feist. W (2006), "Influence of Thermal Insulation and Phase change Material on energy Demand and Co2 Emissions in Different European Climates", Passive Haus Institut [Online]. Available from:

www.corporate.basf.com/basfcorp/html/e/energieeffizienz/pdf/Study_PHI_E.pdf [Accessed: 25,01,2009].

Givoni. B (1998), “Climate Considerations in Building and Urban design”, Canada: John Wiley & Sons, Inc.
Gschwander. S, Schossig. P, “Phase Change Slurries as heat storage material for cooling applications”. Fraunhofer Institute für Solare Energiesysteme, Freiburg, Germany. Available from: http://www.pcm-storage.info/voe/paper_eurosun2006_gsch.pdf [Accessed: 19-05-2008].

Havenga. K (2008), “Floors, Walls and Tiles – vital components of any luxury leisure facility” BASF Publications. Available from: Sahar Arbabioon upon request [Accessed: 12-10-2008].

Heinz. A and Streicher. W (2001), “Application of Phase Change Materials and PCM-Slurries for Thermal Energy Storage” [online]. Institute of Thermal Engineering Graz University of Technology. Available form: http://intraweb.stockton.edu/eyos/energy_studies/content/docs/FINAL_PAPERS/8B-4.pdf [Accessed 12-10-2008].

Khudhair. A, Farid. M (2002), “A review on energy conservation in building applications with thermal storage by latent heat using phase change materials”, Energy conversion and Management [online].Vol.45, 2004, pp: 263-275. Available from: www.sciencedirect.com [Accessed: 13-06-2008].

“Latent Heat”, The Physical Environment [Online]. Available from: www.uwsp.edu [Accessed: 25-10-2008].

Medina. M, King. J, Zhang. M (2008), “On the heat transfer rate reduction of structural insulated panels (SIPs) outfitted with phase change materials (PCMs)”, Energy [Online]. Vol 33, 2008, pp: 667–678. Available from: www.sciencedirect.com
[Accessed: 13-06-2008].

Ministry of Energy, United Arab Emirates, (2006), “Initial National Communication to the United Nations Framework Convention on Climate Change”, Ministry of Energy, United Arab Emirates [Online]. Available from: http://unfccc.int/resource/docs/natc/arenc1.pdf [Accessed: 23-12-2008].

Mostaedi. A (2002), “Sustainable Architecture, Low Tech Houses”, Spain: CarlsBroto &Josep M Minguet.

National Research Council Canada, (2005), "Senerflex Wall System", National Research Council Canada [Online]. Available from: http://irc.nrc-cnrc.gc.ca/ccmc/registry/pdf/13062_e.pdf, and www.google.com [Accessed: 6-11-08].

Pasupathy. A, Velraj. A (2008), "Effect of double layer phase change material in building roof for year round thermal management", Energy and Buildings [Online]. Vol 40, 2008, pp: 193-203. Available from: www.sciencedirect.com [Accessed: 13-06-2008].

PCM Limited, (2007), "PlusICE Thermal Energy Storage Design Guide", Phase Change Material Products Limited, [Online], Cambridge shire, United Kingdom. Available from: www.pcmproducts.net [Accessed: 16-09-2008].

"Polystyrene", Wikipedia the free encyclopedia [Online]. Available from: http://en.wikipedia.org/wiki/Polystyrene [Accessed: 22-07-2008].
"Pantene", Wikipedia the free encyclopedia [Online]. Available from: http://en.wikipedia.org/wiki/Pentane [Accessed: 22-07-2008].

Picture, Available from: http://www.lrz-muenchen.de/~Passivhaus/images/d5.jpg [Accessed: 23-09-2008].
Picture, Available from:
http://www.kreisel.ua/technologies/thermal_insulation/_images/technologie/tech_2_05.jpg [Accessed: 23-09-2008].
Shilei. L, Neng. Z, Ghohui. F (2006), "Impact of phase change wall room on indoor thermal environment in winter", Energy and Buildings [Online]. Vol 38, 2006, pp: 18-24. Available from: www.sciencedriect.com [Accessed: 13-06-2008].

Santmouris. M, Asimkopoulos. D (2001), "Passive Cooling of Buildings", London: James & James (Science Publishers) ltd.

Schmidt. M (2008), "EIFS Introduction", BASF Publications, Available from: Sahar Arbabioon upon request [23-07-2008].
Stritih. U (2003), "Heat Transfer Enhancement in Latent Heat Thermal Storage System for Buildings", Energy and Buildings [Online]. Vol 35, 2003, pp:1097-1104. Available from: www.sciencedirect.com [Accessed: 17-05-2008].

Schossing. P, Henning. H, Gschwander. S, Haussmann (2005), "Micro-encapsulated phase-change materials integrated into construction materials", Solar Energy Materials & Solar Cells [Online]. Vol89, 2005, pp:297-306. Available from: www.sciencedirect.com [Accessed: 17-05-2008].

"Sealant and Wall System Warranty", BASF Publications [Online]. Available from: www.senergy.cc/documents/tech%20bulletins/1030842_sealant_warranty.pdf [Accessed: 29,01,2009].

"Senergy® E.I.F.S", Wall System Design [Online]. Available from: http://www.carter-waters.com/E.I.F.S._and_Protection_Board.pdf [Accessed: 18-09-2008].

"The 3-Liter House", BASF Publications [Online]. Available from: www.corporate.basf.com/basfcorp/html/e/energieeffizienz/pdf/3lh_e.pdf [Accessed: 25, 01, 2009].

"Thermal Conductivity", Wikipedia the free encyclopedia [Online]. Available from: http://en.wikipedia.org/wiki/Thermal_conductivity [Accessed: 14-07-2008].

Urtel. M (2006), "Wax in the wall for a pleasant indoor climate", BASF publications, Available from: http://www.corporate.basf.com/file/3695.defile/Micornal_story_engl.doc?id=AwarTnCv5NbcP2-c. [Accessed: 22-10-2008].

Urtel. M (2006), "Wax in the wall for a pleasant indoor climate", BASF publications, Available from: http://www.corporate.basf.com/file/3695.defile/Micornal_story_engl.doc?id=AwarTnCv5NbcP2-c [Accessed: 22-10-2008].

US Department of Energy (2008), "Polyisocyanurate Insulation Materials", US Department of Energy, Energy Efficiency and Renewable Energy [Online]. Available from: http://apps1.eere.energy.gov/consumer/your_home/insulation_airsealing/index.cfm/mytopic=11590 [Accessed: 17-11-2008].

"U-Value", The Encyclopedia of Alternative Energy and Sustainable Living [Online]. Available from: http://www.daviddarling.info/encyclopedia/U/AE_U-value.html [Accessed: 12-08-2008].

Volker. C, Kornadt. O, Ostry. M (2008), "Temperature reduction due to the application of phase change materials", Energy and Buildings [Online]. Vol 40, 2008, pp: 937-944. Available from: www.sciencedirect.com [Accessed: 23-05-2008].

"Weather in United Arab Emirates", South Travels [Online]. Available from: http://www.southtravels.com/middleeast/uae/weather.html [Accessed: 23-06-2008].

"What Is Extruded Polystyrene Insulation (XEPS)". Diversifoam Product [Online]. Available from: http://www.diversifoam.com [Accessed: 11-12-2008].

"What is a U-Value", Sustainable Energy Ireland (SEI) [Online]. Available from: http://www.sei.ie/About_Energy/Energy_Technologies/Insulation/What_is_a_U_VAlue.pdf [Accessed: 12-10-2008].