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Feasibility of converting existing residential buildings to net zero-energy buildings in Egypt

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FEASIBILITY OF CONVERTING EXISTING RESIDENTIAL BUILDINGS TO NET ZERO-ENERGY BUILDINGS IN EGYPT

A Case Study

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ABSTRACT

Green architecture, sustainable buildings, environmentally friendly, and other terms have recently become popular in the construction fields among both professionals and non-professionals. Although it is mostly needed and highly feasible, the application of these ideas is not yet at the same level of popularity in Egypt. Researchers are trying to fill this gap by providing different types of recommendations, methodologies, and guidelines to be followed.

The aim of this research is to propose a method to be used in solving the energy problem in the building sector in Egypt. Since it is concerned with the existing building stock, the methodology will be addressing retrofitting strategies not new design strategies. The research suggests the nZEB (net zero-energy buildings) methodology as a possible solution for the problem and provides a guideline to be used among the rest of existing building types. The research utilizes energy simulation to validate its initial assumptions and to test the feasibility of the proposed guideline. The final outcome of the research is a method that combines both retrofitting and renewable energy strategies that suit the Egyptian context and potential to convert existing buildings to nZEB buildings.

The study starts with the analysis of the current situation of both the existing buildings and the energy sector in Egypt. First, it reviews the classification of the existing building types in the Egyptian context, analyzing the energy consumption patterns and the inefficiencies leading to these patterns, then defining the nZEB concept to familiarize the reader with its different aspects. The empirical part of the study utilizes several cases for a number of prototypes of residential building types in Egypt. Finally, a suggested guideline is applied to an actual existing building and its feasibility is tested by simulation.

The research concludes a potential energy saving by applying nZEB strategies to existing residential buildings in Egypt. Future research is required on different building types to validate the nZEB across different building types.

KEYWORDS: RETROFIT, ZERO ENERGY BUILDINGS, EXISTING RESIDENTAIL BUILDINGS, PV PANELS, EGYPT.

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CHAPTER ONE: INTRODUCTION

1.1. Introduction

The increasing energy consumption rates and the accompanied greenhouse gas emissions are considered one of the world's greatest concerns recently. The total energy sold in Egypt for the year 2014 reached 120 terra watt hour with an annual average growth rate of 5.2%. (Eehc, 2015) The building sector alone -including all building types- contributes with 40% of total energy consumption and one third of greenhouse gas emissions globally, and the numbers are even higher in Egypt, reaching 51% of total energy sold in 2014. (Unep Sbci, 2009) (Eehc, 2015) Mentioning the harmful emissions in Egypt, the CO_2 per capita reached 3.88 ton/year in the latest statistics provided by CAPMAS for the year 2011 rising from 2.93 ton/year in 2008. (CPMAS, 2013) For this reason the building sector represents a large potential for significantly reducing the energy demand and the harmful emissions.

A survey including 1500 apartments in three governments in Egypt revealed the energy efficiency problem in the existing buildings in the Egyptian context. It showed that all the surveyed buildings suffered from poor thermal performance and indoor air quality. It was found that 80% of the investigated samples used at least one air conditioning unit to overcome the inefficiency. The envelopes of these buildings were described to be of low air tightness, having single glazed openings, walls were non-insulated and no shading treatment was installed. (Attia, Evrard, & Gratia, 2012) These numbers give a sense of the severity of energy performance of buildings in Egypt.

Among the relatively new strategies that have been practiced all over the world in the last few years is Net-Zero Energy Building concept. This concept aims at designing greener buildings in terms of energy usage. The whole concept is based on two major aspects: the first is energy saving, and the second is renewable energy generation. Both aspects are equally important as well as equally disregarded in the Egyptian context. This is due to depending on the conventional building technology on one hand and the ambiguity of the renewable energy systems on the other hand. Saving energy usually equals saving money, and this is the motivator for people to pursue advanced energy solutions, and recently it also secures the abundance of energy itself. A possible solution is retrofitting existing buildings to net zero energy buildings through enhancing the envelope's efficiency that will reflect on the reduction of energy usage of the building, while also integrating renewable energy with the existing structure to generate clean energy.

1.2. Observations and Research Problem

1.2.1. Observation:

The energy problem in Egypt is becoming a priority to all levels, from the political and decision making level to the average Egyptian citizen. As previously mentioned, the building sector has a significant role in formulating this predicament. A problem so profound has to be solved sustainably in order for it not to reoccur again in the future; therefore, sustainability aspects will be discussed later in this chapter.

On regional, national and international levels, energy policy is considering energy efficiency in buildings as a future target for the building design. This is why Zero-Energy Building design is recently taking a leading role in all the architecture, the architectural engineering, and the building physics sectors and having a significant importance among researchers on these fields. (Deng, Wang, & Dai, 2014) The European Energy Performance of Buildings Directive (EPBD) has published a recast on 2010 that defines some of its goals including that by 31 December 2020 all new buildings must be nearly zero-energy buildings (nZEB) in the Member States. (European Commission, 2010) Also The US Department of Energy (DOE) has proposed ‘marketable Zero-Energy Homes in 2020’ as a strategic goal to be achieved. (Alrashed & Asif, 2012) Following the same pattern, the Solar Heating and Cooling Program (SHC) of the International Energy Agency (IEA) -that has 20 member countries from all over the world- approved the Task 40 (Towards Net Zero Energy Solar Buildings) in 2008.(Deng et al., 2014)

1.2.2. Research Problem:

There are two main aspects of the problem: first, the increased energy consumption compared to the energy supply in Egypt that is mostly generated from fossil fuels. Second, the loss of this energy within the process of reaching thermal comfort inside the building due to the low levels of insulation of existing buildings. More specifically, energy should be used more efficiently and less fossil-fuel-based energy should be generated. So, a methodology or a guideline that covers both aspects is needed.

As will be widely discussed in the next two chapters, the literature considering nZEBs, retrofit of existing buildings, energy efficiency and renewable energy, it was clear that nZEBs has found its way to the building sector worldwide. It has escalated to the point of setting energy policy goals in terms of nZEBs, as mentioned before. On the other hand, literature showed lack of publications concerned with nZEBs in Egypt and its complete absence from the Egyptian energy policy targets. This shows that the nZEB concept is not yet popular enough within the Egyptian context -since it has no reflection on the Egyptian energy policy- so more research needs to be done in the area specifying the Egyptian climate, building characteristics, and market availability.

The research reviewed different suggested strategies from various published papers -as will be discussed thoroughly- and showed that many approaches were proposed with the absence of claiming that a specific methodology or strategy is considered optimum. Also provided methodologies usually tackled only one of the two basic aspects of the research, either nZEB methodology or retrofit methodology, and in both cases the studies were dedicated to cold climates. This raised the urge of proposing a new one that compiles the two aspects together and consider the hot arid climate.

One of the few published papers proving the feasibility of nZEBs in Egypt dedicated the study to new design buildings not existing ones. (Reda, Tuominen, Hedman, & Ibrahim, 2015) The research used an exemplary model of a non-existing building and based the whole study on simulation results. This highlights the importance of providing studies that involve hands on project like this current thesis. Moreover, this paper also stated some prospects for future research that included incorporating the economics of the solutions based on actual market prices which is provided by this research.

1.2.3. Rationale of Studying Existing Buildings:

Existing buildings represent the actual urban context, it participates with a significant share in the current energy problem but at the same time it symbolizes the solution. If the proposed guideline was successfully implemented and repeated within the existing building fabric, then a significant portion of the problem will be solved. Any action taken on the existing range will instantly be mirrored on the present status. The main reasons behind selecting existing buildings over new buildings can be stated as follows:

- For a new residential building to be built as an nZEB, the owner of the building will meet the expense of enhancing the building's energy efficiency performance. This might not be convenient for the owner because they will not benefit from the future electricity saving.
- By targeting existing buildings, the users of these buildings will be addressed, rather than the owners. This will increase the possibility of implementation because the users are aware of the disadvantages of the poor insulated traditional building, as they have already experienced it. They will also be aware of the amount of electricity consumed regularly, and it affects them directly, so they would encourage solving this problem
- Since the scope of research is residential buildings, so it is basically a block of shared ownership, if occupied. So the actual cost of converting a whole building will be divided on the number of apartments or residential units. At the same time, the methodology can be partially or even individually applied, which makes it easier.
- The lack of awareness of the benefits of green or zero-energy buildings will make it hard to market for the concept itself, but in case of existing buildings the outcomes of the conversion can be calculated by numbers –as will be seen later- so it will be easier for the user to conceive.

In the general case the net zero-energy concept is pursued by new buildings, because it is simpler to apply the passive design strategies that concern with building orientation, windows' sealing, double wall envelopes, adequate wall to window ratio and other strategies. As per existing buildings, options are limited because most of the previously mentioned techniques could not be used. For instance, the building orientation or the wall to window ratio could not be changed. So more sophisticated approaches have to be recommended, tested and implemented.

1.3. Research Questions

Can existing residential buildings in Egypt achieve the standards of net zero-energy buildings by the means of retrofitting and utilizing renewable energy systems?

Can this be achieved by market available products and at an affordable price?

1.4. Research Methodology

There are two basic types of research: Fundamental research and Applied research. (Uusitalo, 2014) According to this classification, the fundamental or theoretical research is concerned with analyzing a certain fact or phenomena. A fundamental research is not expected to solve any particular problem, it basically provides further investigation for a certain matter or scientific theory. The outcome of this type of research acts as a foundation for an applied research. On the whole, the fundamental research seeks generalization, and does not work on a specific case or problem.

As per the second type: applied research, its main goal is to find a solution for a practical problem that provides a solution for immediate use. It aims at specification rather than generalization and it normally addresses a particular paradigm. This type includes case study, interdisciplinary, and experimental research. Applied research usually builds on fundamental research outcomes, similar to moving from general to specific.

The aim of this research is to introduce the nZEB concept as a scientific and practical solution to the energy problem in Egypt. Consequently, there is a problem that needs to be solved, from what classifies the research as an applied experimental case study research. For the aim of testing the practicability of retrofitting existing buildings to achieve net zero-energy buildings quantitative methodology can be used. Numbers will provide solid data on whether the hypothesis is possible or not.

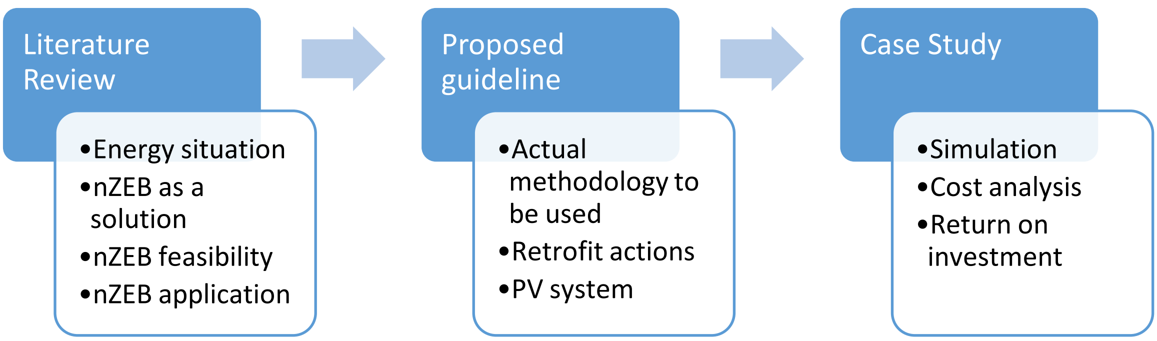


Fig (1-1): Research methodology

As seen in figure (1-1) the literature review part starts with the problem definition through reviewing the energy situation in Egypt in order to be able to determine the dimensions of the problem. Afterwards, it starts introducing the nZEB concept as a suggested solution for the problem. First, defining the nZEB takes place, then a clear understanding of the current global and local status of the nZEB is targeted. It is followed by considering the feasibility and application of this solution. Analyzing the nZEB methodologies helps in suggesting adequate solutions and proposing a proper methodology that suits the current situation which is the next step of the research.

1.5. Research Structure

Proposing a guideline to be used as a guideline for any existing residential building that is planned to be converted to nZEB is one of the expected outcomes of the research. The studied literature provided the research with different types of strategies of either retrofit or nZEB. The research provides a novel strategy that combines both the retrofit and the nZEB and at the same time respects the Egyptian context and considers its needs. Following the standard research structure, it has two main parts: theoretical and practical. The research starts with the theoretical part where literature review is performed in order to collect as much as possible of the published works related to this subject. Followed by the practical part where the research targets implementing the proposed guideline on the pragmatic level.

The observation and the analysis of the research problem helped in formulating the research question that eventually molded the hypothesis. Based on the expected outcomes of the research, the methodology was determined, then the research structure as seen in fig (1-2) was developed. By reaching a solid research methodology and structure, the introduction phase that aims at presenting the basic idea of the research is fulfilled.

The literature review in general is the backbone of any research, it is where the justification of the research worthiness is proved, the research gaps are highlighted, and the rationale behind the hypothesis is addressed. In this research, the literature review is basically concerned with two issues: the current status of the Egyptian context, and net zero-energy buildings in general. As per the current situation in Egypt, it focuses on both the existing building stock as well as the energy situation because those two aspects articulate the research problem. The second main component of the literature review is the net zero energy buildings, mainly defining the concept, discussing its strategies and methodologies, checking its practicability, and finally reviewing case studies of previous projects.

The key outcome of the research is a methodology of converting existing residential buildings to net zero-energy buildings. Then after the guideline is proposed and explained, the validation is implemented at the empirical part of the research. The validation depends on a tool-based case study analysis, where the research question is answered by applying the proposed guideline on a hands-on project and verifying its feasibility through simulation tools. There are many simulation programs that could be used for studying the energy patterns of a building. HEED, eQuest, Vasari, ECOTECT and DesignBuilder are examples of these programs. DesignBuilder is characterized by its high accuracy, variety in data-entry level, performing parametric analyses, and has an organized interface, for these reasons it was selected for this study. (Attia, 2013)

Conclusion of chapter I:

This chapter started with an introduction to the subject, followed by the observation that paved the way to the problem definition and the motivation for the research. The hypothesis was then concluded based on the previously stated problem. Then the research methodology was proposed followed by the research structure to walk the reader through the contents of the thesis.

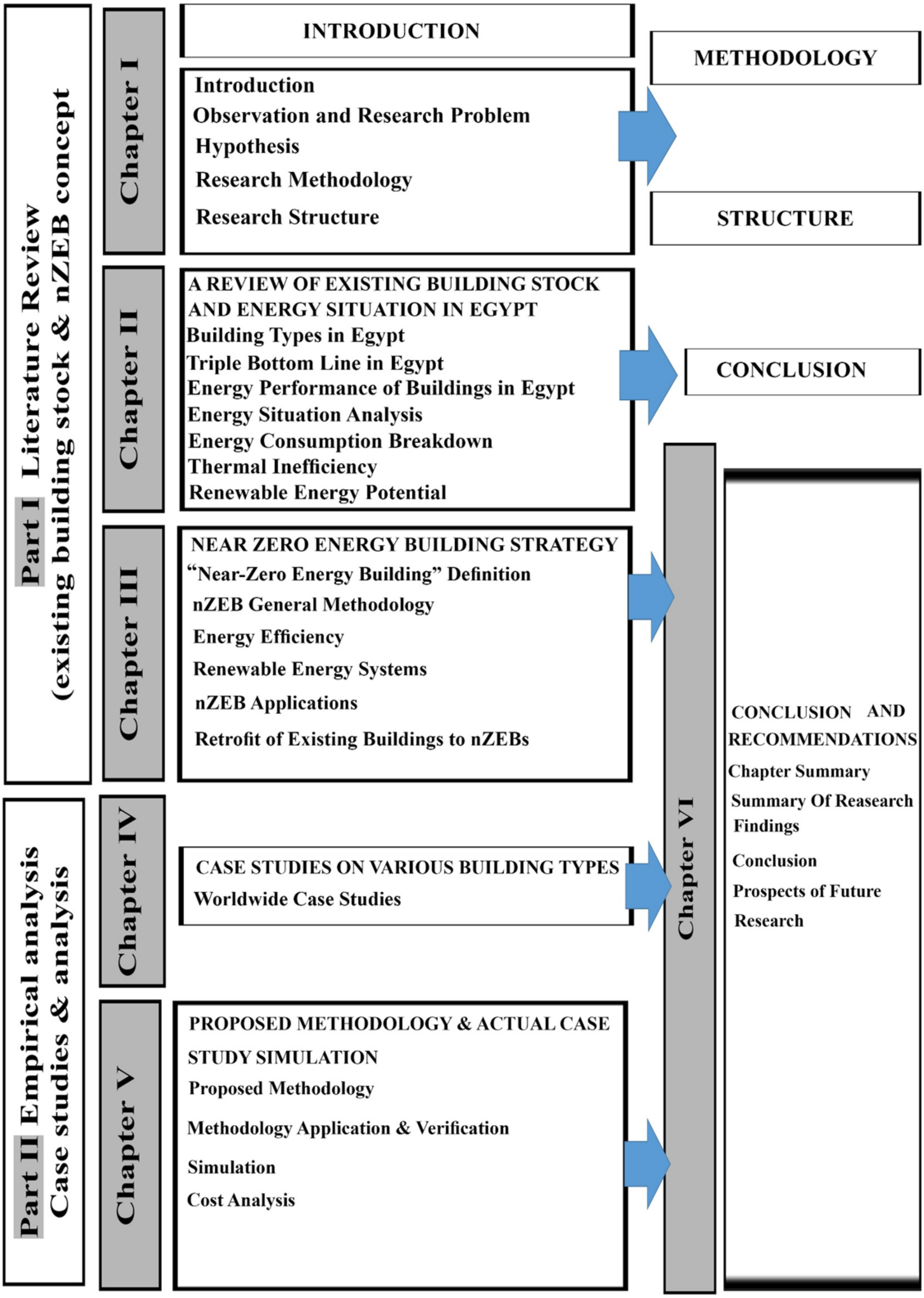


Fig (1-2): Research structure chart

CHAPTER TWO: A REVIEW OF EXISTING BUILDING STOCK AND ENERGY SITUATION IN EGYPT

2.1. Building Types in Egypt

The building sector consumes 40% of the energy generated on a global scale, while it consumes more than 51% in Egypt according to the annual report of the ministry of electricity. (Eehc, 2015) In other words, the existing buildings represent both the problem and the solution, because if a clear methodology is proposed to convert existing buildings into zero-energy buildings then the majority of the urban fabric will be affected. Unlike solutions for new design buildings that would take a lot of time to show results, working on existing buildings would reflect immediately on the current energy consumption situation.

In order to analyze the existing building situation, a building type classification had to be performed. This classification focuses on the energy consumption aspect, so it respects the factors that affect the energy performance of the building. Adopted from Attia (2013) the classification beholds five main building types. The five types cover the majority of residential building types in Egypt, the types are as follows:

1. Bearing walls system with thermal mass.
2. Reinforced concrete skeleton with masonry and thermal mass.
3. Reinforced concrete skeleton with masonry and no thermal mass.
4. Reinforced concrete skeleton with masonry and wall air gap.
5. Reinforced concrete skeleton with masonry and wall insulation. (Attia, 2013)

2.2 Triple Bottom Line in Egypt

Sustainability has three main pillars: Economic, social and environmental, if the three were not considered, the balance would not be achieved. Addressing the Egyptian context means considering the unique nature of these aspects in Egypt. Figure (1-1) reflects the three aspects on the building field and expresses the benefits of applying the green building concepts on each aspect.

I. Economic pillar:

In order to provide a sustainable vision, the most important aspect which is economics will come first. Although the retrofit of existing buildings might seem to be a costly solution, if the life cycle approach was considered, then it would be clear that the payback period of the retrofit will be acceptable. On the other hand, installing renewable energy systems is a pure economic decision, not only because of the expected rise in energy prices -due to the policy of decreasing subsidies in Egypt (Reda et al., 2015)- but also because securing one's own source of electricity will reflect directly on the economics of the building.

Alternative resources for energy generation is becoming a necessity rather than a luxury after the frequent electricity cutoff in the past few years. In this case, the option of renewable energy generation added to any building would mean better marketing opportunity as well as higher property price. In other words, any greening step is usually perceived as a mere environmental move, while if the financial side of such a step was practically considered, then its economic benefits will be revealed. At a later stage of this research, the economic benefit will be calculated in actual numbers including a complete cost analysis and return on investment values.

II. Environmental pillar:

The environmental aspect is vividly presented in this case, as it starts with the general approach of decreasing the CO_2 emissions by using less fossil-fuel-based sources of energy. This is particularly important when considering that the CO_2 consumption per capita in ton is rising following the following trends: 3.98 in 1973 and reached 4.18 in 2004 with a growth rate of 5%. (Pérez-Lombard, Ortiz, & Pout, 2008) Also it focuses on reducing the absolute amount of energy consumed which will result in decreasing the raw material consumption of the overall process. Furthermore, using renewable energy system does not only decrease the negative implications of fossil fuel energy resources, but also endorses the use of clean energy in general.

Another environmental beneficial implication is resulting from improving the insulation levels of the buildings in Egypt, which is: the less use of air-conditioner units. This will reflect on the less use of raw materials and at the same time the lower negative implications of the air-conditioning units' operation on the environment. Adding to this the better indoor environmental air quality that would be provided after the retrofit due to the enhanced thermal comfort.

III. Social pillar:

Lastly comes the social aspect that has many reflections, some comes from the occupants' satisfaction, others come from the owners' satisfaction. First of all is the thermal comfort of the indoor environment that would lead to the wellbeing of the occupants as surveyed in a research that proved the satisfaction of the interviewed occupants of zero-energy buildings. The occupants' wellbeing will reflect on their productivity and general comfort that would be translated to money for the building owner. (Berry, Whaley, Davidson, & Saman, 2014)

From another point of view, both the owner and the occupant will benefit from the aspect of securing a steady source of electricity. The recent electricity cutoff in Egypt led to a lot of social implications like the significant discontentment among occupants of different building types. So if this inconvenience could be avoided, then a state of general satisfaction could be reached. Another social benefit could be the societal connection between different building occupants during the decision making and the implementation phases of the retrofit or the energy system installation.

2.3 Energy Performance of Buildings in Egypt

The only official source of energy consumption data in Egypt is the ministry of electricity and renewable energy. This body gives an annual report that provides statistics of the electricity generated and distributed throughout the given year. In its latest published report for the year 2013/2014, it stated that 51.3% of the overall electricity consumed goes to the residential buildings as seen in figure (2-1).

Purpose of Usage	Quantity (GWh)
Industry	17303
Agriculture	5528
Government & Public Utilities	13622
Residential	61962
Commercial Shops	5003
Public lighting	5692
Others	11716
Total	**120826**

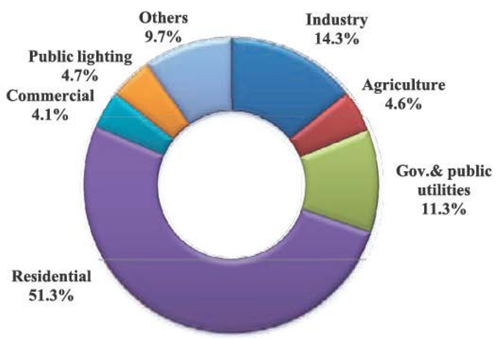


Fig (2-1): Amount and percentages of energy sold according to purpose of usage (Eehc, 2015)

The report does not specify a breakdown of usage for this amount of electricity. Consequently, the amount of energy needed for each purpose is not determined, for example the amount of energy consumed to reach thermal comfort. One of the sources that provides energy breakdown data was a study that surveyed the electricity usage in an urban community in Cairo. The study revealed that 74% of the electricity used is consumed towards reaching thermal comfort, where 65% goes to cooling purposes while 9% goes to heating ones. (Attia, 2013) Figure (2-2) shows the exact breakdown of the energy usage according to Attia's study. This shows the importance of solving the thermal comfort aspects and proves that if the building insulation efficiency was enhanced, the energy saving will be significant. More analysis on thee energy inefficiency in Egypt will be discussed later in the chapter.

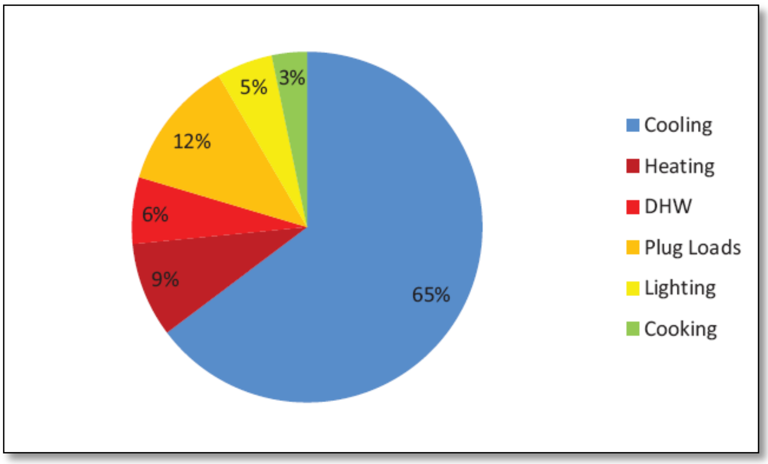


Fig (2-2): Energy consumption per household in an urban community in Cairo (Attia & Herde, 2007)

2.4. Energy Situation Analysis

Some facts about the energy consumption in Egypt says a lot about the problem. For example the fact that electricity generation has increased by 500% during the period 1982–2005 from nearly 22 TWH to 108.4 TWH at an average annual growth rate of 6.9%. (Ibrahim, 2012) As a result, oil and gas consumed by the electricity sector has jumped during the same period from around 3.7 MTOE to nearly 21 MTOE. Also, figure (2-3) shows the discrepancies between the energy supply and demand with respect to population growth.

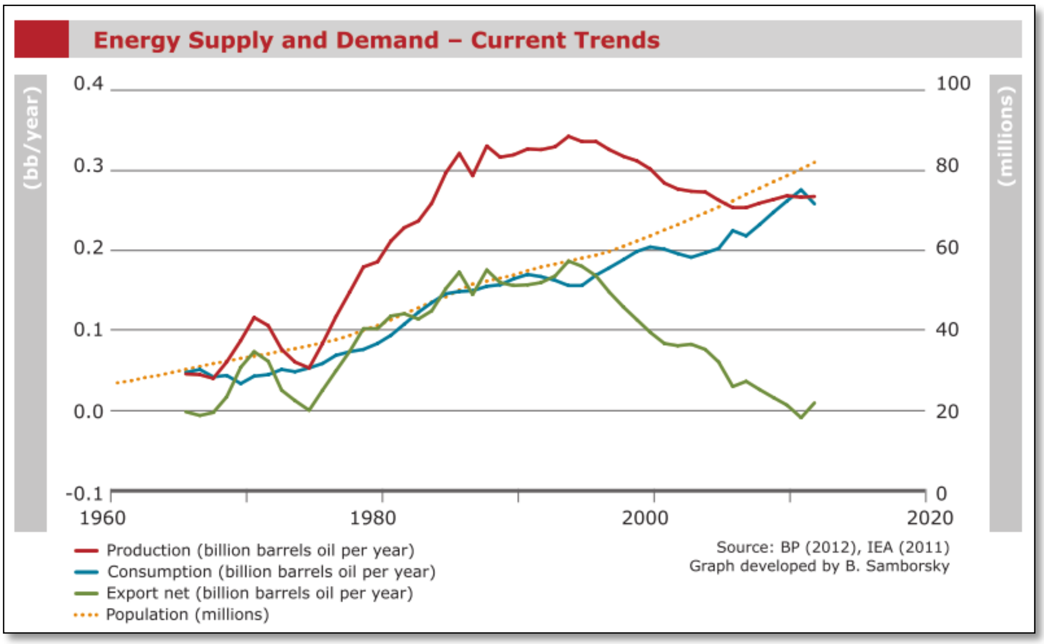


Fig (2-3): Energy supply and demand and population growth (Rcreee, 2012)

2.4.1. Energy Consumption:

The building sector is account for a 40% of the total final energy consumption, occupying the third place after industry and transport sectors. Moreover, expected growth of energy use in the built environment in the next 20 years is 34%, at an average rate of 1.5%. The residential sector will contribute with 67% of the energy consumption in 2030 and 33% for the non-domestic sector. (Pérez-Lombard et al., 2008)

During the last two decades primary energy has grown by 49% and CO2 emissions by 43%, with an average annual increase of 2% and 1.8% respectively according to the International Energy Agency data for energy consumption trends. (Pérez-Lombard et al., 2008)Predictions for the Middle East -and areas of growing economy- show that this trend will continue to grow at an average annual rate of 3.2% and will exceed the growing rate of developed countries by 2020. Figure (2-4) illustrates the total energy sold for each year in Egypt from 2009-2014 showing that the annual growth rate is 5.2%.

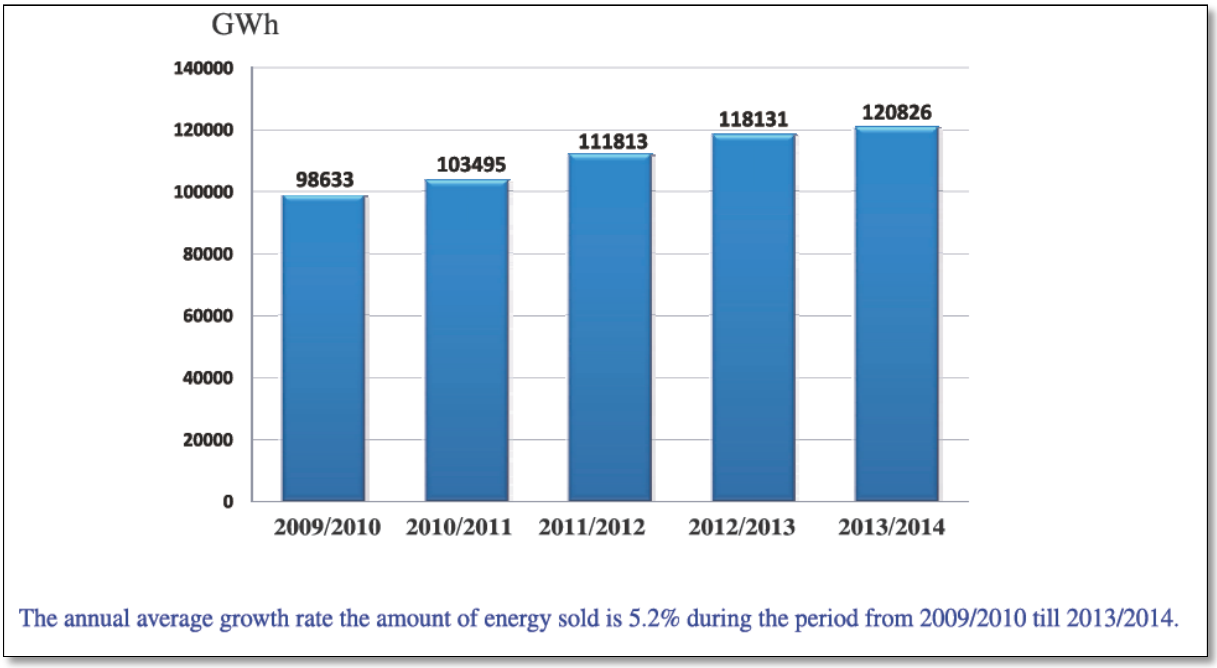


Fig (2-4): Total energy sold from 2009-2014 (Eehc, 2015)

2.5. Energy Consumption Breakdown

The three quarters of the total energy consumed that goes towards thermal comfort highlights the possible saving potential that accompanies this issue. In order to provide an adequate solution for this problem, a thorough understanding of the thermal comfort aspect in general -and its application in Egypt in particular- has to be achieved. After understanding the thermal comfort aspects, the reason behind the low thermal efficiency will be discussed so that the solutions would be mostly effective.

2.5.1. Thermal Comfort:

Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment. (Turner et al., 2008) According to the American society of heating, refrigerating and air-conditioning engineers ASHREA in its handbook for the year 2007, thermal comfort depends mainly on six factors. Those six factors are considered reliant on either environmental or personal parameters. Four factors are affected by the environmental parameters: air temperature, mean radiant temperature, air velocity, and humidity while the rest depend on personal ones: metabolic rate and clothing.(Ashrae, 2007) ”Due to biological variance beyond occupants and psychological phenomena, neither perfect conditions nor well defined comfort boundary settings exist, but rather a comfort zone with a band of operative temperatures that satisfy the highest percentage of occupants". (Attia, 2013)

Fig (2-5): Climatic regions of Egypt (Attia, 2013)

2.5.2 Thermal Comfort in Egypt:

In order to analyze the thermal comfort in the Egyptian context, some climate studies have to be done. First, climate classification as defined in Attia (2013), Egypt has three main climatic regions as seen in figure (2-5). The majority of the area of the country is considered to be hot from mild to dry. While the coastal areas are considered hot humid, representing a very small percent of the overall area. It's important here to mention that the global warming has a great role in increasing the arid zones all over the world in the last fifty years. In Africa alone, an increase by 5% in the area of arid zones was detected to be the greatest percent among all the continents.

There is already an increase in temperature profile allover Egypt in the last 10 years. This aspect of climate change complicates the problem in Egypt because most of the buildings are not well insulated from what increases the energy needed to reach thermal comfort to a significant extent. Some surveys conducted in the Egyptian context concluded that electricity use is considerably dominated by the seasonal use of air conditioners, as will be discussed more in depth.

To summarize the thermal comfort range in Egypt, the HBRC had defined the acceptable ranges for Cairo as follows:

- Indoor air temperature between 24 degree C and 29 degree C
- Relative humidity between 30% and 50%
- Air velocity 0.5 to 1.5 m/s
- Solar exposure is desirable when temperature is less than 23 degree C
- Cooling is needed when temperature is more than 31 degree C. (HBRC, 2005)

Figure (2-6) shows ASHREA's standard 55 for the Psychometric comfort chart on the left side and a practical adaptation by Attia (2013) to make the chart representative of the comfort range in Egypt.

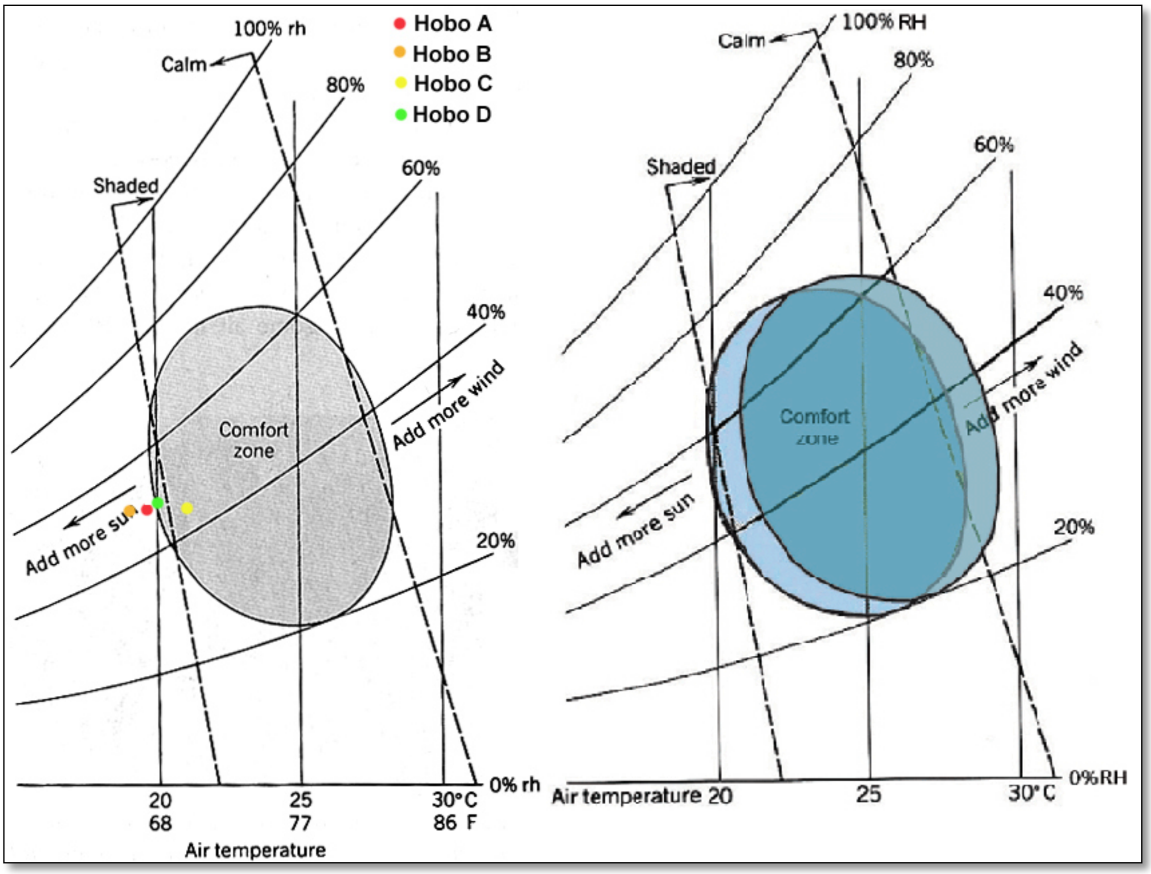
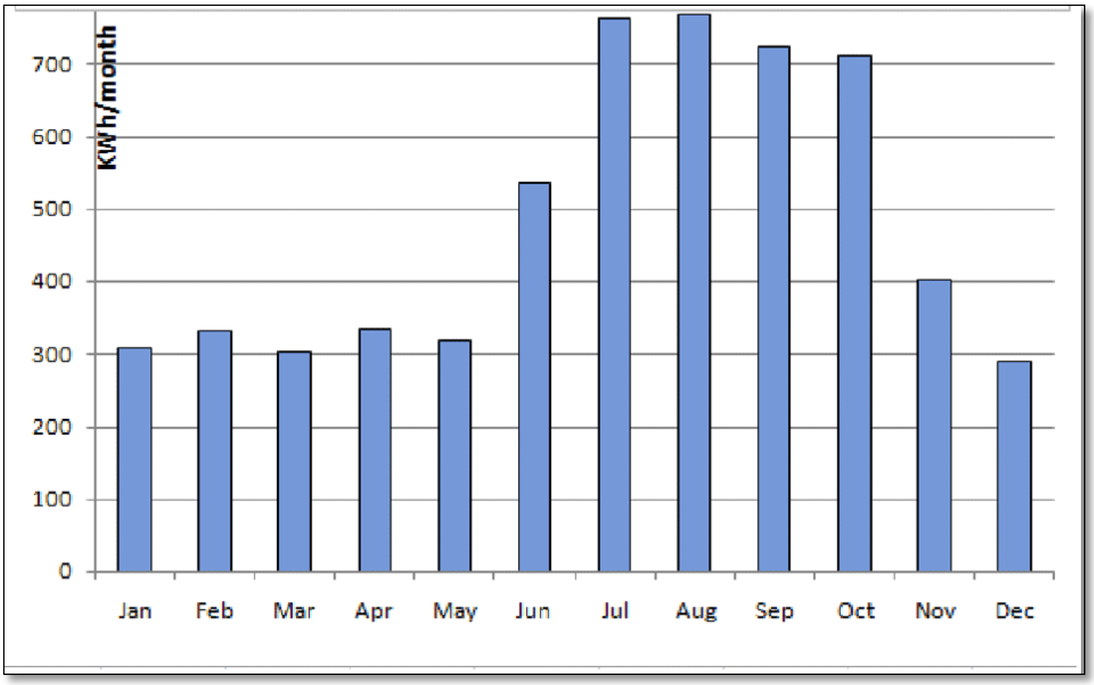


Fig (2-6): Comfort zone chart (ASHREA, 2005) (Attia & Herde, 2007)

2.6. Thermal Inefficiency

Buildings in Egypt are characterized by low levels of insulation from what leads to a very poor thermal performance and low indoor air quality. A survey conducted by Attia, Evrard, et al., (2012) revealed that the building envelopes of the surveyed buildings were not airtight, all the openings were single glazed, walls were not insulated and no shading treatment was provided. To compensate for this technical problem, 80% of the apartments installed at least one air-conditioner unit, and this leads to the peak electric loads that causes failure and complete shutdown of the grid, as experienced recently in Egypt. It is worth saying that the final survey findings showed that the use of air-conditioners raised the annual electricity bill by 44% to 57% in Cairo. Figure (2-7) shows the average electric monthly demand for typical residential building in Egypt, it reveals the peak periods of electric consumption to be the hottest months of the year from what proves the effect of thermal comfort on the electricity consumption. Similarly, figure (2-8) shows the increasing sales of fans and air-conditioning units from the year 1996 until the year 2010 displaying the wide jump at the year 2008.



Fig(2-7): Average monthly metric consumption pattern per apartment in Cairo (Attia & Herde, 2007)

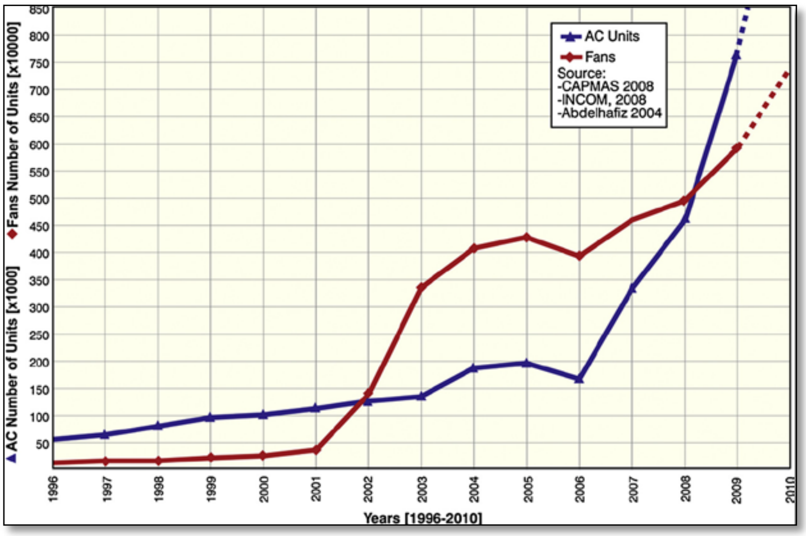


Fig (2-8): Air-conditioning and fans sales in Egypt (Attia, Evrard, et al., 2012)

Decreasing the electricity consumption that will reflect directly on decreasing the energy consumption cannot be reached without solving the thermal inefficiency problem. Thermal inefficiency has two main aspects:

a. **Envelope:** The envelope performance controls the amount of heat transmitted to and from the building. So its status reflects directly on the building's energy consumption. The envelope is composed of walls, windows, roofs and shading system –if applicable.
   - Walls: the type construction and the material of the wall are the factors that affect thermal transmittance. The wall type could be a single wall, a double wall, or a double wall with cavity. From the material point of view, the wall could be constructed from normal bricks or hollow bricks each with different thermal mass.
   - Windows: single glazed windows have low insulation properties because the solar radiation is easily transmitted to the indoor of the building. On the other hand, double glazed windows with air cavity in between the layers acts as a good insulator. Similarly, the type of the window section whether it's wooden frame or aluminum frame also affects the efficiency of insulation.
   - Roofs: usually the roofs are concrete with normal heat and humidity insulation sheets, if these techniques were enhanced, better indoor environment could be achieved for the top floor.
   - Solar shades: among the strategies that help in reducing the cooling load is installing sun shades on the openings of the facades that face direct sun

radiation according to the building orientation and the shading of the surrounding buildings.

b. **Efficient Appliances:** The second main aspect is the appliances in general and particularly the HVAC system. Most importantly comes the HVAC system because if the cooling system is efficient it will consume the least amount of energy to perform. While if the system is worn out it may consume a large amount of energy and not fulfill the occupant demand. The rest of the electric appliances also play an important role in energy saving. Although recently the Egyptian market provided efficiency degree labels for some devices as in fig (2-9), still there's no energy efficiency label like energy star in the USA.

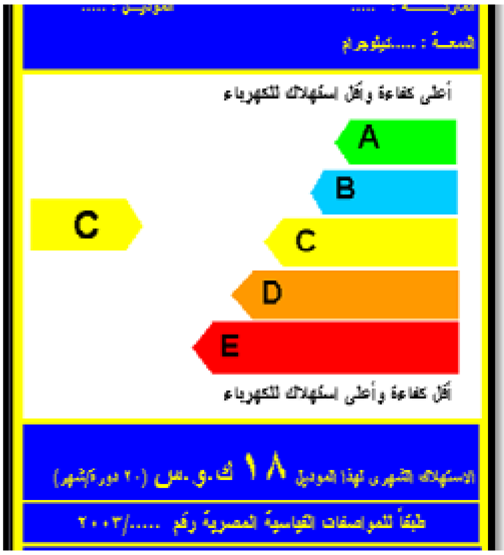


Fig (2-9): Efficiency degree label

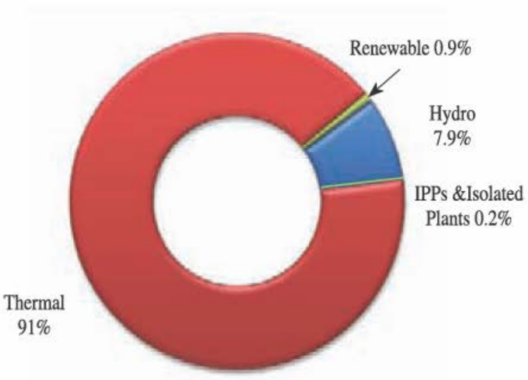
"The use of renewable energy technologies for cooling residential buildings in Egypt should be further investigated. This might result into energy neutral or net zero energy buildings". (Attia, Evrard, et al., 2012) This quote at the discussion of Attia's paper, that is considered one of the important references in the building energy field specifically dedicated to Egypt, summarizes the aim of this thesis and explains a part of its research question.

2.7. Renewable Energy Potential

On the other hand, statistics say that Egypt's potential of solar energy is 40,000 tetra watt hour per year, while the total installed capacity is around 21,435 MW. (Potential of solar thermal energy, 2015) (NREA, 2015) Although Egypt has a very high potential compared to other countries in the world, the installation capacity does not reflect the same value, as shown in fig (2-10) both the PV panels and CSP represent 1% of the total installed capacity in Egypt. Adding to the previous information the current electricity crisis that Egypt is facing, only one answer is feasible: solar energy application, which cannot be done without thorough research that links the existing situation to possible strategies.

By Type and Technology (GWh)* :

Type		2012/2013	2013/2014	Variance%
Steam	Affiliated Companies	62076	62971	1.4
	Private Sector	14264	14154	(0.8)
Gas Turbine		14032	10790	(23)
Combined Cycle		59365	65034	9.5
Total of Thermal*		149737	152949	2.1
New & Renewable	Hydro	13121	13352	1.8
	Wind	1260	1332	5.7
	Solar /Thermal	237	114	(51.9)
Total Grid		164355	167747	2.1
Isolated Plants		240	241	0.4
Purchased from (IPP's)		33	62	87.9
Grand Total		164628	168050	2.1



*The Energy generated includes commissioning tests.

Fig (2-10): Generated and purchased energy according to source (Eehc, 2015)

Furthermore, the demand of PV in the Egyptian market is considered limited so far, and mainly led by private intreprises controlled by individual entrepreneurs. So insteaad of being driven by the local and regional market forces, those interprises fulfill only the vision of owners. Acccording to a study analyzing the renewable energy resources in the Egyptian electricity market, it was stated that the local PV market size is in the tens of millions of Egyptian pounds. This market size is considered limited given Egypt's solar potentials and energy-supply situation.(Ibrahim, 2012)

Conclusion of chapter II:

This chapter focuses on classifying and analyzing the existing building stock in Egypt along with the energy performance of the existing buildings. Followed by the current energy situation with both of its traits, the consumption and the energy efficiency. Then the analysis of the major element of energy consumption, the thermal comfort and thermal inefficiency in

Egypt. Last but not least was the renewable energy potential and its effect on solving the problem.

CHAPTER THREE: "NET ZERO-ENERGY BUILDING" STRATEGIES

3.1. "Net Zero-Energy Building" Definition

Standards for ranking sustainable building design processes like LEED, Ecohomes, and PassivHaus are successful tools for assessment and evaluation of energy efficiency and zero-energy buildings, but none of these standards provide specific guidelines or design strategies that could be used by architects or engineers.(Wang, Gwilliam, & Jones, 2009) These standards -especially LEED- are being used recently in the Middle East and in Egypt, yet the building certification does not reflect whether the building is nZEB or not. In fact the nZEB concept is not well introduced in the Egyptian building sector so far -as will be discussed later on- this is why defining the nZEB should be the first step in the way of understanding and then implementing the idea.

To be able to define the zero-energy building, the energy performance of a building has to be defined first. As stated in the EPBD 2010 recast final report, the energy performance can be identified on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use. It also has to reflect the heating and cooling energy needs to maintain thermal comfort inside the building, along with domestic hot water needs. Accordingly, a net zero-energy building is a building that has a very high energy performance -as described previously- and the remaining energy should be covered to a very significant extent by energy from renewable sources. (European Commission, 2010)

A clear definition of the nZEBs is: "*A zero energy building refers to a building with a net energy consumption of zero over a typical year. It implies that the energy demand for heat and electrical power is reduced, and this reduced demand is met on an annual basis from renewable energy supply*". (Wang et al., 2009)

To sum up the characteristics of nZEBs as stated by the EPBD recast:

- Having a very high energy performance.
- Energy demand should be reduced to nearly zero or very low.
- Energy requirements should be fulfilled to a very significant extent by renewable resources. (Hermelink et al., 2013)

The first aspect depends mainly on enhancing the insulation of the building, which can be reached, for example, through restricting the U-values of the building envelope or controlling the windows thermal transmittance. The second aspect is ambiguous to a great extent because it is hard to determine what the "very low" amount of energy means. At the same time, the amount of energy consumed in a building depends on intangible factors like the user's behavior and expected thermal comfort level, regardless of how energy efficient the building is. As per the third aspect, it simply aims at calculating the electricity demand and managing to cover it through renewable in-site or off-site sources.(Szalay & Zöld, 2014) Figure (3-1) demonstrates the three phases of reaching net zero energy building.

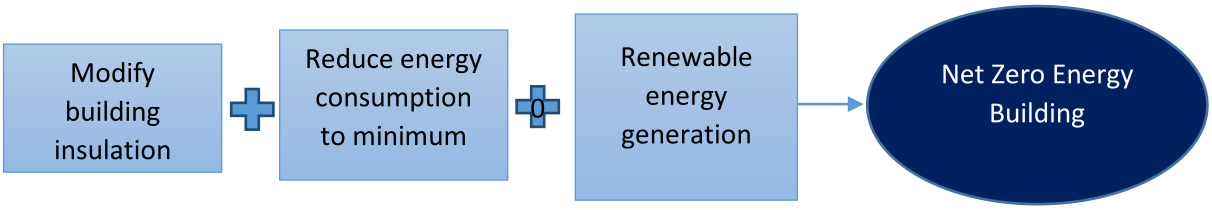


Fig (3-1): Aspects of reaching net zero-energy building

3.2. nZEB General Methodology

There is no specific guidelines or design strategies to act as a clear methodology for nZEB design process, yet some research have defined three basic steps to be followed. (Sun, Huang, & Huang, 2015)(Wang et al., 2009)(Szalay & Zöld, 2014)(Sartori, Napolitano, & Voss, 2012)(Deng et al., 2014)(Garde et al., 2014)

1. **Data Collection and Analysis:**

The first and primary step on the way of zero-energy building approach is the collection and analysis of local climate data in order to assess the climate potential and make important decisions. For example, building's energy system design and renewable energy system selection will be determined according to the results of the analysis. Wind, Solar radiation and ambient temperature are the main aspects that should be studied.

2. **Energy Performance Enhancement:**

The second step will be concerned with enhancing the energy performance of the building and testing the results using software modeling techniques. The main focus will be on factors affecting heating and cooling loads and thermal comfort of the indoor environment. The building envelope characteristics defined as the facade design and the U-value of the used materials are the basic aspects to be studied as well as the level of insulation of the windows.

3. **Renewable Energy Systems:**

Based on the climate data analysis and software modeling, the final step would be determining the renewable energy system to be used. Various computer programs could be used to simulate the energy demand and generation of different renewable sources like TRNSYS, EnergyPlus, Homer and DesignBuilder. The exact number of PV arrays, wind turbines or solar heaters is to be determined in addition to the scheme of connecting the renewable energy system to the grid.

4. **Main Aspects of nZEBs:**

From another point of view, Attia et al. stated that the nZEB design has six main aspects as shown in Table (1-1). This study agrees with what Attia claimed, and this is why most of these aspects will be discussed in the thesis. Some aspects were excluded from further discussion, like 'passive strategies' because the study tackles already existing buildings and discards new building design strategies.

The six main building design aspects of NZEBs design.	
1. Metric	There are several definitions for NZEBs that are based on energy, environmental or economic balance. Therefore, a NZEB simulation tool must allow the variation of the balance metric
2. Comfort level and climate	The net zero energy definition is very sensitive towards climate. Consequentially, designing NZEBs depends on the thermal comfort level. Different comfort models, e.g. static model and the adaptive model, can influence the ‘net zero’ objective
3. Passive strategies	Passive strategies are very fundamental in the design of NZEB including day lighting, natural ventilation, thermal mass and shading

4. Energy efficiency	By definition, a NZEB must be a very efficient building. This implies complying with energy efficiency codes and standards and considering the building envelope performance, low infiltration rates, and reduce artificial lighting and plug loads
5. Renewable energy systems (RES)	RES are an integral part of NZEB that needs to be addressed early on in relation to building from addressing the panels' area, mounting position, row spacing and inclination
6. Innovative solutions and technologies	The aggressive nature of 'net zero' objective requires always implementing innovative and new solutions and technologies Used

Table (3-1): The six main aspects of nZEBs, adopted from (Attia, Gratia, De Herde, & Hensen, 2012)

Different definitions and methodologies describe the nZEB concept and from different points of view, but its two core concepts stay the same: 1- Energy efficiency and decreasing energy consumption, and 2- Renewable energy generation. This is why those two essential aspects will be further discussed in the following sections.

3.3. Energy Efficiency

3.3.1. Energy Efficiency for Existing Buildings:

Energy efficiency is a fundamental aspect of the nZEB approach, "… *It implies that the energy demand for heat and electrical power is reduced, and this reduced demand is met on an annual basis from renewable energy supply*". (Wang et al., 2009) When analyzing the existing highly efficient building concepts, it was clear that the high level of insulation, efficient windows, high level of air tightness and installing efficient appliances are the typical elements of energy efficiency.(Szalay & Zöld, 2014) (Attia, Evrard, et al., 2012)

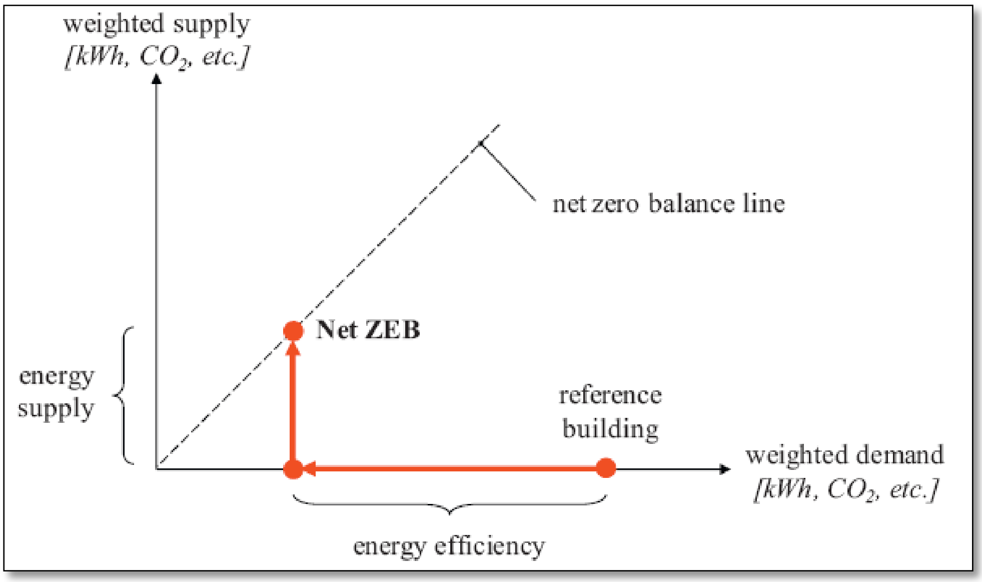


Fig (3-2): nZEB energy efficiency balance (Sartori et al., 2012)

Energy efficiency does not come at the expenses of thermal comfort or electrical demands' fulfillment, on the contrary, energy efficient buildings are able to provide the users with their needs, but at minimum energy usage. Moreover, cost-effectiveness and environmental aspects are positively affected by the energy decrease methodology. Some of the suitable strategies to improve the energy efficiency of a building are choosing adequate building envelope, installing efficient conditioning systems and enhancing the windows' insulation levels. (Rodriguez-Ubinas, Rodriguez, Voss, & Todorovic, 2014)

3.3.2. Hybrid Solutions:

Some researches state that energy reduction process in the aim of reaching energy efficiency is even more advantageous towards environmental and financial aspects than installing renewable energy systems. As emphasized by Thomas & Duffy (2013), the less energy a building consumes, the smaller a renewable energy system is required to reach net-zero. This is why energy efficiency should come as a first priority in the design strategy of nZEBs and if the designer succeeded in decreasing the energy consumption to a significant degree, then the renewable energy phase would be simplified to a great extent.

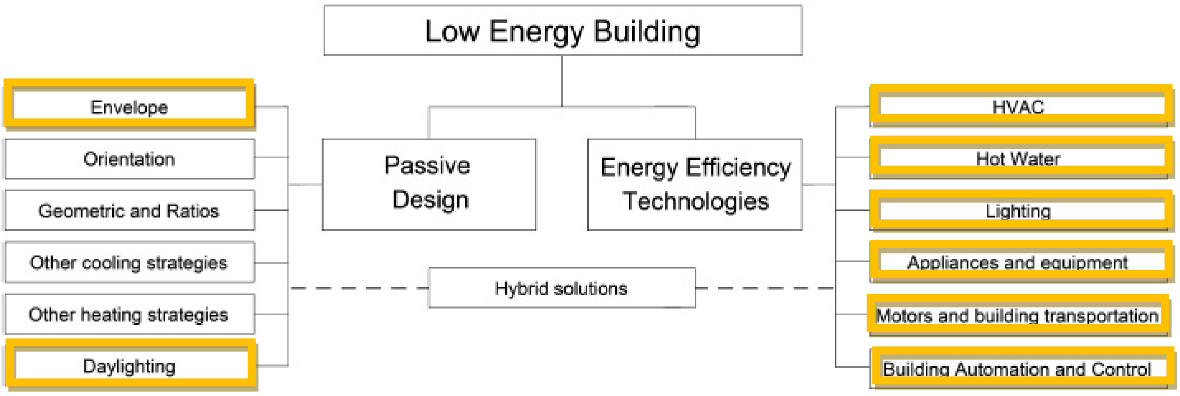


Fig (3-3): Hybrid solutions for low energy buildings (Rodriguez-Ubinas et al., 2014)

Fig (3-3) shows the hybrid solutions of both the passive design and energy efficiency technologies. The shown solutions can be implemented on the new building design, while the author added a layer of highlight to the solutions that represent the only possible actions for existing buildings. The energy efficiency technologies shown in the figure can be implemented on existing buildings, like installing an effective HVAC system and decreasing the hot water and lighting usage. These technologies are expected to decrease energy consumption to a significant extent. In the general case the passive applications could not be used for existing buildings, but in this study the author is discussing the feasibility of tackling some passive strategies from the existing building perspective. For example, the building envelope could be enhanced by adding some layers to the envelope in order to improve its insulation levels.

3.3.3. Further Recommendations:

Non-technical issues like legislations, building codes, incentives and awareness should complement the technical aspects discussed before. Some of these recommendations were proposed by Thomas & Duffy (2013)as follows:

- Building codes for state and local officials should increase energy conservation requirements.
- Funding and promoting incentives to encourage both energy efficiency and renewable energy.
- Architects, engineers and builders should teach building owners and users how to operate and monitor energy efficiency systems.
- They should also clarify any vagueness associated with net-energy predictions.

- Discussing with the users how their behavior will affect energy consumption levels.
- Builders should make sure of the appropriate installment and functioning of the systems used.

3.4 Renewable Energy Systems

Integration of the renewable energy supply into the building design phase can be easily implemented in case of new buildings. On the other hand, it can be added to the building or be a part of a community renewable energy supply in the case of retrofitting of existing buildings. Since most of the renewable energy applications are normally non-transmittable; its power generation depends on the availability of the power resource at any given time, then the main grid must be used as a backup. In other words, the renewable energy supply will generate the demanded electricity as long as the renewable power is available, and export the excess generation to the grid, while the grid compensates for the electrical demand when the renewable power is off. Figure (3-4) illustrates the nZEB balance with regards to onsite renewables and the energy grid. (Wang et al., 2009)(Sartori et al., 2012)

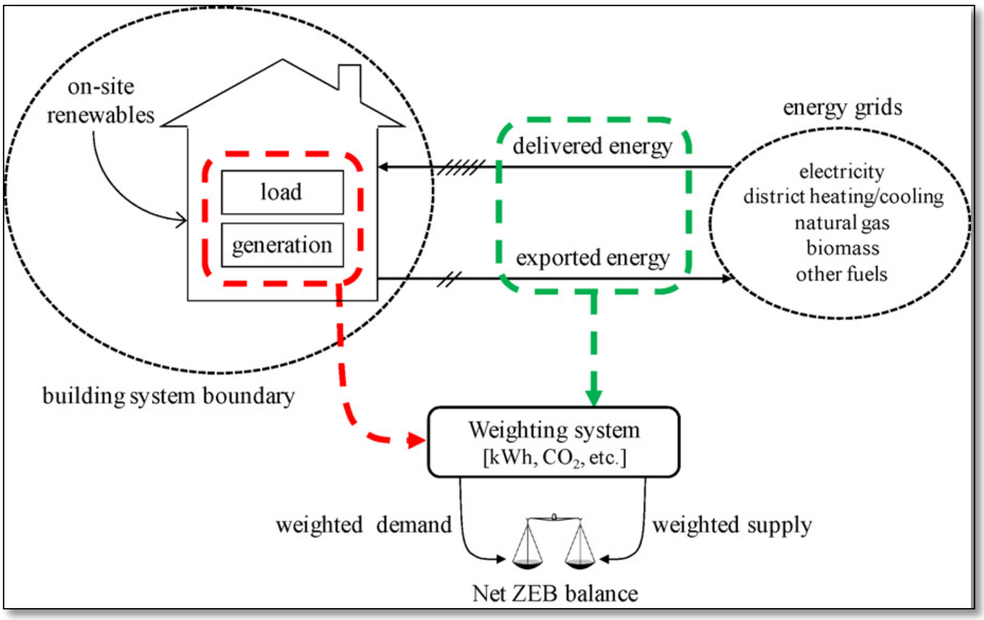


Fig (3-4): System structure and basic elements on nZEBs (Sartori et al., 2012)

3.4.1. RES and nZEBs:

The choice of which renewable energy system to be used must follow the results of the climate data analysis because each area has its own potential that shows which system is the most adequate. Solar radiation and wind data are usually the most basic data needed, although PV and solar thermal systems play a central role in nZEBs in general. (Attia, Hamdy, O'Brien, & Carlucci, 2013) In some cases where the wind power shows a significant potential, and where a suitable field is available, small wind turbines could be installed. Since this study is dedicated to existing buildings in Egypt, then this option is not tackled, due to the rareness of appropriate fields attached to existing buildings, and at the same time, due to the abundance of solar energy in Egypt.

3.5. nZEB Applications

3.5.1. nZEB Globally:

Literature considering case studies from all over the world analyze the possibility of applying the nZEB concept in different areas according to specific climate data of the country. For example in the Zero Energy House in Denmark the authors state that 'Zero Energy House is dimensioned to be self-sufficient in space heating and hot-water supply during normal climatic conditions in Denmark.'(Esbensen & Korsgaard, 1977). Another literature considering UK discusses a case study that demonstrates that it's possible to achieve the zero energy homes in the UK. (Wang et al., 2009)

In New England Thomas & Duffy (2013) conducted a research on 10 case studies and the results showed that all the studied nZEBs achieved at least half the electricity consumption of a control house and six out of ten nZEBs achieved net-zero energy or better and they proposed a quantifiable evidence in support of increasing energy conservation requirements and renewable energy incentives in residential building codes of New England. Another study scoping a wider range; Mediterranean climate, rather than a single country, stated that the performed calculations and analysis of the case study show that achieving zero energy and zero on-site CO2 emission houses in this area is a doable goal.(Ferrante & Cascella, 2011)

3.5.2. nZEB Feasibility:

Other studies tackled a more general approach and addressed the possibility of building nZEBs efficiently in an affordable manner in cold climates in general, or the possibility of achieving nZEB without having to change the most common building shapes.(Wang et al., 2009)(Szalay & Zöld, 2014) Detailed case studies' analysis will be elaborated further in the research. An interesting approach was adopted by Berry et al. (2014) when the authors explored nZEBs from the perspective of building users where they used interviews with households and energy consumption monitoring for a case study in south Australia. It was evident that users felt more thermally comfortable, assured that energy saving was achieved, and were comfortable with the energy technologies in their nZEB buildings.

3.6. Retrofit of Existing Buildings to nZEBs

Building retrofit may include various aspects like aesthetic or structural aspects, but these forms of retrofit does not contribute to converting the building into a green one. The type of retrofit that will be focused on is the energy retrofit, tackling both sides: energy consumption and energy generation.

3.6.1. Data Gathering:

The first step of retrofitting an existing building is basically the building performance analysis, because this will define the amount of renovation the building needs and identifies the areas of inefficiency. Consequently, the building performance data collection comes first, as Tianzhen Hong, Yang, Hill, & Feng (2014) stated, the three types of data that need to be collected are as follows:

- Energy use data that include whole building total energy use as well as major energy end uses, a seen in fig (3-5).
- Operating data of HVAC systems because it represents a significant portion of the overall energy consumption of any building.
- Indoor and outdoor environmental data like air temperature, air humidity, CO2 level, luminance level, noise level because these factors directly affects the thermal comfort as well as the environmental air quality inside the building.

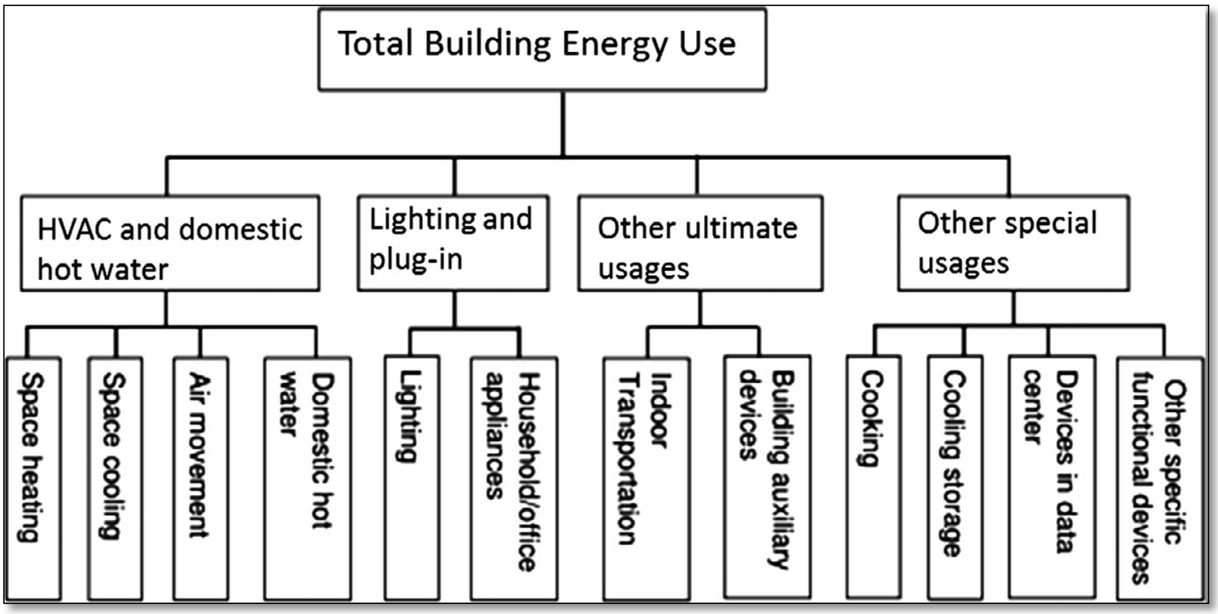


Fig (3-5): Total building energy use (Tianzhen Hong et al., 2014)

3.6.2. Data Analysis:

After data collection phase comes the data analysis phase, where building performance analytics take place. In studies focusing on the data analytics Tianzhen Hong et al. (2014) and Ma, Cooper, Daly, & Ledo (2012) stated three levels of analytics to be followed in order to help building managers qualify and quantify the building's energy performance. The three consecutive levels are Energy profiling, then Energy benchmarking, then the last level would be energy diagnostics.

- Energy profiling: each building is considered on individual basis and the energy consumption is measured on different time scales; daily, weekly, monthly and annually.
- Energy benchmarking: A good example of a benchmarking tool is a rating system like LEED or Energy Star Portfolio Manager. This approach identifies the energy saving potential of the building through comparing it to similar buildings in the database.
- Energy diagnostics: Detecting the inefficiencies within different building energy systems or components –based on the first two levels results- and proposing a way to enhance them.

3.6.3. Implementation, Commissioning and Verification:

On-site implementation of the chosen retrofit strategies then testing and commissioning will be done to confirm that the systems are well installed and operating as designed. Verification is the final step that takes place through post measurements that verify the energy savings as well as post occupancy surveys to measure the occupants and owners satisfaction.

3.6.4. Building Retrofit Technologies:

To implement building retrofit strategies some technologies are needed, to summarize the possible technologies that could be used in building retrofit, Ma et al. (2012) categorized these technologies in three categories: Demand side management technologies, supply side management technologies and energy consumption patterns. Fig (3-6) shows a breakdown of such technologies by describing the demand side management technologies into two major parts: heating and cooling demand reduction, and energy efficient equipment and low energy technologies. On the other hand, the energy consumption pattern was denoted as human factors because the consumption level is basically determined by the users' behavior. In the last category -the supply side management- the different renewable energy systems and electrical retrofits are stated.

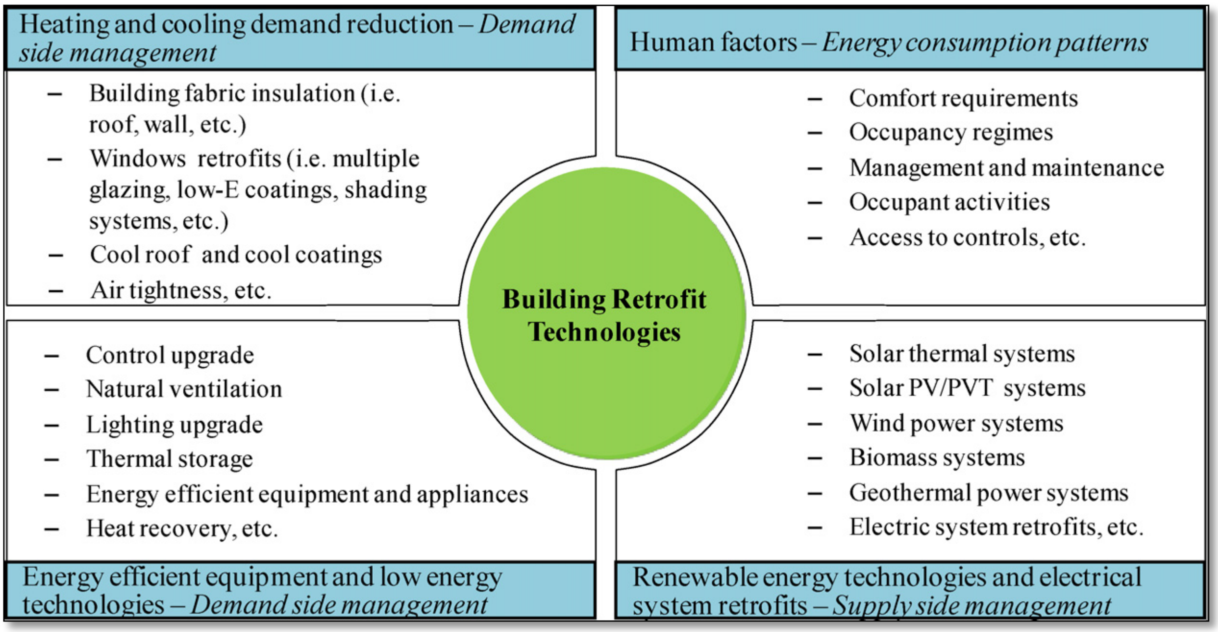


Fig (3-6): Building retrofit technologies (Ma et al., 2012)

3.6.5. Retrofit Technology Analysis:

Some literature provided a pros and cons study that would assess different alternatives of the possible retrofit actions. The study done by Sauchelli, Masera, D'Antona, & Manzolini (2014) summarized the outcomes of the analyses done within a project of retrofitting an old school in Italy to net zero-energy building as follows in table (3-2) and table (3-3) where the first one discusses the alternatives for glazed facades and the second one discusses the opaque ones.

Strategy	Pros	Cons
Additional external glazed façade	_Reduction of thermal bridges _Preservation of the original building envelope (existing windows and exposed concrete) and its protection _Potential greenhouse effect to improve the passive energy behavior _Possible integration of solar shading devices	_Potential alteration of the appearance of the building _Need to refurbish also the existing damaged windows _Possible structural problem related to the unknown residual structural resistance of the existing structure (new loads applied)
Additional internal double glazed window	_Reduction of thermal bridges (thermal insulation around the new cavity) _Preservation of the existing windows and of the overall external aesthetic aspect of the building _ Potential greenhouse effect to improve the passive energy behavior; _Possible integration of solar shading	_Reduction of classrooms net floor area _Need to refurbish also the existing damaged windows _Need to protect and treat the existing façade in exposed concrete

	devices	
Replacement of all the windows with new high performance and thermally insulated windows	_Minimal aesthetic impact (especially with innovative high performance small section aluminum profile) _No need to refurbish existing windows _Limited cost if innovative aluminum frame windows are adopted	_Difficult reduction of thermal bridges _Need to protect and treat the existing façade in exposed concrete _Need to define a position for the solar shading devices

Table (3-2): Investigated alternatives for glazed façade (Sauchelli et al., 2014)

Strategy	Pros	Cons
Internal thermal insulation	_Improvement of the internal acoustic _Preservation of the external aspect of the façade _Easy to realize (no external special scaffoldings due to the complex shape of the building)	_Difficulties in thermal bridges resolution _Need to protect and treat the existing façade in exposed concrete _Reduction of the internal net floor area
External thermal insulation	_Reduction and resolution of most of the thermal bridges _No reduction of internal net floor area	_Need of “out of shape” scaffoldings with complex geometries _Change of the external appearance of the building
Roofs external thermal insulation	_Improvement of roofs thermal performances _No reduction of internal net	NA

	area _Reduction and resolution of most of the thermal bridges	

Table (3-3): Investigated alternatives for opaque façade (Sauchelli et al., 2014)

The comparison between the three approaches of the glazed façade show a balanced set of pros and cons, the decision would depend on the given situation of each project uniquely. Only one disadvantage of the third alternative might make a difference: replacement of the whole window structure, because it is a costly solution compared to the other solutions. On the other hand, the opaque façade alternatives provide a standard solution: roof insulation that showed no cons at all while the other two alternatives have great discrepancies and the decision depends also on the status of the project.

A more specific in depth analysis is provided by Asadi, Da Silva, Antunes, & Dias (2012) that addresses specific materials comparisons in terms of physical properties and thermal performance. The following tables (3-4) and (3-5) show external wall insulation materials and roof insulation materials respectively.

Insulation Type	Thickness (m)	Thermal Conductivity (W/m◦C)
Stone wool	0.03	0.034
Glass wool	0.05	0.038
EPS (expanded polystyrene)	0.03	0.036
Sprayed polyurethane	0.02	0.042
Cork	0.01	0.04

Table (3-4): Characteristics of alternative external wall insulation materials (Asadi et al., 2012)

Insulation Type	Thickness (m)	Thermal Conductivity (W/m◦C)
Sprayed polyurethane	0.02	0.042
EPS (expanded polystyrene)	0.03	0.033
XPS (extruded polystyrene)	0.04	0.034
Stone wool	0.065	0.037

Table (3-5): Characteristics of alternative roof insulation materials (Asadi et al., 2012)

The provided study gives a handy comparison between different insulating materials used in the energy enhancing process of the retrofit in order to simplify the decision making process for the stakeholders of the project.

3.6.6. nZEBs in Egypt:

Although the Egyptian national energy strategy has no reference of net Zero-Energy Buildings, still it has a more generic strategy towards a greener environment. In Feb 2008 a target was established that aimed at increasing the amount of electricity generated from renewable resources to 20% of the total electricity demand by 2020. In 2012 the total electricity consumption reached 29.3 GW of which 3.4 generated from renewable resources, representing 11.6%. (Rcreee, 2012) Since Egypt is in a critical need of decreasing the electricity demand, and with considering the previously mentioned renewable energy goal, then the nZEB solution seems to fit perfectly. However, if considering nZEBs not energy efficiency in general, then no literature provides any data about existing nZEBs in Egypt, and only a small number of research tackle the subject.

An interesting recent study has analyzed different scenarios of nZEBs in Borg El Arab city. (Reda et al., 2015) The study provides two building scenarios: Low investment scenario (LIS) and High investment scenario (HIS) and both were compared to a benchmark scenario that represents the minimum requirements of the Egyptian Energy codes, it was called Business as usual scenario (BaU). The first scenario does not include renewable energy applications because it provides a low investment option, so it includes some envelope solutions and system technologies to reduce the energy usage. The energy savings for this scenario reached half the consumption of the reference case. While the second scenario is more costly, it resembles a complete strategy of nZEBs because it beholds both the energy reduction aspect and the renewable energy aspects. For this scenario energy reached 5% of the reference case and reached zero energy when the size of PV panels increased.

The research had followed a methodology similar to the one previously discussed in the literature review. It determined three basic phases: phase one was the investigation phase. The behavioral patterns of the occupants and its implication on the energy usage was conducted as a survey. Phase two was energy assessment phase where cost effective systems and building envelope solutions were provided by the help of stakeholders, local authorities and market key players. The final phase was the energy analysis that included the three scenarios: BaU, LIS and HIS using data from the master plan of the city. Dynamic simulation modeling tools -TRNSYS and TRNBuild- were used in order to assess energy production and consumption while including PV and solar thermal systems, as well as determining the energy needs of the building. This is why the study is considered a simulation-survey based energy assessment.

Three building models were built as case studies for simulation, each model with different features according to the scenario it represents. Different types of system technologies and enevelope solutions were used for every scenario as selected by local stakeholders, authorities, and market key players. Those sysem technologies along with the thermal properties of the envelope, internal loads of occupants, appliances and lighting was assigned to every building model in the TRNSYS system model.

The results show the final energy balance that defines the LIS scenario (final energy balance= 3043.3 kWh) as an energy efficient building compared to the BaU scenario (final energy balance = 4750.6 kWh), while HISa is an efficient building that generates clean energy at the same time (final energy balance=1207.4 kWh). The particularly interesting results were of HISb that resembled a zero-energy building (final energy balance=114.4 kWh) and HISc that ended up as a net energy-plus building because the PV array generates even more electricity than the amount needed by the building (final energy balance=−578 kWh).

The study proves that energy efficient buildings could be built in the Egyptian climate and context if the building envelope and the overall insulation were designed to decrease the building’s energy demand. At the same time it proved the net zero energy buildings potential for new buildings in Egypt. The study's results are promising but are dedicated to new building's design, this is why the scope of this research will be considered a calibration of this study to fit existing buildings rather than new ones.

Conclusion of chapter III:

As the nZEB is a part of the hypothesis, so this chapter started with the different definitions of the net zero energy buildings in the literature in order to familiarize the reader with the concept. It then moved to the methodology of nZEBs that directed the path towards the two basic aspects of nZEBs: energy efficiency and renewable energy generation. Each of these aspects was discussed showing their importance and the guidelines for implementation. Then, extrapolating the previous research outcomes with the same scope of research discussing the two strategies together: the retrofit and the nZEBs, reviewing the different strategies and the nZEB in Egypt.

CHAPTER FOUR: CASE STUDIES ON VARIOUS BUILDING TYPES

4.1. Worldwide Case Studies

Analysing case studies of projects that have already been implemented is beneficial in terms of acquiring experience, proving the feasibility of the approach and testing the effectiveness of the proposed strategies. Using the exact figures for the amounts of energy saved is useful in measuring the retrofit actions efficiency, while the figures for the amount of energy generated from the renewable energy systems gives some guidelines to the energy generation design phase. The overview of the cases in general gives a solid feedback on how to perform in future projects.

The European commission had an integrated project called BRITA in PuBs (Bringing Retrofit Innovation to Action in Public Buildings) that aims at promoting for retrofit solutions in the market to enhance the buildings' energy performance and integrate renewable solutions with reasonable economics. The project used eight demonstration buildings as case studies from different areas in Europe: North, Central, South and East as shown in figure (4-1) (Bringing Retrofit Innovation to Application in Public Buildings, 2009). A review on six these projects as analysed by (Ardente, Beccali, Cellura, & Mistretta, 2011) will be provided to help understand the retrofit process practically. Similarly, a residential case study analysed by Voss, Karsten, Musall, & Eike (2012) is reviewed to cover the residential building type.

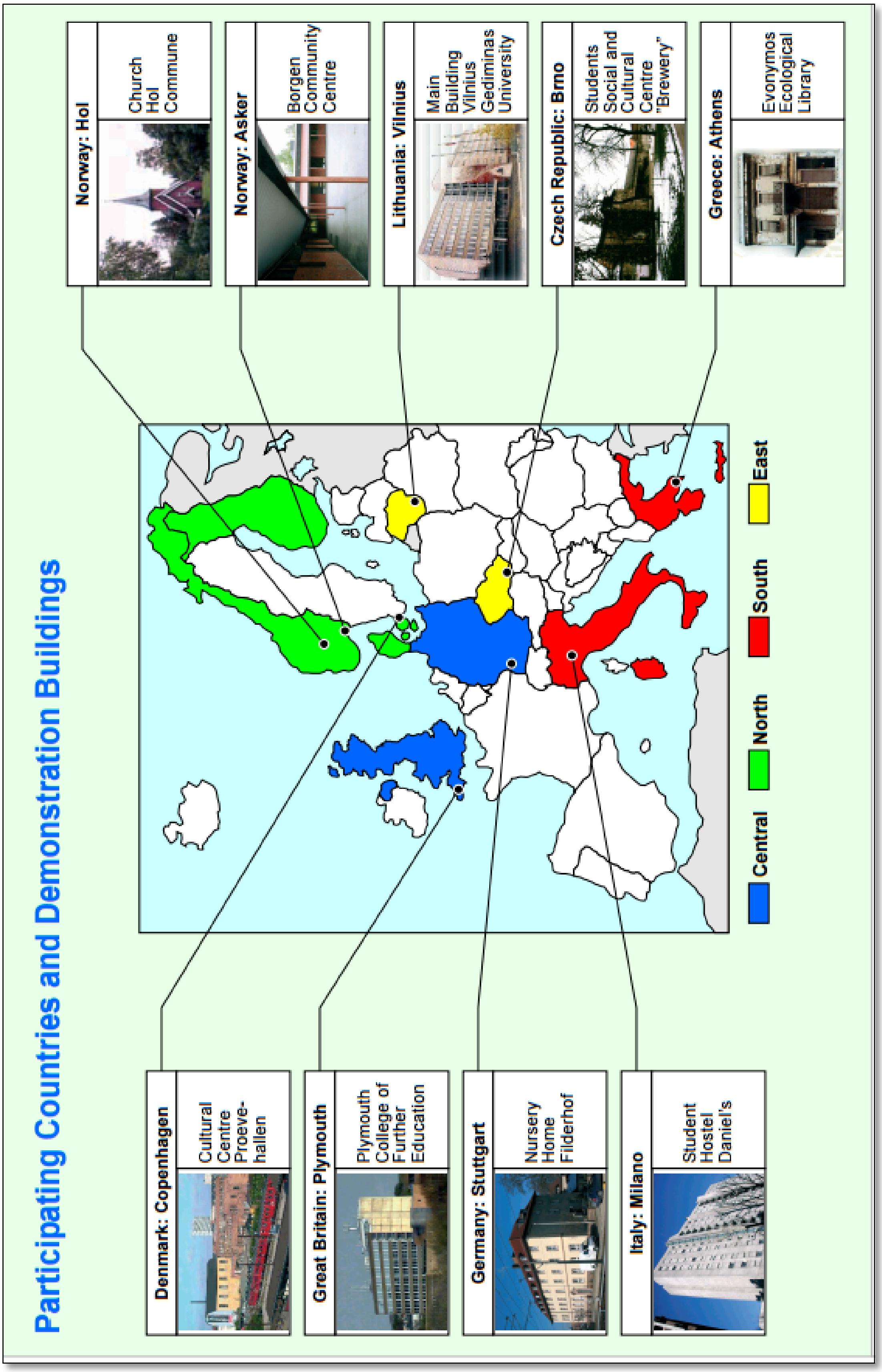


Fig (4-1): BRITA project map (BRITA in PuBs, 2008)

4.1.1. Case Study: Brno University, Guest House, Czech Republic:

Figure (4-2): Brno university, before and after (BRITA in PuBs, 2008)

Total Floor Area: 2660 m2

Main Problems: no usable heating system, naturally ventilated but with no enough openings.

Retrofit Actions and Saved Energy:

- Renovating the building envelope with new thermal insulation: mineral wool boards of 100 mm for the façade and the roof, and with 60 mm polystyrene boards for the ground floor to save 126 MJ/(m2 year)
- High-efficiency windows to reduce the thermal losses and the lighting need: installation of low-e windows that saved 123 MJ/ (m2 year).
- Installation of PV panels and of high-efficiency technology for heating and ventilation. Contributed to primary energy saving with 443 GJ/year,
- High-efficiency HVAC system involved a yearly electricity saving of 14 GJ/year

Yearly total primary energy savings: 586 GJ/year

4.1.2. Case Study: Hol Church, Norway:

Figure (4-3): Hol church, before and after (BRITA in PuBs, 2008)

Total Floor Area: 555 m2

Main Problems: The retrofit was performed on an ancient Norwegian timber church.

Retrofit Actions and Saved Energy:

- Renovation of the building roof and under floor, by means of new thermal rock wool insulation. Saving 246 GJ/year.
- High-efficiency windows to reduce the thermal losses and the lighting needed.
- Installation of PV panels and of a solar thermal system saved 1.5 GJ/year, and solar thermal systems saved 9 GJ/year.
- Introduction of efficient lighting. 50 GJ/year.

Yearly total primary energy savings: 8612 GJ/year

4.1.3. Case Study: Plymouth College of Further Education, United Kingdom:

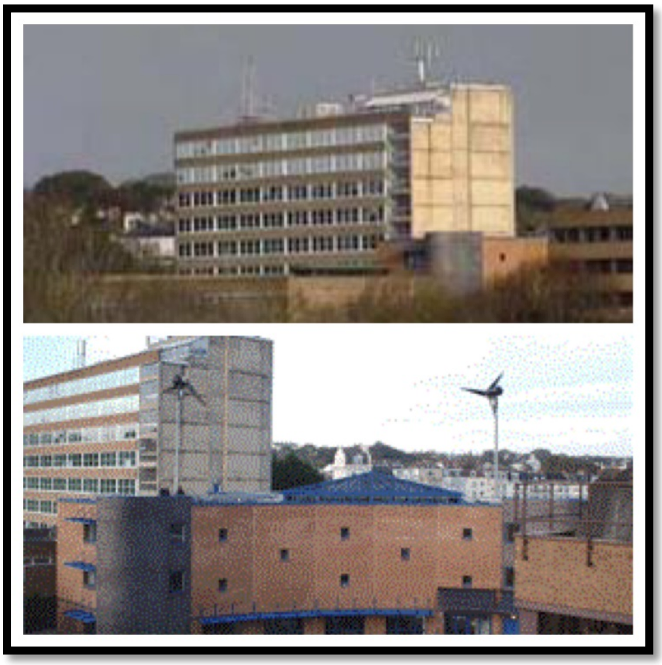


Figure (4-4): Plymouth College, before and after (BRITA in PuBs, 2008)

Total Floor Area: 5794 m2

Main Problems: The existing building had simple50-mm cavity wall construction with no insulation, single glazed windows, and external facades had poor state of repair.

Retrofit Actions and Saved Energy:

- Modifications for heating, cooling and lighting control, solar glare control, and thermal gains reduction were designed but not yet realised.
- Installation of two 6-kW wind turbines on the roof of the building.

Yearly total primary energy savings: 143 GJ/year.

4.1.4. Case Study: Cultural Centre, Prøvehallen, Denmark:

Figure (4-5): Cultural centre, before and after (BRITA in PuBs, 2008)

Total Floor Area: 2300 m2

Main Problems: Had not been used for a number of years, minimal construction with no insulation in the walls and simple single glass metal frame windows.

Retrofit Actions and Saved Energy:

- Reduction of the envelope thermal transmittance by facade and roof insulation using mineral wool boards that saved 65 GJ/ (year).
- Installation of high-efficiency windows saved 86 GJ/ (year).
- Installation of a PV plant and a PV/T solar collector, which is cooled by a heat pump to increase the efficiency of the PVs saving 302 GJ/year.
- Installation of a high-efficiency HVAC system that saved 2113 GJ/year.

Yearly total primary energy savings: 192 GJ/year

4.1.5. Case Study: Nursing Home, Germany:

Figure (4-6): Nursing home, before and after (BRITA in PuBs, 2008)

Total Floor Area: 2131 m2

Main Problems: Heating system had an old measurement control system, boiler system did not work very efficiently, no mechanical ventilation system was installed, and lighting system did not work efficiently.

Retrofit Actions and Saved Energy:

- Wall insulation with mineral-fibre wool that saved 352 MJ/ (m2 year).
- Installation of high performance windows with triple glasses with a U-value of 1W/ (m2 K) and thermal spacers to reduce the thermal bridges at the edges, saved 127MJ/ (m2 year).
- Installation of a PV system with a yearly production of 12.6 kWh/y saving 81 MJ/ (m2 year).
- Installation of thermal solar plant to provide 32% of the domestic hot water demand saving 866 MJ/ (m2 year).
- Installation of a high-efficiency HVAC system that saved 841 MJ/ (m2 year).
- Installation of an efficient lighting system saved 163.6 MJ/ (m2 year).

Yearly total primary energy savings: 433 GJ/year.

4.1.6. Case Study: Vilnius Gediminas Technical University, Lithuania:

Figure (4-7): Technical University, before and after (BRITA in PuBs, 2008)

Total Floor Area: 8484 m2

Main Problems: Panels of the facades are pervious to moisture, thermal transmittance of the walls was 1.07 W/ (m2 K).

Retrofit Actions and Saved Energy:

- Replacement of old thermal insulation of the walls and installation of high thermal performance materials in the building envelope
- Renovation of the roof with the introduction of a waterproof layer, both of envelope retrofit saved 125 MJ/ (m2 year).
- Installation of high performance windows with low emissivity glasses and low thermal transmittance, saved 116 MJ/ (m2 year).

Yearly total primary energy savings: 1546 GJ/year.

4.1.7. Case Study: Blaue Heimat, Residential Building, Heidelberg:

Fig (4-8): Blue Heimat, before and after.(Voss et al., 2012)

Total Floor Area: 4689 m2

Main Problems: The existing building had very poor thermal insulation, single glazed windows, and outdated energy and warm water supply systems.

Retrofit Actions and Saved Energy:

- Installation of 20 cm thick thermal insulation to the solid external walls.
- Installation of 18 cm in-filled mineral wool insulation to the roof.
- Triple glazed windows with wooden or wooden-aluminium composite frames are used.
- PV array installed on part of the roof.

Yearly total primary energy savings: 98 kWh/m2.

The analysed case studies show buildings of different building types; university building, church, nursery, residential building, and of different current situations; old, deteriorated or having specific site or structural problems. However, all the case studies were retrofitted to an energy efficient building and a renewable energy system was installed to generate the rest of the electricity demand. The results of the yearly total energy savings for all cases show a great potential of existing building retrofit in different circumstances.

Conclusion of chapter IV:

The case study chapter comes near the end of the study to review case studies from different locations of the world, all already implemented projects and analysing the strategies executed and their efficiencies. Different building types were discussed and different retrofit actions and the amount of energy saved in each case.

CHAPTER FIVE: PROPOSED GUIDELINE AND ACTUAL CASE STUDY SIMULATION

5.1. Proposed Guideline

In this research a specific combination between two approaches: retrofitting approach and nZEB approach is proposed, this is the reason behind mixing the methodologies of the two approaches to generate the novel adequate methodology or guideline. By calibrating the previously mentioned strategies in the literature and then refining some changes, the hybrid guideline is proposed as seen in fig (5-1). (Taehoon Hong, Koo, Kim, & Seon Park, 2014) (Ma et al., 2012) (Attia, Gratia, et al., 2012) (Wang et al., 2009)

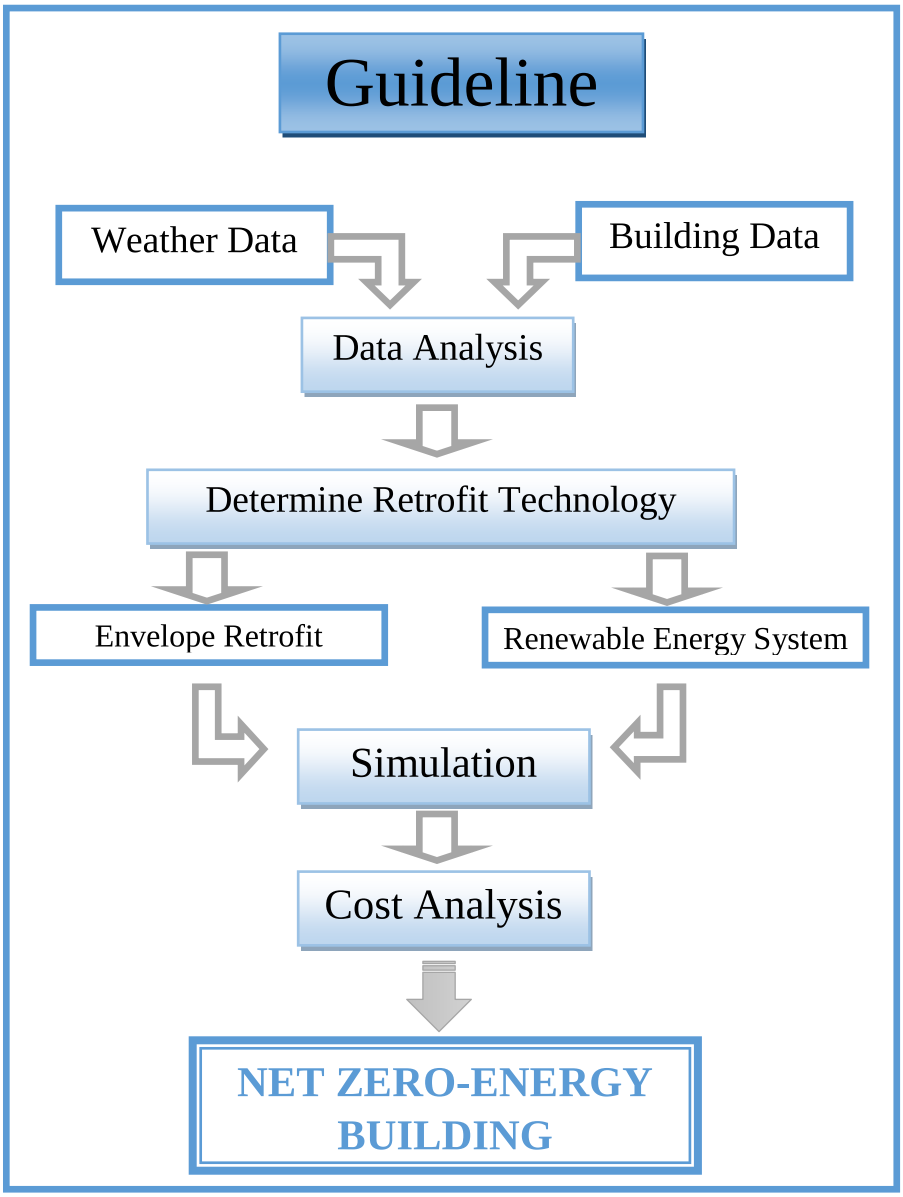


Fig (5-1): Proposed guideline

5.2. Methodology Application:

Implementation of the theoretical study on an existing project gives the chance to the study to develop from being an analytical research to a hands-on experiment. This research will utilize an actual residential building in Nasr City area as its case study. The building has certain energy performance level and needs a certain amount of electricity to perform. If the energy performance could be enhanced and the electricity could be generated through PV panels, then the building can be a zero-energy building.

The research will propose some changes to the envelope using market available products in order to enhance the energy performance of the building and decrease the amount of energy needed to the minimum. Similarly, it will provide the building with the optimum design solution for the panel's location, their quantity, as well as the pricing from the Egyptian market. The use of energy simulation program will determine the amount of energy saved by the retrofit actions and comparing it to the current values in order to verify the proposed methodology. The application of the guideline is detailed as follows:

5.2.1. Weather data:

Weather data is important because the renewable energy application will depend on the possible potential of the given location. The scope of the study will cover one type of renewable resources: solar PV panels, not only because solar energy represents the most abundant resource of renewable energy in Egypt, but also because it's the easiest type to be used and implemented by individuals without the need of governmental mega-scale projects. (Potential of solar thermal energy, 2015)

5.2.1.1. Weather data gathering:

Collecting the solar data for Cairo –the project location- will be the first step, and then analysing the data in order to have all the given for the decision making process. Based on data from the Egyptian Solar Radiation Atlas, the monthly average values of daily global solar radiation is stated in table (5-1). (Fayek, 2012) The results are drawn on fig (5-2) showing that the highest intensity values lie in the summer months while the lowest values are in the winter months.(Mosalam Shaltout, Hassan, & Fathy, 2001)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily radiation in kWh/m2/day	3.18	4.30	5.60	6.68	7.39	8.01	7.93	7.36	6.34	4.93	3.73	2.96

Table (5-1): Daily solar radiation (Fayek, 2012)

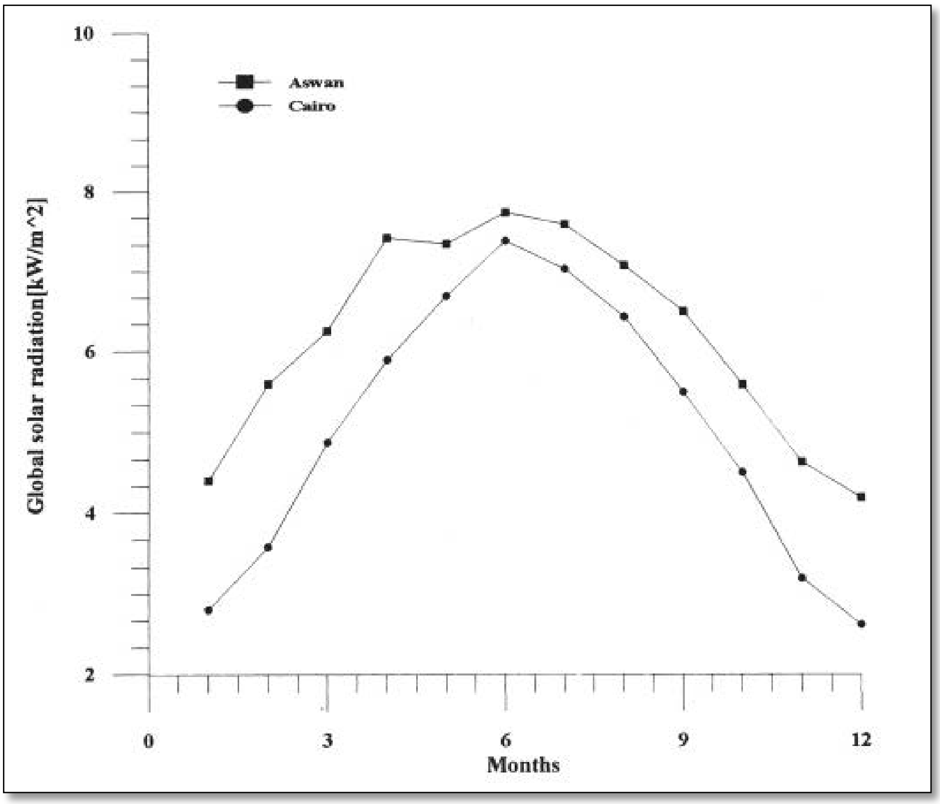


Fig (5-2): Global solar radiation (Mosalam Shaltout et al., 2001)

5.2.1.2. Weather data analysis:

Using the data gathered in the previous section, some analysis will be done in order to determine the best PV panel inclination angle, and the best type that would suit the Egyptian context. Based on a paper by Fayek (2012) that tested actual PV panels installed in Cairo for a whole year with different inclination angles (15 and 30 degrees) and concluded that the 30 degree inclination is optimum based on Cairo's meteorological data.

For the type of panel to be thin film, mono crystalline or poly crystalline will have a great influence on the amount of electricity generated. The same paper by Fayek (2012) discusses the difference between the three types and concluded that the poly crystalline type generates the largest amount of energy.

Fig (5-3) and (5-4) show the comparison between the two inclination angles and the three types of PV panels. Fig (5-3a) shows the results for a sunny day with tilt angel 15 degrees and fig (5-3b) shows a sunny day with tilt angel 30 degrees. While fig (5-4a) is a cold day with tilt angel 15 degrees and (5-4b) is when the tilt angle is changed to 30 degrees. Both figures show the three types of panels simultaneously.

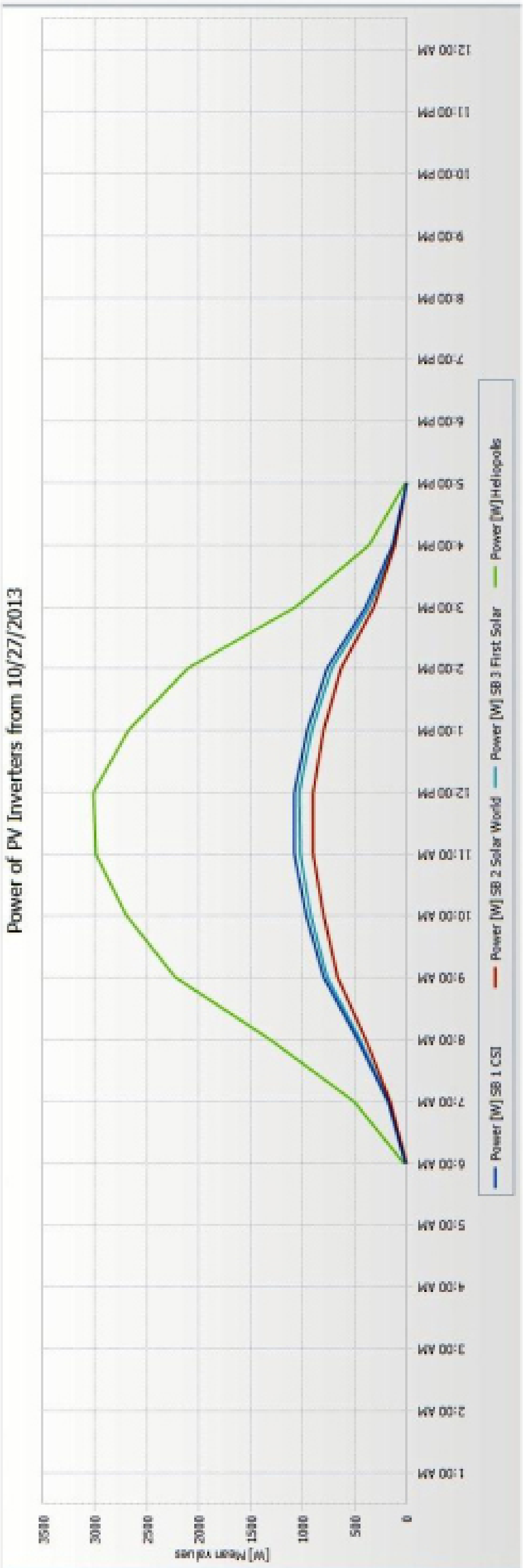
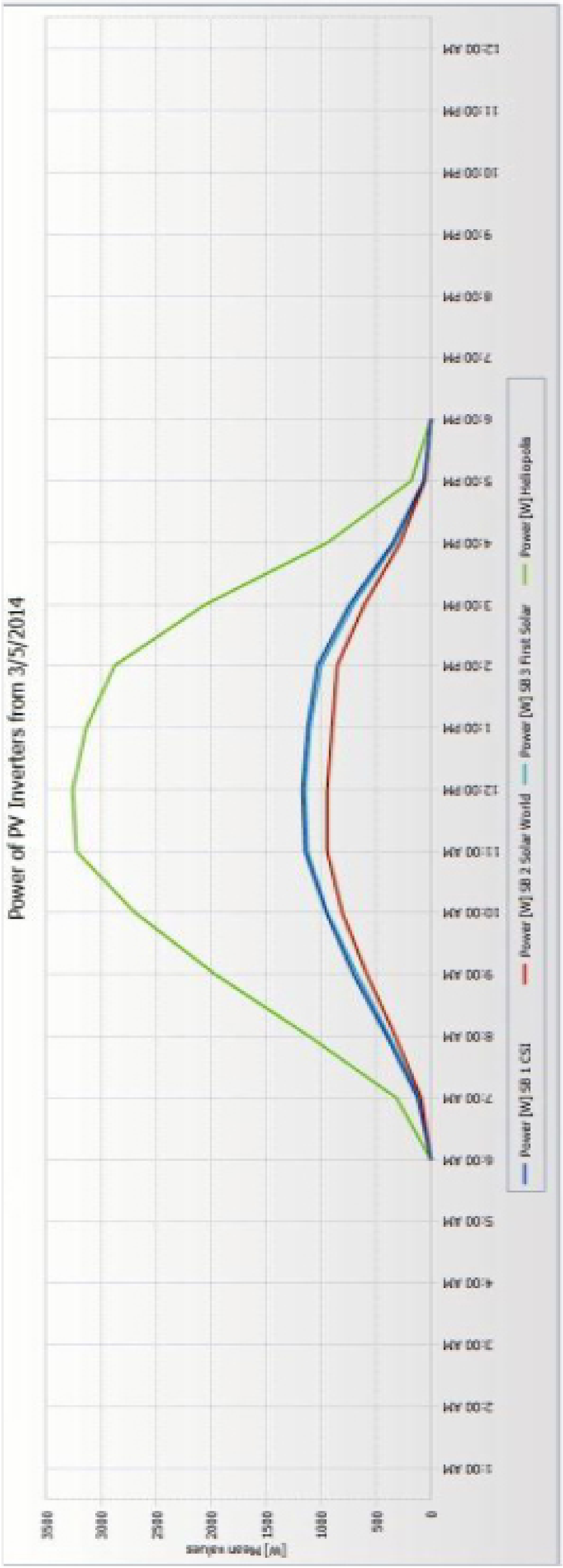
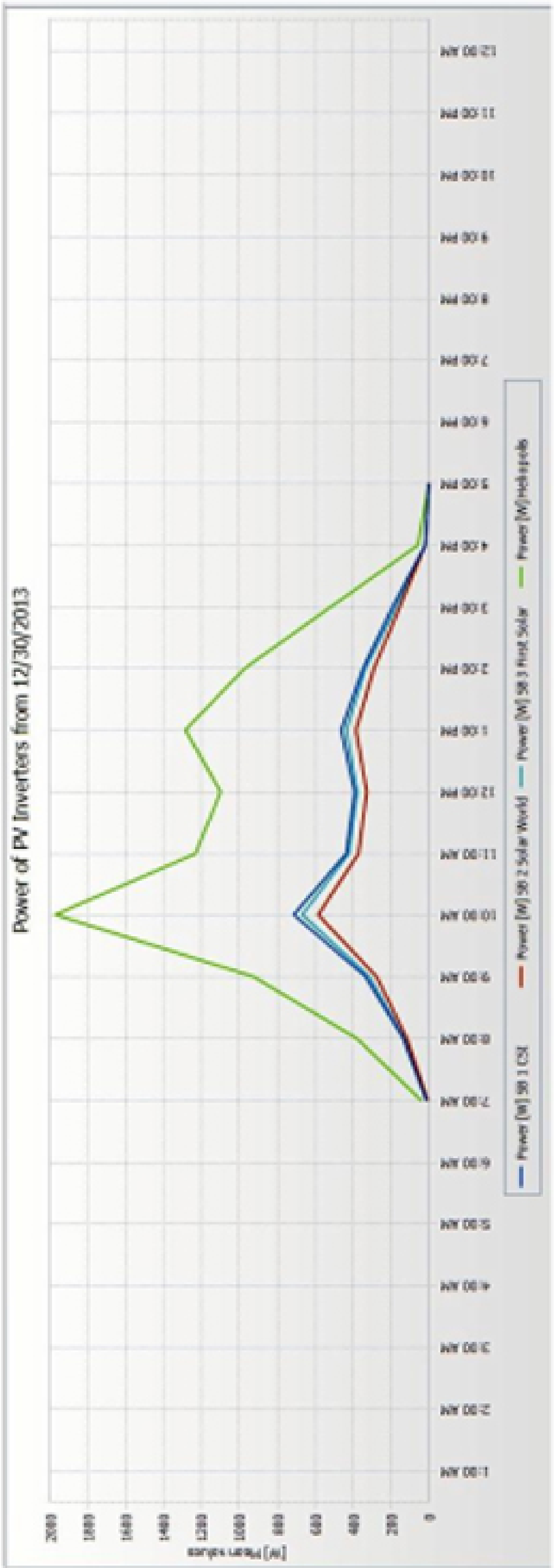


Fig (5-3a)



Fig(5-3b)

Electricity generation in a sunny day for 15 and 30 degrees (Fayek, 2012)



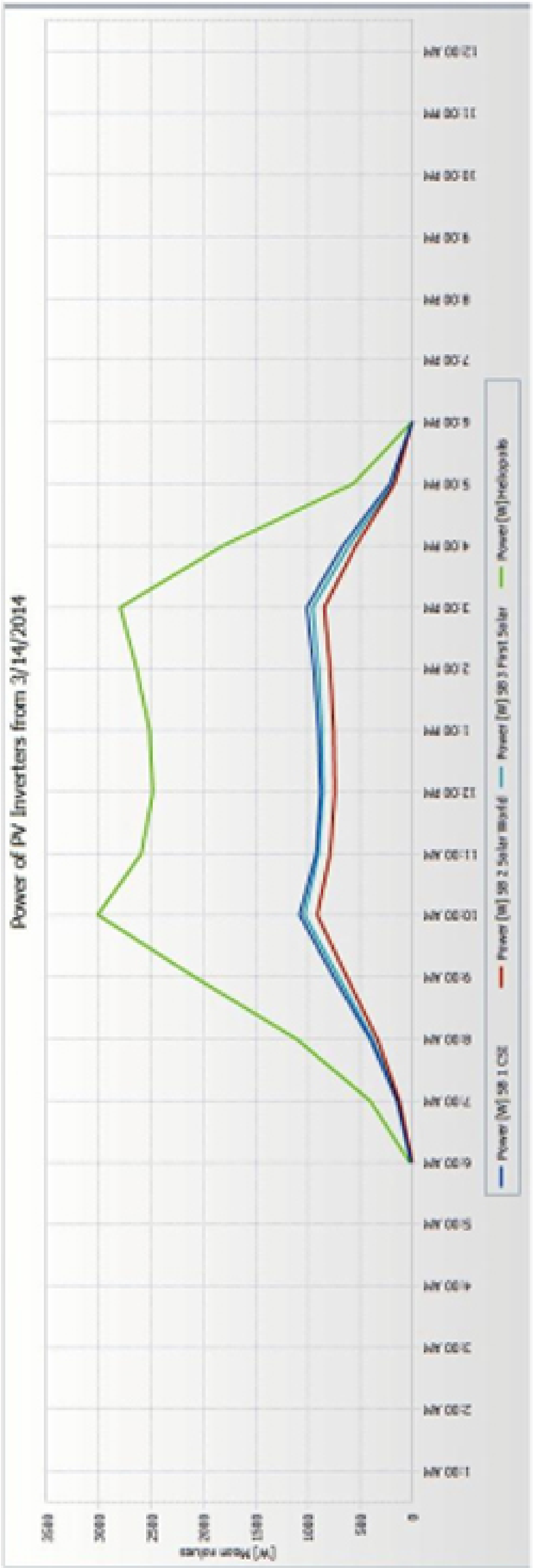


Fig (5-4a) **Fig (5-4b)**

Electricity generation in a cold day for 15 and 30 degrees (Fayek, 2012)

5.2.2. Building data:

To decide the adequate retrofit actions the building's current performance has to be evaluated, so the data gathering step must come first.

5.2.2.1. Building data gathering:

The case study building is a 5 storey residential building with two apartments per floor each of an approximate area of 140 m2 and total surface area of the building is 300 m2. The building has one staircase and one elevator acting as the core vertical circulation. The typical floor plan and 3d model for the prototype are as seen in figures (5-5) and (5-6) respectively. The building is located in an average residential community in Nasr City area with orientation North-South as seen in figures (5-7) and (5-8).

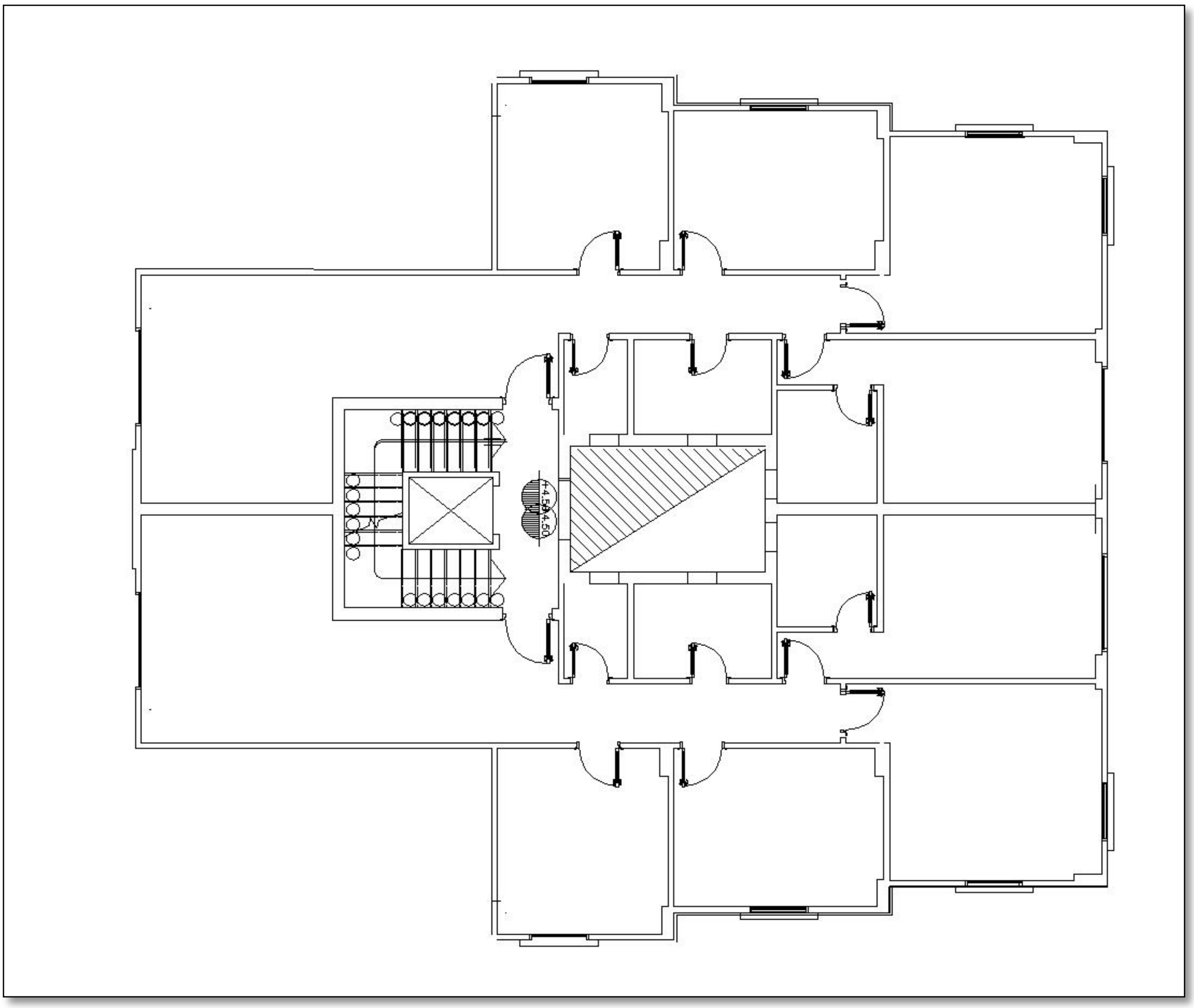


Fig (5-5): Typical floor plan for case study building

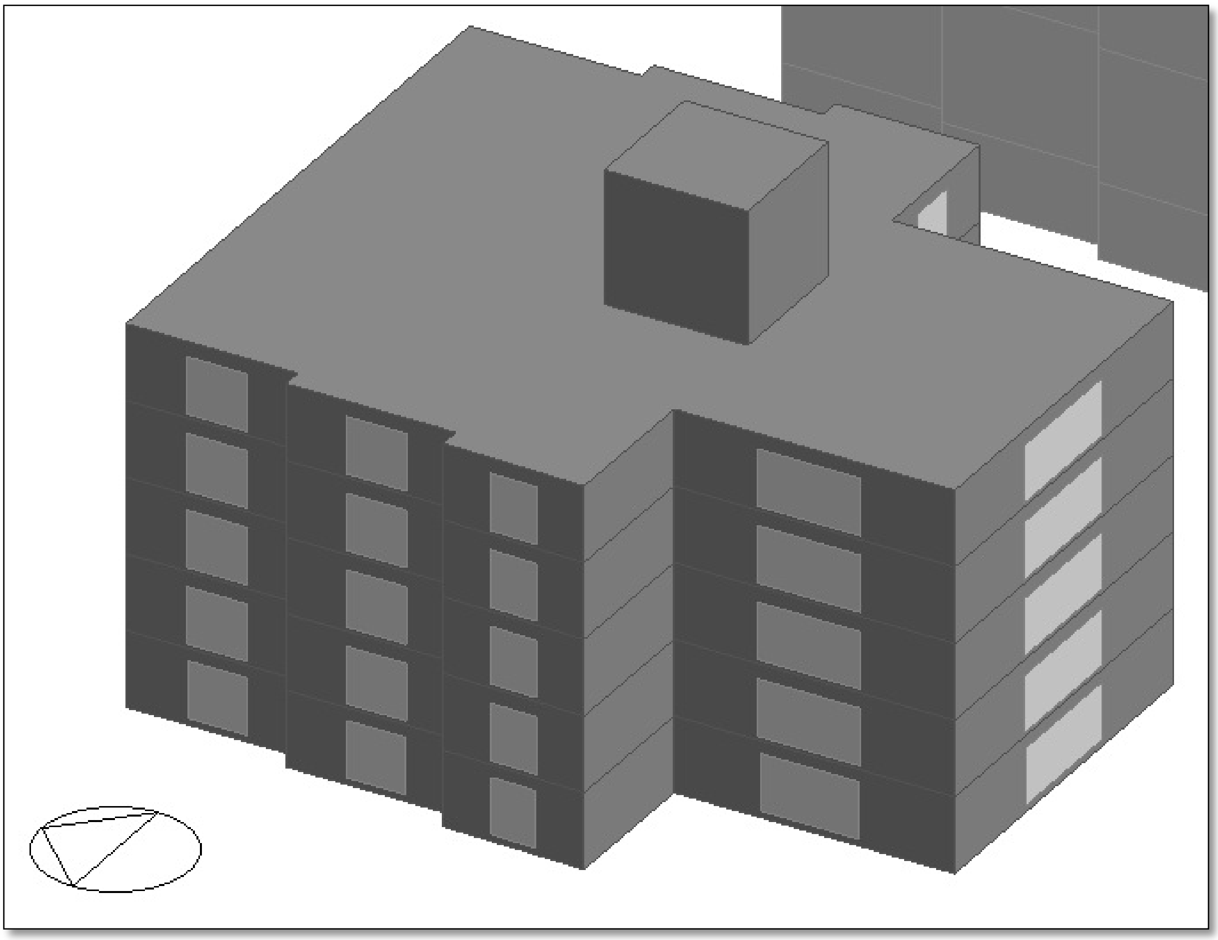


Fig (5-6): 3d model for simulation building

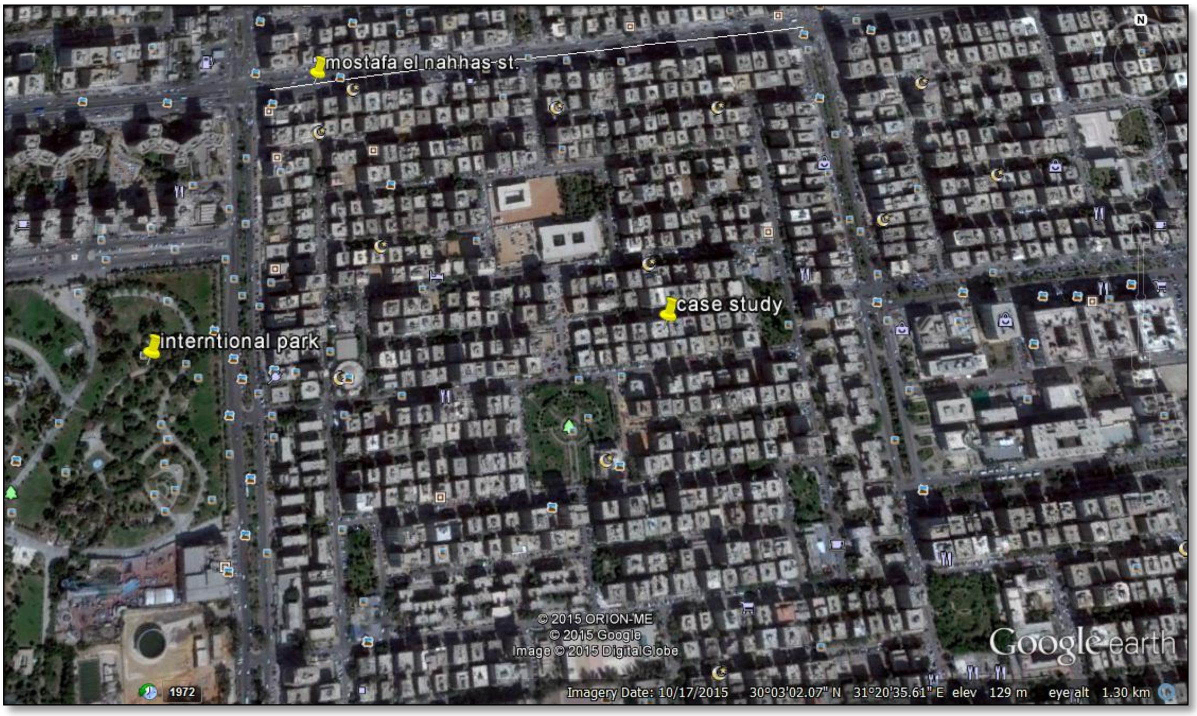


Fig (5-7): zoom-out location of the case study

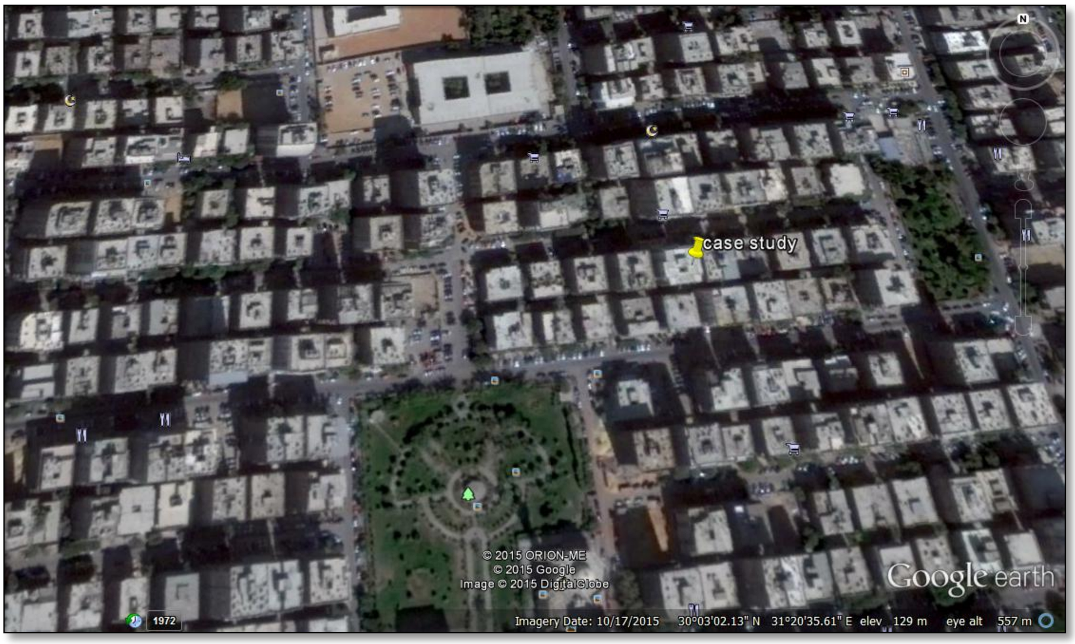


Fig (5-8): zoom-in location of the case study

The building's vertical envelope is a single wall of 25 cm thick bricks, having aluminium framed windows. No insulation is installed in the outside or the inside of the envelope. The roof layering is the finishing tiles, the waterproofing membrane, the thermal insulation, and then the concrete slab that is covered by pilaster from inside.

5.2.2.2. Building data analysis:

The most important data to be considered in this case is the energy consumption data because it has a direct impact on the amount of energy to be saved either through retrofit or to be generated by the renewable energy system. An average consumption monthly rates were detected as seen in fig (5-9) from the actual electricity bills of the case study building.

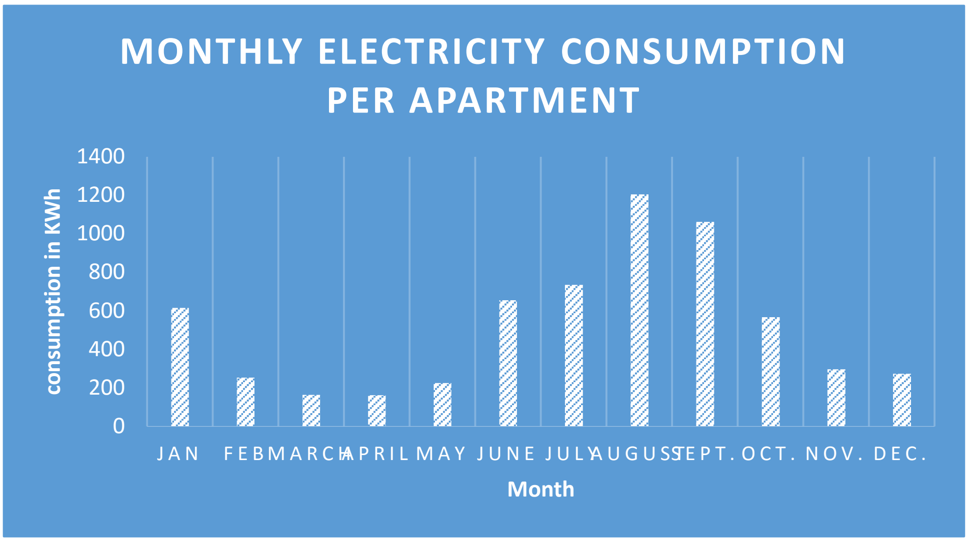


Fig (5-9): Monthly electricity consumption per apartment in the case study building - 2015

The total average electricity consumption per apartment is 6,206 kWh/year. In order to calculate the electricity consumption for the whole building, then the 10 apartments have to be considered: 62,060 kWh/year approximately 62,000 kWh/year.

By analysing the data provided in the previous section and through visual investigation, it was found that the building's energy performance can be categorized as poor due to the following:

- The building is only insulated by the traditional thermal insulation on the roof of the top floor –as provided by the owner.
- There is no shading over the windows to prevent direct sunlight from entering the interior space.
- The windows are single glazed.
- The windows are leaking, so the amount of heat energy transferred from the outside to the inside is significant.
- The HVAC system is split system not central, and mostly in a moderate condition.

5.2.3. Determining suitable retrofit technologies:

5.2.3.1. Envelope retrofit:

Based on the data analysis of the building's energy performance, the retrofit technologies that compensate for the inefficiencies of the current building status could be proposed as follows:

1. **Window Type:**

Before choosing the best window type, a comparison between different options was considered as follows:

Window type	Single	Double	Triple
U value (W/m2 K)	7.24	2.43	Not specified
Price (LE/m2)	700	1200	Not available
Best option		✔	

Table (5-2): Comparison between different window types (HBRC, 2006)

The single glazed window section is the already existing section in the current status, so if replaced with a new one the amount of energy saved will be negligible. The double glazed section saves a considerable amount of energy –according to simulation- and it is available in the market. The triple glazed section saves more energy than the double glazed, but it is not available in the Egyptian market.

Accordingly, the windows will be replaced with double glazed aluminium framed windows with clear glass. The window section is composed of 6mm glazing on each side, separated by 10mm air space as shown in fig (5-10). The total glazing area was calculated to be 120 m2, as every apartment has 6 windows: 4 (1.5x1) and 2 (2.5x1.5). So the total glazing area for one apartment is 12 m2, which equals 120m2 for the 10 apartments. Based on field research, the price of the previously mentioned window section ranges from 1100-1300 LE/m2.

Glazing area per apartment = 12 m2 (for 6 windows)	Glazing area for whole building = 120 m2	Price per m2 = 1200 LE

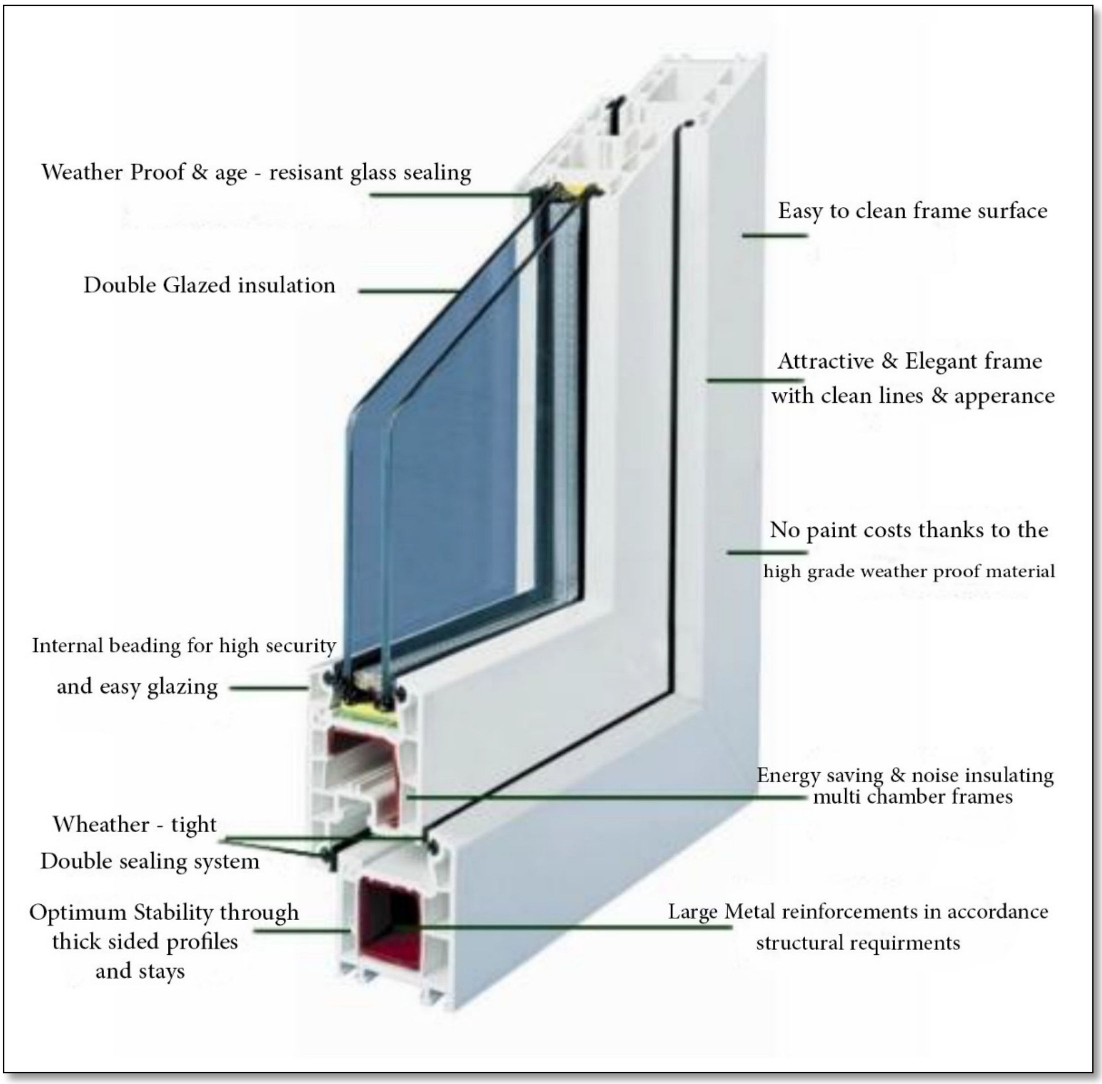


Fig (5-10): Double glazed window section (Window, 2015)

2. Window Coating:

There are different types of coating available, a comparison between the most appropriate types as stated by the manufacturer included the external reflection percentage of the film that represents the amount of privacy preserved for the users. (Films, 2015) Similarly the total solar energy rejected by the film is considered, and finally its price:

Film type	Silver 20	Prestige 70	Night vision 25
Exterior visible reflection	58%	9%	20%
TSER (total solar energy rejected)	77	50	60
Price (LE/m2)	268	582	361
Best option	✓		

Table (5-3): Comparison between different glass film types

Therefore, the windows will be protected using film coating as shown in fig (5-11). A transparent film used to coat the surface of the windows from the inside is suggested. This film's commercial name is silver p20 sun control, engineered by 3M Solar Films originated in UK. This film type is chosen not only for its low price and high amount of solar energy rejected, but also for its external reflective property that provides privacy for the users, which is favoured in the Egyptian society.

The amount of energy saved for every 100 square meters of glass retrofitted with energy-saving films, a building's energy needs is reduced by up to 10,600 kWh per year which is comparable to reducing its CO_2 emissions by about 9,500kg (IQue, 2015) (Films, 2015). These are the numbers given by the manufacturer, but in the actual case study, the simulation used the technical data of the chosen material as listed in the DesignBuilder program by its commercial name: 3M solar protection film.

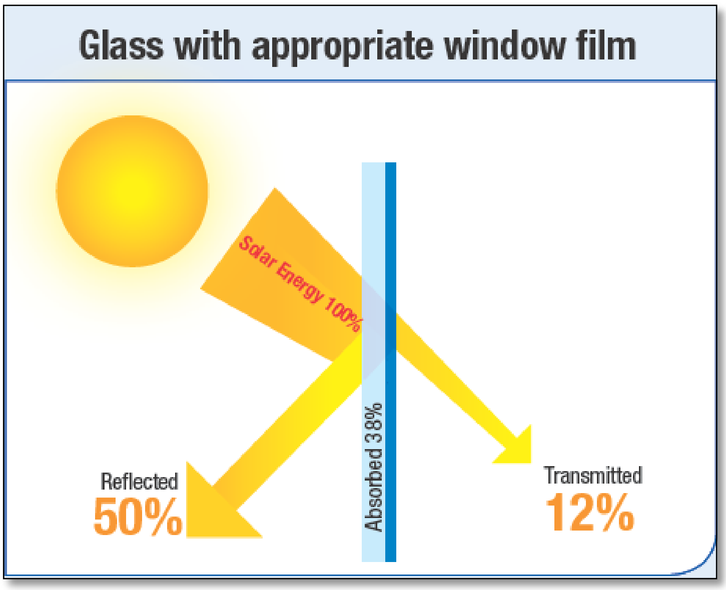


Fig (5-11): Glass coating film (Films, 2015)

The overall area to be covered by the film is calculated by subtracting the aluminium frame area from the previously calculated window's area. Knowing that the frame's thickness is 5 cm, then the net area of the glass is 102m2 for the whole building.

Total windows area = 120 m2

Total frame area = 18 m2

Net glazing area = 120 – 18 = 102 m2

Price = 268 LE/m2

3. **Wall Insulation:**

According to a study that compared different finishing materials with their U-values -a measure of the heat transmission through a given material with lower numbers indicating better insulating properties- the different cladding materials were compared in table (5-4). (Georgia, 2014) By adding the prices in the Egyptian market to the comparison chart, the next results were found:

Cladding type	Gypsum board	Marmox board	Wood cladding
U-value	0.6	0.19	0.34
Price (LE/m2)	100	95	500
Best option		✔	

Table (5-4): Comparison between different cladding options

The chosen option is compressed polystyrene thermal insulation boards (commercial name: Marmox board) available at CMB company. The material comes in the form of sheets (250x60cm) thickness ranges from (0.4 -10 cm) the chosen thickness is 2 cm. Available in blue and grey colours while other colours could be manufactured upon request, given that its applied to the inside of the building, it can be covered paint or wallpaper. Boards are installed using cement mortar, all the technical data and the detailed description of the material is available in the material's reference. (CMB, 2015b)

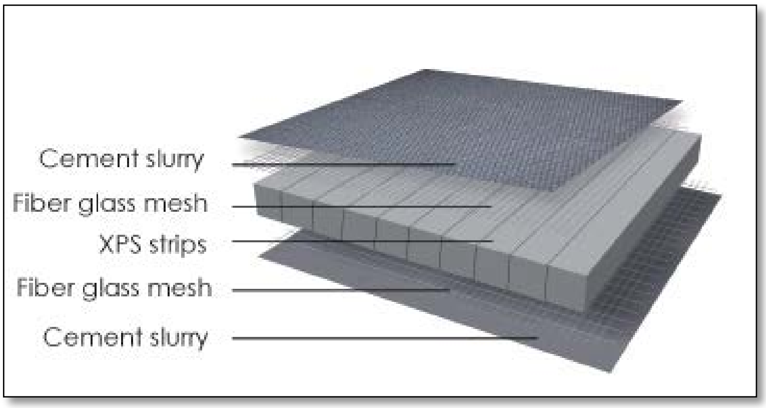


Fig (5-12): Marmox boards for wall insulation (CMB, 2015a)

To calculate the quantity of tiles needed for the wall cladding, the circumference of the building is multiplied to the total building height -assuming that the material will be installed on the outside of the building. The total area to be covered is 18x15= 1,275 m2 then the windows' area is subtracted to have the net area = 1,275- 120 = 1,115 m2. The price per m2 is 64.7 LE according to the supplier's offer.

Total building circumference = 1,275 m2

Total windows area = 120 m2

Net cladding area = 1,275 – 120 = 1,115 m2

Price = 264.7 LE/m2

4. **Roof Insulation:**

The most common insulation material for roofs in Egypt is the traditional foam sheets of which pricing ranges from 2500-3500 LE/m3 based on the thickness. The non-traditional material introduced here is thermal insulating tiles (commercial name: Tilefoam) available at CMB. A comparison between those two types is as follows:

Type	Traditional foam	Tilefoam
Price for 2.5 cm thick (LE/m2)	67.5	65
Installation process	Uninstall current floor finish, then install foam, then re-install floor	Can replace existing floor finish because it is

	finish	found in the form of tiles with final finishing.
Best option		✔

Table (5-5): Comparison between different roof insulation foam types

The tiles are 30x30 cm and thickness (2-5cm), its water absorption by submerging is negligible, and this is why it is suitable for rooftops. It is available in plain grey colour or patterns. Can be easily installed using cement mortar. All the needed data are found on the reference. (Tilefoam, 2015) This material is characterized by its high thermal resistance from what reflects on its energy saving potential as seen in table (5-6).

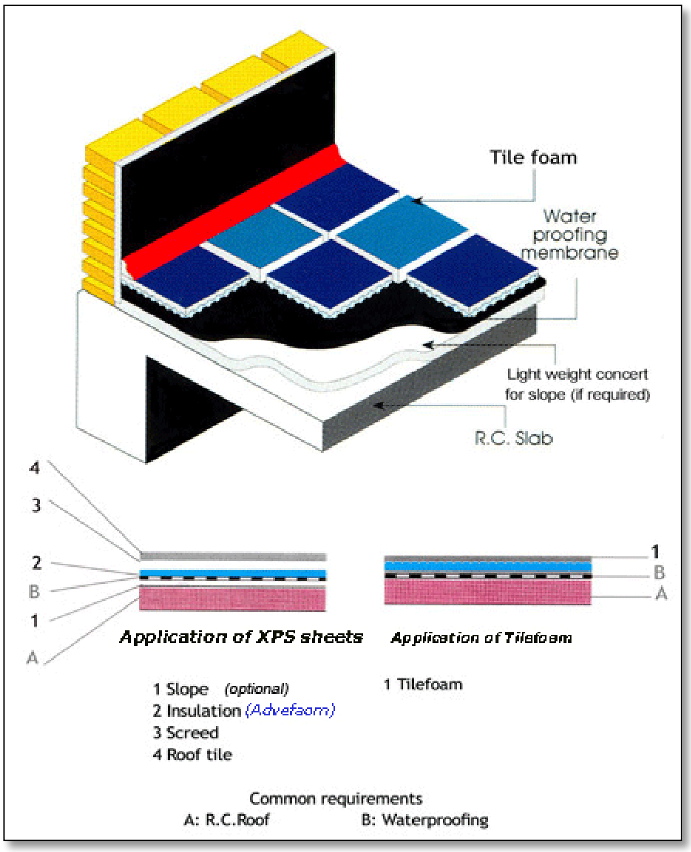
Thickness of foam layer (Advefoam) (cm)	% of energy saved
1 cm	47.1%
1.5 cm	57.0%
2 cm	63.7%
2.5 cm	68.7%
3 cm	72.4%

Table (5-6): Tilefoam energy saving percentages (Tilefoam, 2015)

The simple installation instructions and the calibration potential for the tiles to be installed on the roof makes this material an appropriate choice for the roof insulation. Figure (5-13) shows the installation method and the rain water outlet. The overall area of the roof to be covered by the tilefoam is calculated to be 309 m2 after subtracting the stair room. The market price for the Tilefoam is 65 LE/m2 from CMB.

Net roof area = 309 m2

Price = 65 LE/m2



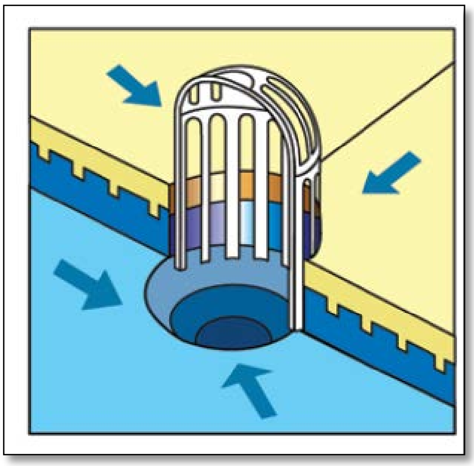


Fig (5-13): Tilefoam installation method and roof water outlet (Tilefoam, 2015)

5. **Electrical Appliances: HVAC, lighting, and electric appliances:** since these appliances are individually installed and its consumption depends on the users' behaviour and level of awareness, then it will not be included as a retrofit action. It was mentioned in order to give further recommendations if needed.

5.2.3.2. Implementation, Commissioning and Verification:

At this stage the retrofit selected actions are to be performed in the site of concern, then commissioning takes place to make sure that all the systems are correctly installed according to the specs. Then the verification step is meant to test the changes done. This stage is mentioned to reserve the sequence of the guideline, while it will not be practically implemented for this simulation-based case study.

5.2.4. Determining Suitable Renewable Energy Technology:

5.2.4.1. System selection:

In this case study, only one type of renewable energy is considered in order for the study to be able to cover all the aspects of this type. The chosen system will be solar photo-voltaic panels, in the following section the exact design and implementation steps will be discussed.

5.2.4.2. System design:

A. Design basic data:

- Location: Nasr City, Cairo, Egypt
- Global Horizontal irradiance GHI: annual average = 5.4 kWh/m2/day
- Building average consumption: 24 kW
- Maximum power needed: 12040 kWh during August

B. Panels basic data:

- The panels' orientation: panels will be installed facing south direction based on the solar data analysis provided previously.
- The panels' inclination angle: will be 30 degrees for the reasons mentioned in section 5.2.1.2.
- Type of panels will be poly crystalline type because it generates the largest amount of energy in the Egyptian circumstances, as discussed before in section 5.2.1.2.
- The spacing between panels in order to avoid surplus shading of the panels on each other was calculated that if the tilting angle was 30 degrees, then a space of 60 cm must be between each row of panels and the one proceeding it.

The final results of the comparison between the different types of panels in different circumstances and different inclination angles are summarized in table (5-7). It concludes that the poly crystalline panel is the best type to be used and the best inclination angle would be 30 degrees in both summer and winter while considering peak power as well as total energy. The discrepancies between the different types of panels reached 400% between the best and the worst types, and the difference between efficiency based on changing the tilting angle reached 100%. (Fayek, 2012)

Module	Angle	Temp.	Peak power in watts	Total Energy kW.hr/day	kW.hr/m2
Poly crystalline	15	25°c-30°c	1080	6.76	0.74
	30	25°c-30°c	1160	7.76	0.85
	15	17°c-19°c	680	3.74	0.41

	30	17ºc-19ºc	1080	7.85	0.86
Thin film	15	25ºc-30ºc	1020	6.86	0.45
	30	25ºc-30ºc	1140	8.9	0.58
	15	17ºc-19ºc	648	2.89	0.19
	30	17ºc-19ºc	1040	7.52	0.5
Mono crystalline	15	25ºc-30ºc	860	5.82	0.56
	30	25ºc-30ºc	920	5.41	0.52
	15	17ºc-19ºc	548	2.39	0.23
	30	17ºc-19ºc	900	5.82	0.56

Table (5-7): Different modules peak powers and daily output energy at different conditions (Fayek, 2012)

C. Connection to the grid systems:

There are three ways to connect the PV system to the grid, each one has its pros and cons and suits a different situation. The three systems will be described in the following section in order to be able to choose the best option for the case study to make it reach nZEB.

- **Off-grid system:**

In this system the energy generated from the PV panels is dedicated to the building's consumption at the morning time, and the loads are consumed from the main grid at any time that the PV system is not generating enough electricity and at the night time. This system is not connected to the main electricity grid as seen in fig (5-14), and cannot sell generated electricity to the government. It is suitable for companies, hotels, hospitals or any entity that cannot afford the electricity cut-off. This type could serve as a backup source of electricity and to save the electricity bills up to 25% (Cairo Solar,2015).

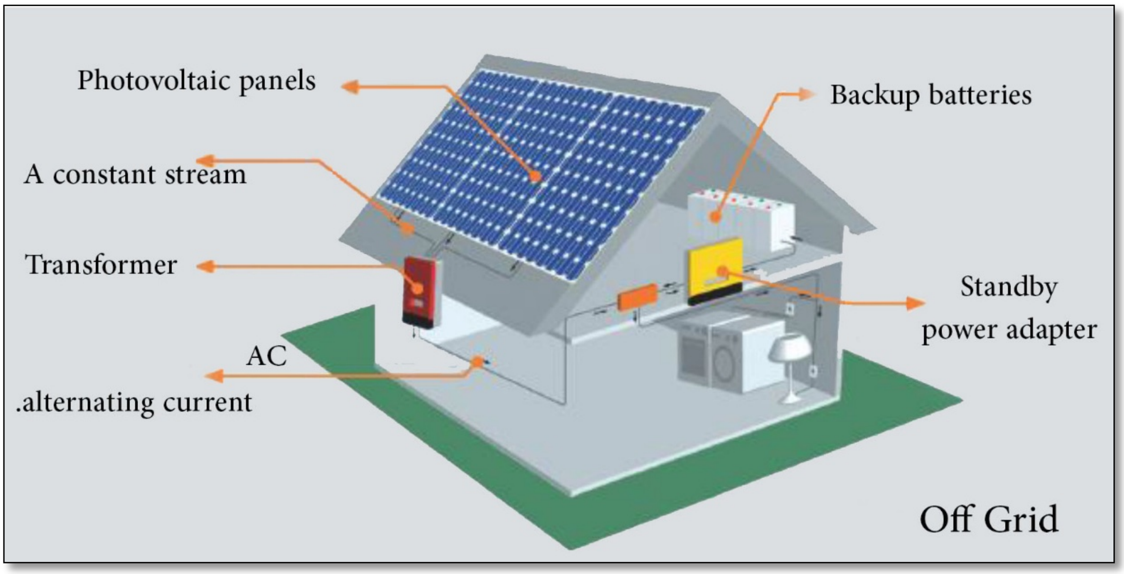


Fig (5-14): Off-grid system (Cairo Solar, 2015)

- **On-grid system:**

This system is connected to the main grid only, it is not connected to the household appliances as seen in figure (5-15). It is dedicated to selling all the generated electricity to the government and this is the highest investment option because it has a return on investment that equals 17% (Cairo Solar, 2015).

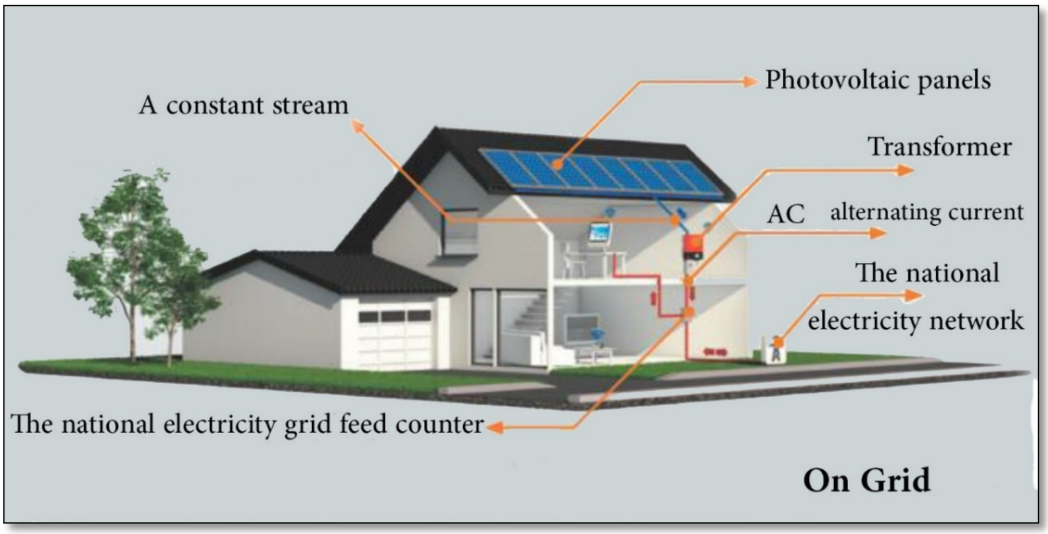


Fig (5-15): On-grid system (Cairo Solar, 2015)

- **Hybrid system:**

This system is a hybrid from both systems as seen in figure (5-16), it is connected to the main grid to sell the generated electricity. At the same time it is connected to the household appliances to cover the consumption in case of electricity cut-off in the morning time. So it basically sells the electricity unless when there is electricity cut-off, in this case it takes is supply directly from the PV system in the morning time and takes it from the battery in the night time. The return on investment for this type is 11% because the system includes battery, from what increases the initial cost, also because some of the electricity is consumed not sold.

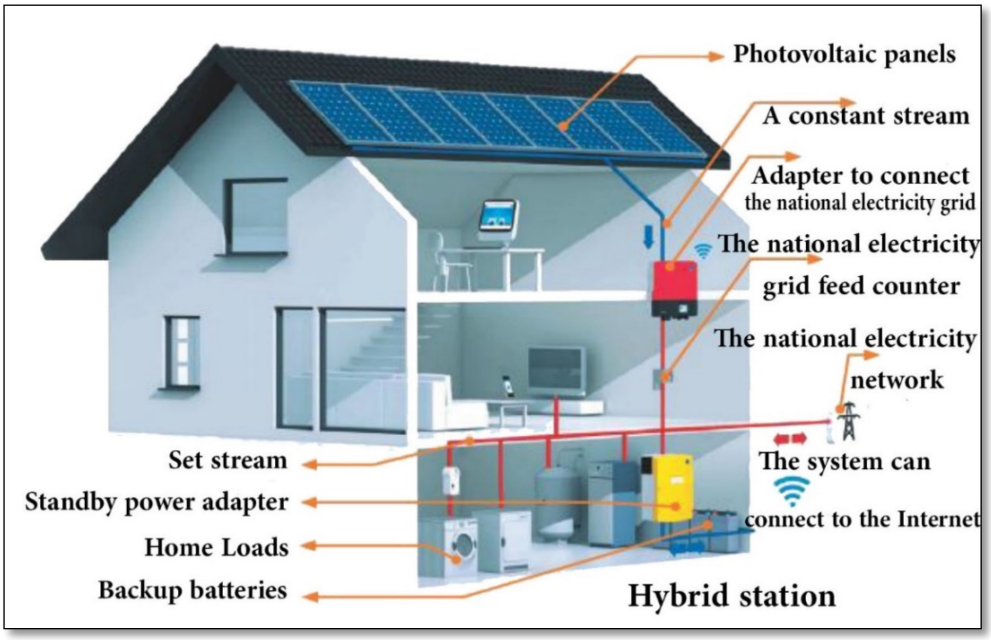


Fig (5-16): Hybrid system (Cairo Solar, 2015)

The three options were considered in order to choose the optimum one for the case study, considering that the aim of the case study is to achieve annual electricity consumption equals zero when subtracted from the energy generated in order to be nZEB. The off-grid system is excluded because it would cover the building's consumption in the morning time only, and the night consumption cannot be compensated. The hybrid system is a supplementary system that is used to back up the electricity cut-off, so it's not in the scope of the case study.

The most suitable system is the On-grid system, because it can generate an amount of electricity equivalent to the amount consumed by the building and sell it to the government's main grid. The selling price is more than the highest buying price, so this solution will save money as will be discussed in details in the cost analysis section. The PV system will be applied when the envelope retrofit is performed, so the amount of electricity needed will be less and consequently the size and price of the PV system will be less.

D. Panel distribution:

After deciding the tilting angle, the orientation and the panel type comes the panel design phase. The figure (5-18) shows the proposed panel distribution including the maximum number of panels that could be installed on the building roof.

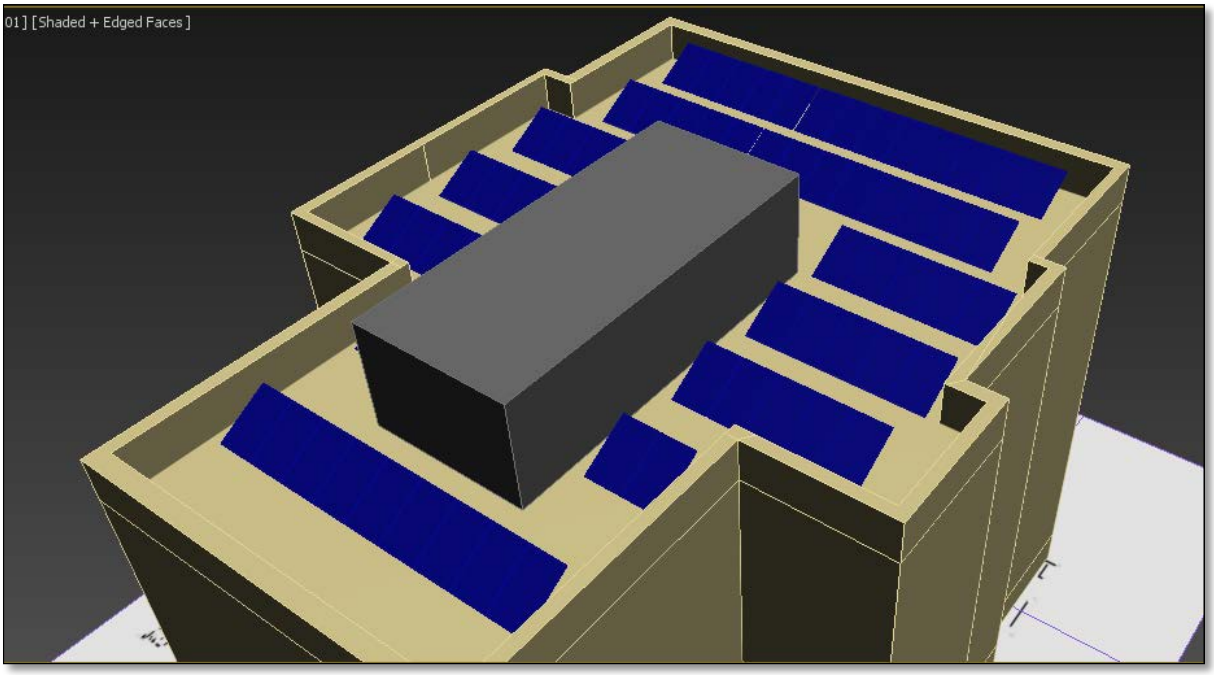


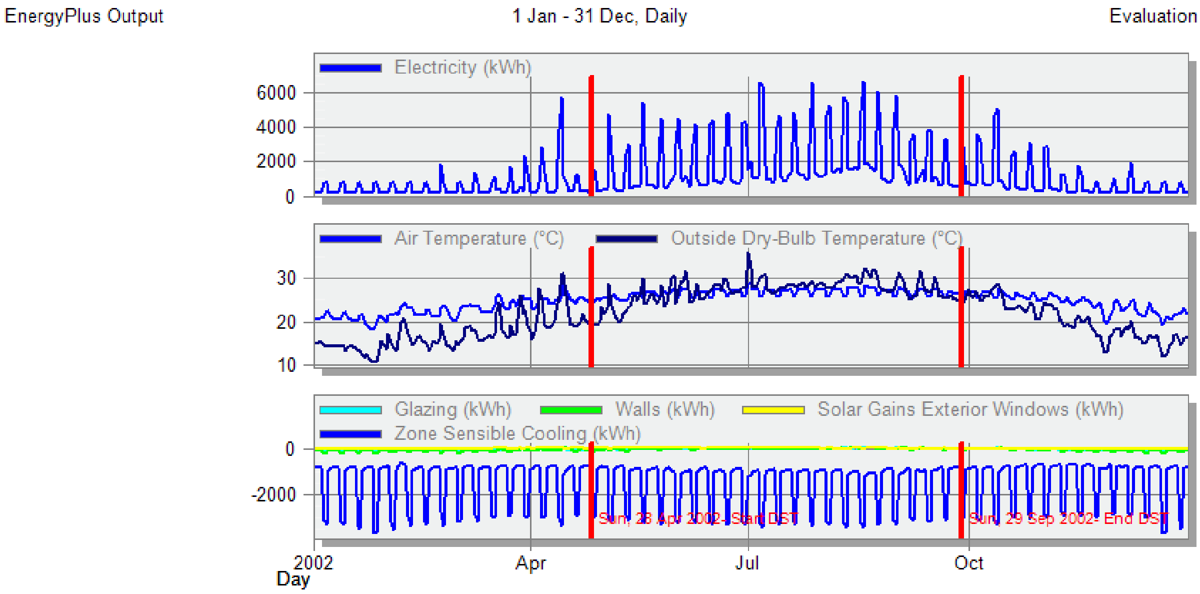
Fig (5-17): PV panel distribution on building's roof

5.3. Simulation

For the retrofit actions to be verified, energy simulation needs to be performed. Using DesignBuilder software the electricity consumption of the existing building with its current situation is done. The retrofit actions are then simulated in order to be able to measure the difference in electricity consumption between the two cases.

5.3.1. Current Situation Simulation:

- Daily simulation:



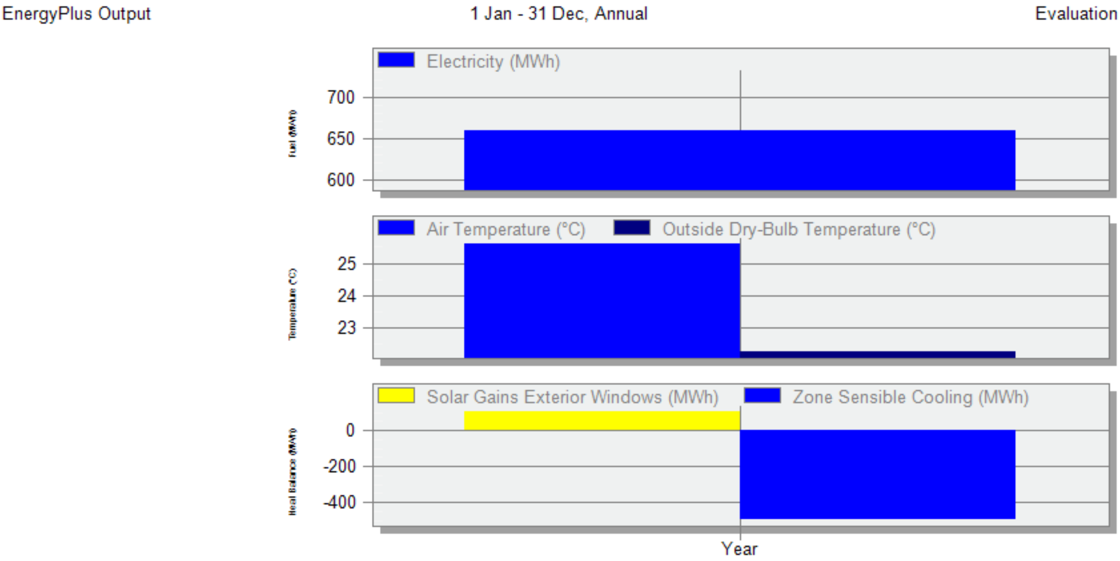
Electricity (kWh)	785.35	234.35	247.94	3030.69	635.66	956.75	1864.81	3258.31	367.86	230.50
Air Temperature (°C)	21.51	23.84	24.24	25.33	26.82	27.21	28.45	25.43	25.80	21.84
Outside Dry-Bulb Temperature (°C)	15.25	18.97	18.53	23.54	26.46	28.54	32.41	25.33	22.91	14.38
Glazing (kWh)	-34.26	-33.80	-43.04	-0.29	16.03	24.70	47.74	20.52	-18.78	-58.51
Walls (kWh)	-147.45	-39.02	-31.75	-63.60	10.33	23.30	62.82	-46.18	-16.14	-25.86
Solar Gains Exterior Windows (kWh)	23.51	29.19	32.85	35.08	37.95	34.62	32.55	32.12	26.12	24.72
Zone Sensible Cooling (kWh)	-3217.67	-741.41	-768.15	-3127.41	-871.72	-929.45	-1167.32	-3040.90	-711.81	-855.90

Fig (5-18): Current situation daily simulation

The daily simulation of the current status of the building in fig (5-18) showed great resemblance to the actual electricity consumption of the building that is provided by the actual electricity bills. It is also clear that the maximum air temperature and outside dry bulb temperature lie between July and September, and this is where the maximum electricity consumption is found.

By comparing the electricity consumption graph to the air temperature graph, it is obvious that the electricity consumption is directly proportional to the air temperature and the outside dry-bulb temperature. This emphasizes the fact that most of the electricity consumed is dedicated to reaching thermal comfort.

- Annual simulation:



Electricity (MWh)	659.69
Air Temperature (°C)	25.62
Outside Dry-Bulb Temperature (°C)	22.25
Solar Gains Exterior Windows (MWh)	107.86
Zone Sensible Cooling (MWh)	-497.61

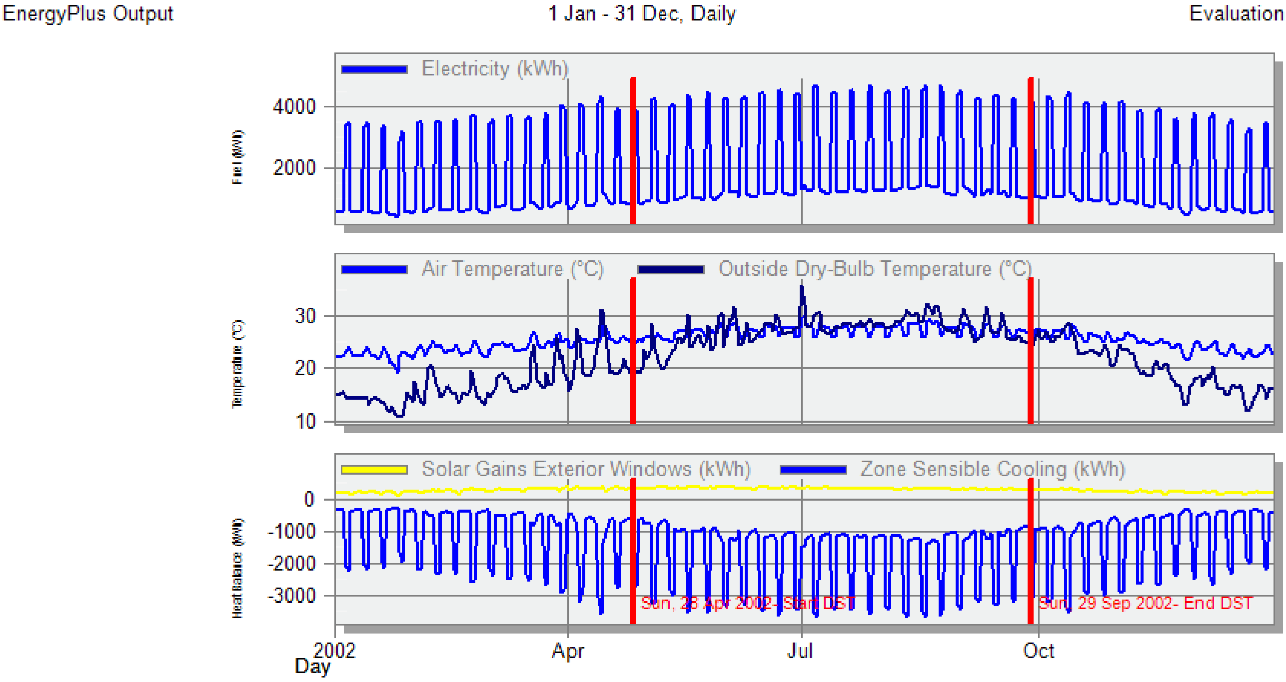
Fig (5-19): Current situation annual simulation

By comparing the annual electricity consumption as seen in fig (5-19) -66000 kWh- to the actually calculated number from the actual electricity bills -62000 kWh- it is found to be almost 5% of variance.

The annual electricity consumption has to be highlighted because it is the value that will be compared to the simulated case in order to show the effectiveness of the proposed retrofit actions. Similarly, since one of the suggested retrofit applications is concerned with window sections and window glass coating, then the solar gains from exterior windows is to be highlighted. It was found to be approximately 108 MWh.

5.3.2. Retrofitted Case Simulation:

- Daily simulation:



Electricity (kWh)	3486.96	774.33	786.22	4096.69	1140.51	1217.96	1419.11	4251.70	953.69	596.06
Air Temperature (°C)	23.77	24.72	24.75	25.46	27.47	27.93	29.17	25.60	26.14	23.11
Outside Dry-Bulb Temperature (°C)	15.25	18.97	18.53	23.54	26.46	28.54	32.41	25.33	22.91	14.38
Solar Gains Exterior Windows (kWh)	234.36	293.08	329.22	352.06	378.20	344.56	326.39	323.29	261.29	246.51
Zone Sensible Cooling (kWh)	-2171.87	-534.02	-551.65	-2999.48	-1044.69	-1113.99	-1374.88	-3110.42	-693.02	-381.67

Fig (5-20): Retrofitted case daily simulation

After performing the proposed retrofit actions, the electricity consumption levels has decreased in general, and the discrepancies between the consumption throughout the different months of the year is decreased. The consistency of the electricity consumption as seen in the first graph and the fact that it didn’t follow the air temperature graph illustrates that the building insulation is improved to the point that it’s not highly affected by the rise in temperature as it was previously.

- Annual simulation:

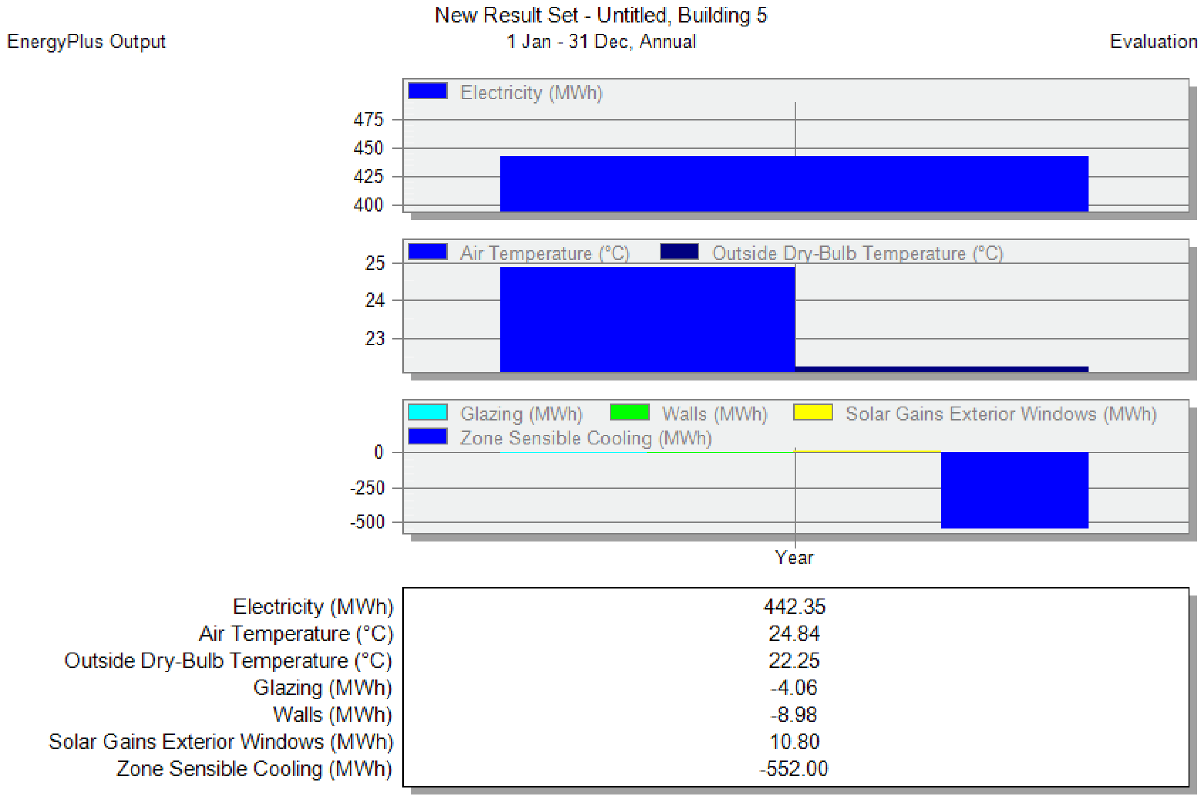


Fig (5-21): Retrofitted case annual simulation

The two values that are significantly important from the annual simulation results are: the annual electricity consumption and the solar gains from exterior windows. The annual electricity consumption has decreased from 66,000 kWh to 44,000 kWh which is equivalent to one third. The solar gains from exterior windows has fallen from 108 MWh to 11 MWh which is approximately one tenth of the original value, and this justifies the substantial decrease in electricity consumption as a result of increasing the building insulation.

5.3.3. Simulation Conclusion:

After considering the envelope retrofit actions the annual electricity consumption is decreased to 44000 kWh instead of 66000 kWh in the current existing case. This shows the impact of the retrofit technologies used and gives a base for the PV system design to work on.

Energy consumption before retrofit = 66,000 kWh	Energy consumption after retrofit = 44,000 kWh	Energy saving = 22,000 kWh

5.4. Cost Analysis

5.4.1. Envelope Retrofit Cost:

Each of the retrofit technologies was discussed in the retrofit technologies section, in the following table the amounts are multiplied by the prices in order to give the total cost.

Item	Area (m2)	Unit price (LE/m2)	Installation price (LE/m2)	Description	Overall price (LE)
Wall insulation	1155	64.7	30	Marmox 2 cm thick sheets	109,378
Roof insulation	309	65	20	Tilefoam 2.5 cm thick tiles	26,265
Window system	120	1,200	--	Double glazed aluminium section	144,000
Insulating film	102	268	--	P18 reflective film	26,156
Total price					**305,799**

Table (5-8): Cost analysis for envelope retrofit actions

5.4.2. Renewable Energy Cost:

For the PV system to be calculated, the amount of electricity resulted from the simulation is used (44,000 kWh). Knowing that every 1 kW power station generates 1800 kWh/year, then the building will need a 24 kW station (44,000/1800). As stated by the supplier, for each 1 kW power station 4 panels and a surface area of 10 m2 of plane roof is needed and it will cost 10,000 LE ("Cairo Solar," 2015). By doing the calculations, the 24 kW station will need 240 m2 of roof area (24x10), which is available for the case study building as seen before in figure (5-18). The rest of the calculations is shown in table (5-9).

Item	Quantity	Unit price	Description	Overall price
PV on-grid system (after retrofit)	96 Panels	10,000 LE/ 1 kW (24 kW needed)	Polycrystalline PV panels	**240,000 LE**

Table (5-9): Cost analysis for PV system after retrofit

5.4.3. Return on Investment:

5.4.3.1. ROI for envelope retrofit

The envelope retrofit actions decreased the energy consumption from 66,000 kWh to 44,000 kWh as per the simulation results. So in order to calculate the return on investment for these actions, the price of the amount of energy saved has to be calculated. For the 22,000 kWh saved, the pricing will be referenced from the feed in tariff FIT as shown in table (5-10).

Household uses	
Consumption segments (kWh / month)	**Piaster / kWh**
0-50	7.5
51-100	14.5
100-200	16
201-350	24
351-650	34
651-1000	60
More than 1000	74

Table (5-10): Consumption tariff prices for the year 2015-2016 (Electricity, 2014a)

An average of 74 piaster / kWh can be assumed because the amount of energy saved will be typically saved from the high level of consumption in the hot months. The amount of money saved can be calculated as: 22,000x0.74 = 16,280 LE per year. On the other hand, the amount of energy to be covered by the renewable energy system is decreased from 36 kW station (66,000/1800) to 24 kW station (44,000/1800). Consequently, the difference between the two stations pricing = 360,000-240,000 = 120,000 LE. ROI can be then calculated as follows: (retrofit pricing – saved PV station pricing)/ money saved by retrofit every year=

(305,799 – 120,000) / 16,280 = 11.4 years.

The return on investment of the retrofit actions may not be short, but the retrofit actions play a very important role in decreasing the energy use and decreasing the amount of PV station needed.

5.4.3.2. ROI for PV system

In order to calculate the return on investment for the PV system, then the payback period has to be calculated. Knowing that the electricity prices ranges from 16 to 74 piasters/kWh depending on the amount of electricity consumed. Table (5-11) shows the exact numbers of the feed in tariffs according to the law no. 1257. (Electricity, 2014a) Also knowing that the feed in tariff for selling electricity generated from solar PV panels is 84.8 piasters/kWh as mentioned in the law no. 1947. (Electricity, 2014b) By knowing these data, the amount of saving can be considered.

On grid system is based on the concept that the PV system is connected to the main grid and the generated electricity will be sold by a fixed price, while the amount of energy consumed has a variable price according to FIT. Table (5-11) shows the monthly electricity consumption and it's pricing throughout a whole year in order to calculate the amount of saving. All the calculations are considering the year 2015 –as per the actual electricity bills collected for the given building- and the consumption tariff is for the same year. The total saving of the whole building per year is approximately 20,000 LE.

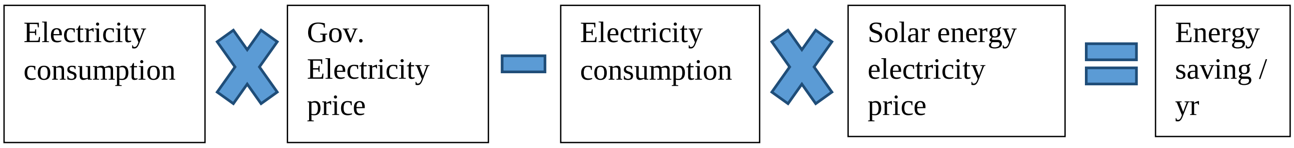


Table (5-11): Monthly electricity consumption and energy saving

Month	Jan	Feb	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Consumption/ aprtm. (Kwh)	615	252	163	162	225	655	734	1204	1061	567	296	272
Gov price (P)	20910	6048	2608	2592	5400	39300	44040	89096	78514	19278	7104	6528
Solar energy price (P)	52275	21420	13855	13770	19125	55675	62390	102340	90185	48195	25160	23120
Saving/month/ aprtm. (P)	31365	15372	11247	11178	13725	16375	18350	13244	11671	28917	18056	16592
Saving/month whole (LE)	3136.5	1537.2	1124.7	1117.8	1372.5	1637.5	1835	1324.4	1167.1	2891.7	1805.6	1659.2
TOTAL SAVING/YR (LE)	20609.2											

In addition to the amount of money saved through the difference between the bought and sold electricity prices, the actual ROI –return on investment- for the whole PV system can be calculated as follows:

24 kWh generates 43,200 kWh/yr

Electricity generated x solar energy pricing = total sold electricity /yr

Total money earned / yr = Energy saved/yr + total sold electricity/ yr

The 1 kW PV station generates 1800 kWh/year and costs 10,000 LE and the kWh is sold to the government by 85 piasters. So if the 24 kW station is considered, then the numbers will be: 24 kW station, generates 43,200 kWh/yr. and cost 240,000 LE, the total price of the sold electricity will be 0.85*43,200= 36,720 LE/yr. Add to this the previously mentioned 20,609 LE, then the total number earned per year will be 36,720+20,609= 57,329 LE. When the capital cost (240,000LE) is divided by the annual earnings (57,329LE) the resulting number is 4.1, so the payback period is 4.1 years. Knowing that the lifetime of the system is approximately 25 years, so the system will generate clean free energy for 21 years.

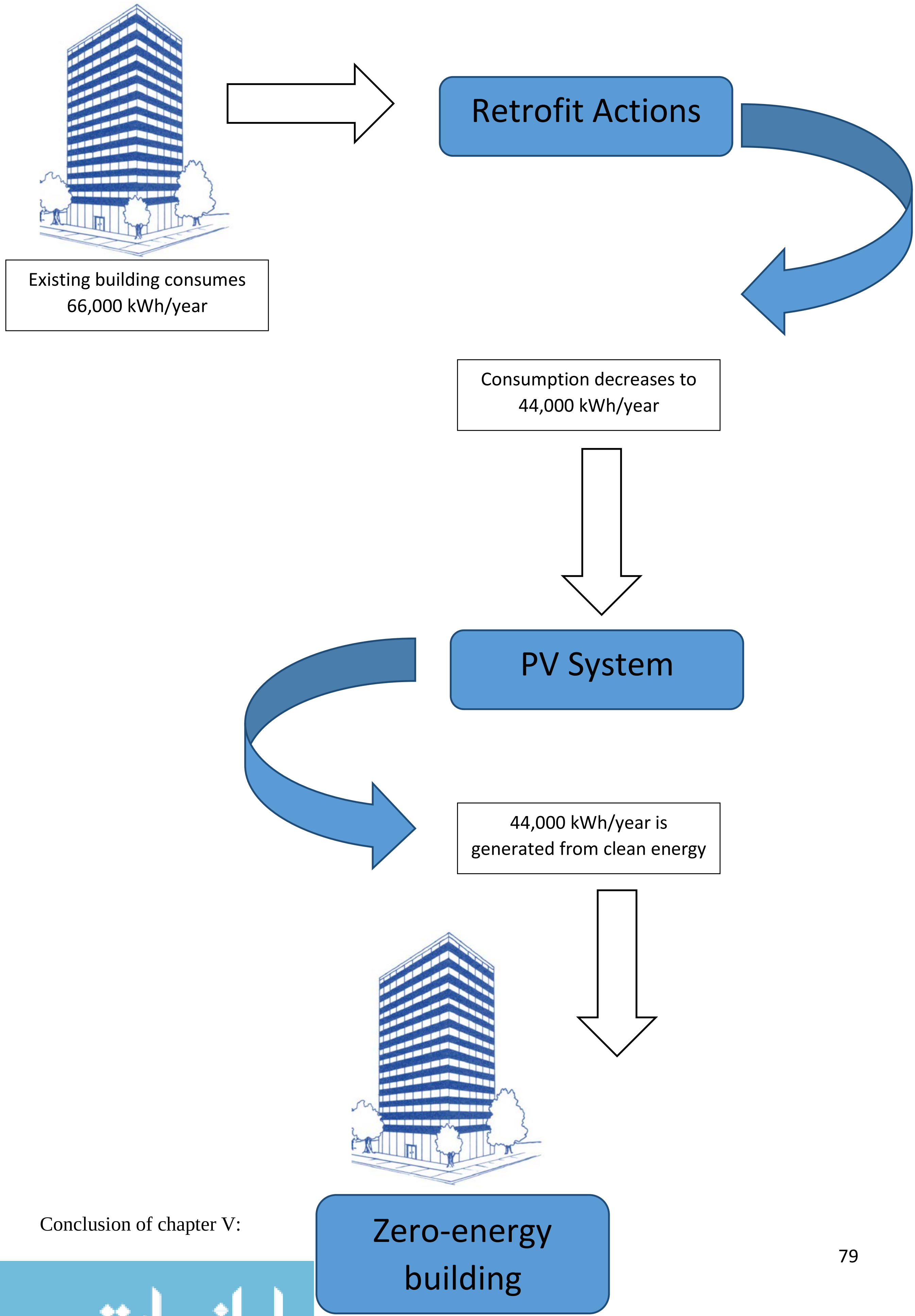
5.4.4. Cost analysis conclusion:

The proposed retrofit actions can reduce the electricity consumption by 22,000 kWh annually from what enhances the energy performance of the building as a first step of the reaching nZEB. The size of the PV system to be used to cover the rest of the consumed electricity is 24 kW/year station. The overall cost for the building to be converted to nZEB can be calculated as follows:

Envelope retrofit = 305,799 LE + PV system = 240,000 LE

Total price for the whole building = 545,799 LE approximately 546,000 LE

Apartment’s share = 54,600 LE



Conclusion of chapter V:

This chapter finalizes the research with introducing the proposed guideline for existing buildings to reach nZEB. The methodology is then tested by applying the steps on an existing residential building. After the methodology is applied, a cost analysis is performed to give actual values for the amount of money saved by retrofitting and installing PV systems. Energy simulation program –DesignBuilder- was used to analyze the energy performance of the existing building sample and compare it to the retrofitted case to show the amount of electricity saved. The chapter ends with the conclusion that existing building can be converted to nZEB by means of retrofit actions and installing PV system.

CHAPTER SIX: DISCUSSION AND CONCLUSION

6.1. Discussion

In recent years, the demand for energy In Egypt had exceeded the current supply, creating and imminent energy crisis. Putting in mind the problems associated with generating energy from traditional fuel resources, this deficit is planned to be supplied from renewable and more sustainable sources. These problems directly affect the three pillars of sustainability; environmental, economic and social aspects. Considering the environmental aspect, the greenhouse gas emissions and the depletion of non-renewable resources are the major problems. The economic aspect reflects the vast amount of economics flooded into the daily increasing prices of fossil fuels. The social aspect is demonstrated in the low levels of satisfaction from building users point of view, along with the insecurity accompanied by the frequent electricity cutoffs taking place recently in Egypt.

The consumption of energy taking place during the process of building and related activities amounts to nearly one half of total energy consumption in Egypt. It is worth mentioning as well that Egypt has significant renewable energy potential that is yet to be realized, namely the high solar irradiance in almost the entire territory of the country. The most significant part of energy consumption in Egypt is directed towards the achievement of thermal comfort. Hence, if the thermal behavior of the buildings could be enhanced, this will case proportional enhancement in energy efficiency.

Currently, the existing buildings in the Egyptian context have poor building envelope; the buildings are not efficiently 'sealed' and are liable to the loss and gain of heat more aggressively. This is translated in poor energy performance, where higher amounts of energy are needed to maintain thermal comfort and compensate for this leaking. “Net zero energy buildings” is a concept that was developed to describe the change needed to be addressed to the building culture. In a way to affect change to existing and planned buildings from the point of view of energy needs and consumptions. By decreasing energy consumption levels, the demand for energy is directly decreased, and in the same time, integrating means of energy generation, so as to make the building self-sufficient or autonomous from the energy point of view.

"Net zero energy buildings" as a concept is much easier to apply to new buildings or buildings that are still in the construction phase. But the situation is different with buildings that are already existing. However retrofitting such buildings in order to apply the concept is still feasible. Areas of inefficiency are exposed through the assessment of energy performance. This assessment indicated the particular reason(s) behind each inefficiency in a way that will enable the enactment of a sufficient retrofitting plan.

Working on the building envelope is a major component of the retrofitting effort in order to enhance its sealing. This will also affect the HVAC system, which will be optimized. Similarly, the design and execution of the HVAC system can be adjusted to match the standards of the "Near Zero Energy Buildings". The success of this retrofitting approach to "Near Zero Energy Buildings" has been proven in many case studies all over the world.
The usage of PV panels to generate solar energy as a renewable energy resource is suitable to the Egyptian context. As mentioned before, the country has high potential for energy generation from solar energy as it has high solar irradiance occurring almost all over the country, and the country's economy can use the boost of manufacturing of PV panel domestically as most of the components are available in the local market.

Climate analysis and experiments provide answers to technical issues in the design of the PV panels. The optimum type of PV panels to be used in the Egyptian climate is the poly crystalline type. As per the optimum orientation and tilting angle for PV panels is south and 30 degree respectively. This is due to the geographic location of Egypt, where most of Egypt's area is north of the Tropic of Cancer. The optimum PV system to be used in case of retrofitting is the on-grid system.

The total reduction in demand for electricity achieved through the application of the proposed retrofit actions can reach up to 18,000 kWh/year. To complement this reduction and achieve the near zero energy goal, the electricity consumption of the building after retrofit can be covered by installing a 24 kW PV station. It was proven by simulation that an existing residential building can be converted to nZEB at an affordable price.

6.2. Limitations

The limitations of the research were basically the lack of literature concerned with the Egyptian existing buildings and its energy performance, and the nZEB in the Egyptian context as well.

The lack of insulating materials in the Egyptian market made it hard for the researcher to find suitable supplies to be used.

The lack of awareness of the importance of research made the suppliers unhelpful to the researcher as a student, while very helpful to the researcher as a client.

Technical limitations included that the simulation calculations were done based on the assumption that all the windows were aluminum sections and were closed all day long while this might change the results slightly if taken into consideration.

Also, the simulation considered cladding all the external facades including the northern ones because in case of excluding one of the facades, the building will not be sealed against thermal exchange with the outside.

The calculations made for the electricity consumption are made for the year 2015 in order to match the actual electricity bills collected for the case study building, while the consumption tariff for the year 2016 will increase, and will keep increasing for the coming years as well.

6.3. Conclusion

This research was set out to propose a valid solution for the energy problem in Egypt with respect to buildings energy consumption. The buildings' energy efficiency in Egypt is significantly low, from what increases the energy demand that is generated from non-renewable resources. Thus, the two main aspects that have to be considered while solving this problem are buildings' insulation and renewable energy generation. The research contributes to solving this problem through regarding those two aspects, specifically existing buildings and solar energy. This is how the proposed guideline evolved as an outcome.

The literature has showed the renewable energy potential and focused also on the existing buildings' status, then it explored Net zero-energy buildings as a conceivable solution for thee problem. NZEBs have been used widely in the previous years in different parts of the world and it proved its feasibility and success. It was mostly applied in cold climates and for new construction buildings, this is why the research had to adjust the present methodologies in order to suit the hot arid climate in Egypt and to make it applicable for existing buildings.

Various case studies and their applications from different locations and representing several building types were discussed to pave the way for the actual case study.

The idea of validating the proposed guideline by applying it to an actual hands on project and exploring its effectiveness through simulation helped forming the methodology of the research. At first the strategy was applied to the case study building and then simulation results showed that the retrofit actions and the PV solution were doable and beneficial in terms of electricity consumption saving and cash saving. Thus, the basic plan of the research was: identifying the problem, exploring possible solutions from literature, adapting a solution that suits the given situation and the status quo, verifying the applicability of this solution through simulation, and finally offering a complete cost analysis for the whole proposal.

The case study building is an average residential building in Cairo that was chosen to act as a prototype. The building's inefficiencies were detected and then possible solutions using market available products were proposed. Also, PV suppliers were contacted and price offers for all the used materials were collected. The needed quantities of each retrofit action were calculated and so the overall price of the retrofit plan was considered. Similarly, the pricing for the PV station that would cover the electricity consumption was calculated. Accordingly, a complete plan of how to convert an existing residential building in Egypt into an nZEB is ready for use with actual products, prices, suppliers as well as a return on investment study.

In a nutshell, the main aim of this study is to prove the feasibility of achieving net zero energy buildings through retrofitting existing residential buildings while considering the Egyptian circumstances. The definition of the nZEB as a building that covers its energy needs with almost no dependence on the grid through the generation of clean energy to alleviate its consumption in one year is applied to the case study building and the building reached this benchmark. The final conclusion of the research is that an existing residential building can generate an amount of solar energy equivalent to the amount of energy consumed within a year. The research proposed market available materials and suppliers for both the retrofit and the PV system and provided actual prices in order to validate the conclusion with an actual cost analysis as well as a return on investment for the whole process.

6.3. Prospect of Future Research

- In the data gathering phase of this research, the author found a lack of research in the nZEB field in Egypt, although literature is available in energy efficiency or renewable energy application. So if future literature could consider the two aspects together this could promote to the nZEB concept and help introduce it to the building sector in Egypt.
- This research was focusing on residential buildings in Egypt, so future research could be dedicated to other building types in order to generalize the results.
- Some of the potential building types might be office buildings, because the owner of this type of buildings is keen on saving the vast amount of money dedicated towards electricity consumption. Also office building owners would be open for accepting the idea of investing in solar PV panels.
- Another suitable building type is hotels, for many reasons: hotels are regularly renovated, so proposing a new methodology of retrofit would be feasible. Also the concept of an environmentally friendly hotel or even resort is established, so it will be familiar to both owners and users. Finally, funding can be collected through optional participation from the guests, which is valid in many areas of the world.
- Joining the nZEB concept to the most popular green building application: LEED rating system, while discovering the aspects of LEED that could help reaching nZEB might be of a great value in putting nZEB into action.
- A complete business model for the proposal to be converted to an actual startup could be considered by non-engineering researches.
- From a social point of view, a survey-based study could collect data on the practicability of applying this guideline and the societal acceptance of this proposal.

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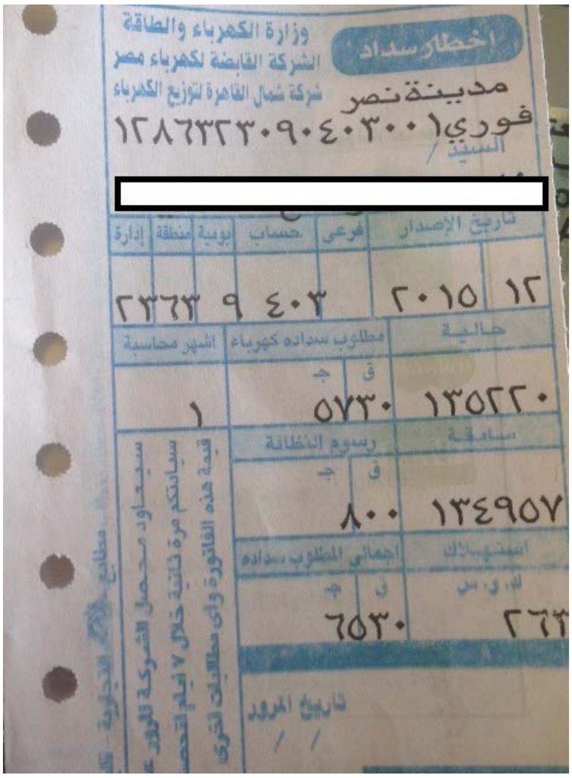
Appendix

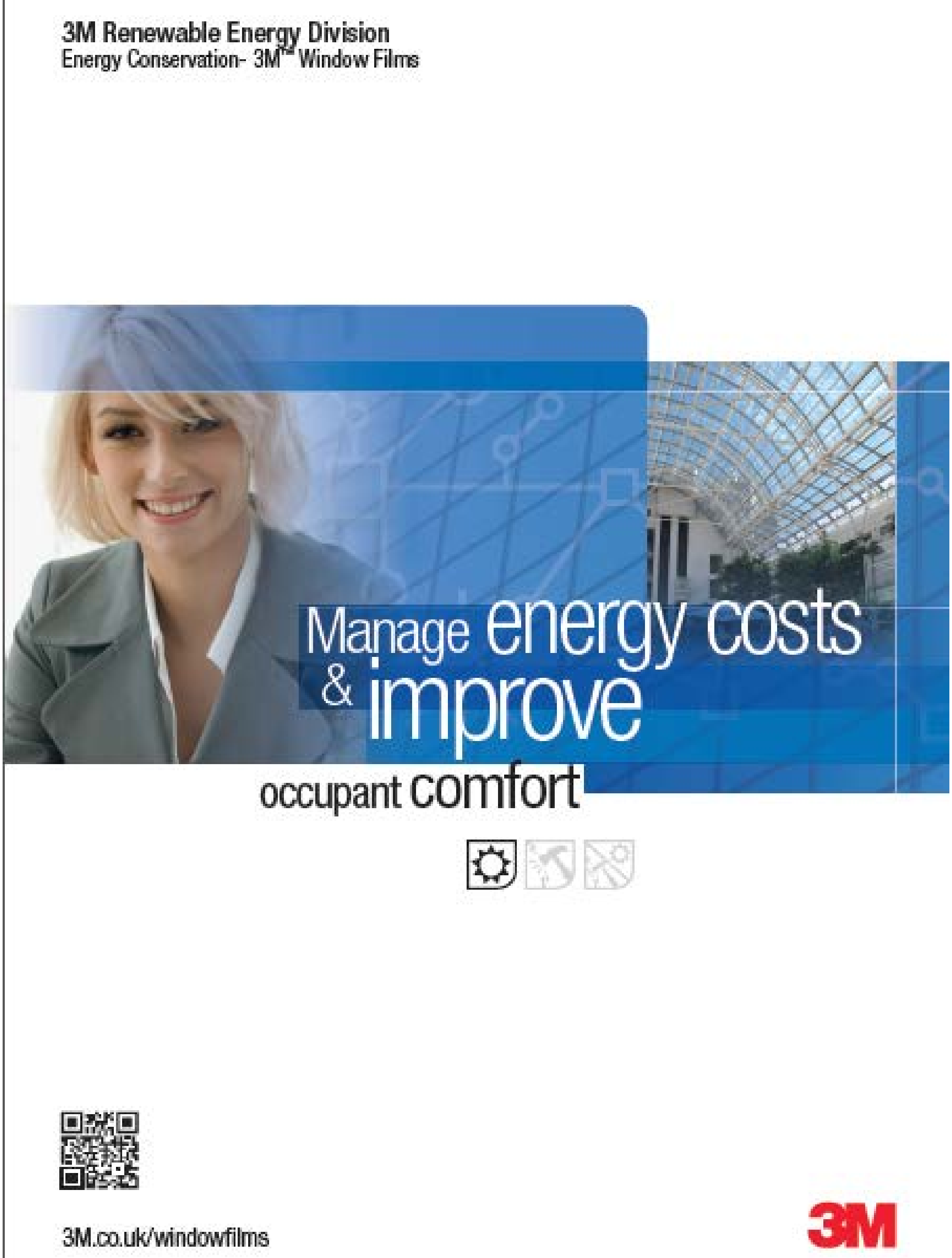
Appendix A:

Electricity bill for the case study building



Appendix B:

Window film brochure



3M™ Solar Films

3M is a leading manufacturer in solar window films. 3M's extensive range includes Prestige, Night Vision, and Low-Energy Films which, can help you reduce your energy bill.

3M Solar Films can be applied to windows in offices, schools, hospitals and government buildings to help overcome the problems associated with solar heat gain.

Energy costs typically represent 30% of a building's annual budget. Rising energy bills and the introduction of carbon reduction targets, have focused building owners on finding ways to reduce their energy bills. Within commercial and public buildings, these energy costs are often driven by HVAC costs, as it costs 3 to 4 times more to cool a building by 1 degree Celsius than to heat it.

3M Sun Control Films can reduce solar heat gain and help to create a balanced environment in buildings, especially in the summer months, when the films can help to reduce the workload of cooling systems and save energy costs.

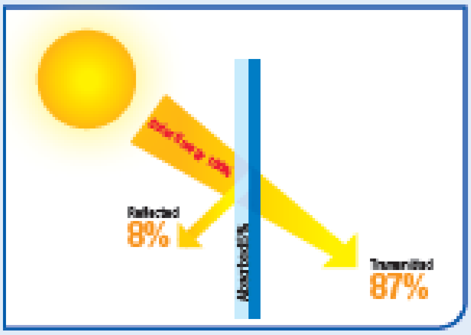
If a building does not have air conditioning, solar films can help with heat gain management to reduce the temperature inside buildings, improving occupant comfort. 3M Sun Control Films are highly transparent and have a high light transmission, maintaining the natural light within the building.

Free Glazing Assessment
Free Energy Reduction Assessment

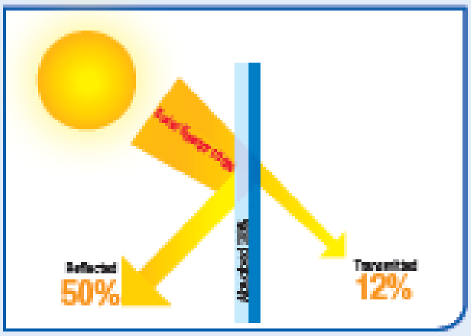
See how applying window film to your building can help to enhance safety and security, increase energy reduction and occupant comfort. Contact us at:

Tel: 0845 600 9543
Email: RenewableUK@mmm.com
3M.co.uk/windowfilm

Unprotected glass



Glass with appropriate window film



Reduce the heat inside your building
↓
Reduce the need for air conditioning
(prolong HVAC life)
↓
Reduce your energy bill
↓
Improve occupant comfort
↓
Improve productivity
↓
Increase profit
↓
Reduce buildings CO2 footprint

Film Properties

Glass type	Film Type	Shading Coefficient	Visible Reflection Exterior	Visible Reflection Interior	Visible Light Transmission	U-value	G-value	TSER	Heat Gain Reduction
Single Pane									
Clear	Amber 35	0.29	54%	60%	30%	0.85	0.25	75%	
Clear	Neutral 35	0.51	20%	18%	36%	0.99	0.44	56%	
Clear	Nickel 50	0.5	24%	23%	50%	0.92	0.44	56%	
Clear	Night Vision 25	0.46	20%	7%	24%	1	0.4	60%	60%
Clear	Night Vision 15	0.33	39%	11%	15%	0.98	0.29	71%	64%
Clear	Prestige 70	0.58	9%	7%	69%		0.5	50%	38%
Clear	Silver 20	0.26	58%	58%	17%	0.93	0.23	77%	
Clear	Silver 35	0.41	36%	40%	35%	0.92	0.36	64%	
Clear	Amber LE35	0.28	52%	56%	30%	0.76	0.25	75%	
Single Pane									
Tinted	Amber 35	0.31	22%	60%	17%	0.85	0.27	73%	
Tinted	Neutral 35	0.45	10%	18%	21%	0.99	0.39	61%	
Tinted	Nickel 50	0.44	12%	22%	30%	0.92	0.38	62%	
Tinted	Night Vision 25	0.43	10%	7%	14%	1	0.38	62%	40%
Tinted	Night Vision 15	0.35	17%	11%	9%	0.98	0.31	69%	51%
Tinted	Prestige 70	0.5	6%	9%	42%		0.43	57%	31%
Tinted	Silver 20	0.3	23%	58%	10%	0.93	0.27	73%	
Tinted	Silver 35	0.39	16%	40%	21%	0.92	0.34	66%	
Tinted	Amber LE35	0.29	22%	56%	18%	0.76	0.25	75%	
Double Pane									
Clear	Amber 35	0.37	53%	61%	28%	0.42	0.32	68%	
Clear	Neutral 35	0.59	24%	19%	32%	0.46	0.51	49%	
Clear	Nickel 50	0.55	28%	25%	45%	0.45	0.48	52%	
Clear	Night Vision 25	0.57	24%	8%	22%	0.47	0.49	51%	29%
Clear	Night Vision 15	0.46	40%	11%	14%	0.46	0.4	60%	43%
Clear	Prestige 70	0.64	15%	13%	62%		0.56	44%	21%
Clear	Silver 20	0.37	55%	58%	15%	0.45	0.33	67%	
Clear	Silver 35	0.49	38%	41%	32%	0.45	0.43	57%	
Clear	Amber LE35	0.37	51%	57%	28%	0.39	0.32	68%	
Double Pane									
Tinted	Amber 35	0.3	22%	61%	16%	0.42	0.26	74%	
Tinted	Neutral 35	0.45	12%	19%	19%	0.46	0.39	61%	
Tinted	Nickel 50	0.42	13%	24%	27%	0.45	0.36	88%	
Tinted	Night Vision 25	0.43	12%	8%	13%	0.47	0.37	63%	27%
Tinted	Night Vision 15	0.37	17%	11%	8%	0.46	0.32	68%	37%
Tinted	Prestige 70	0.48	12%	12%	37%	0.42	58%	20%	20%
Tinted	Silver 20	0.31	23%	58%	9%	0.45	0.27	73%	
Tinted	Silver 35	0.38	16%	41%	19%	0.45	0.33	67%	
Tinted	Amber LE35	0.29	21%	57%	16%	0.39	0.26	74%	

U-value: The ability to prevent thermal energy loss
G-value: Solar Heat Gain Coefficient
TSER: Total Solar Energy Rejected

Appendix C:

PV panel technical details

Smart Systems for Solar Power

IBC SOLAR

TECHNICAL DATA

IBC PolySol	255 ZX	260 ZX
Article number	2204100025 2204100027	2204100026 2204100028

Electrical data (STC):		
STC Power Pmax (Wp)	255	260
STC Nominal Voltage Umpp (V)	30.9	31.1
STC Nominal Current Impp (A)	8.25	8.37
STC Open Circuit Voltage Uoc (V)	37.8	38.1
STC Short Circuit Current Isc (A)	8.83	8.98
Module Efficiency (%)	15.8	16.1
Power Tolerance (Wp)	−0/+5	−0/+5

Electrical data (NOCT):		
800 W/m² NOCT AM 1.5 Power Pmax (Wp)	204.91	208.93
800 W/m² NOCT AM 1.5 Nominal Voltage Umpp (V)	30.86	31.26
800 W/m² NOCT AM 1.5 Open Circuit Voltage Uoc (V)	37.22	37.26
800 W/m² NOCT AM 1.5 Short Circuit Current Isc (A)	7.02	7.08
Relative Efficiency Reduction at 200 W/m² (%)	4.37	4.37

Temperature coefficient:		
NOCT (°C)	46	46
Tempcoeff Isc (%/°C)	+0.07	+0.07
Tempcoeff Voc (mV/°C)	−113.4	−114.3
Tempcoeff Pmpp (%/°C)	−0.39	−0.39

Operating conditions:	
Max. System Voltage (V)	1000
Application Class	A
Reverse Current Ir (A)	15
Current value string fuse (A)	15
Fuse protection from parallel strings	3

Mechanical properties:	
Dimensions (L × W × H in mm)	1639 × 983 × 40
Weight (kg)	18.5
Load capacity (Pa)[2]	5400
Front sheet (mm)	3.2 (low-iron photovoltaic glass and anti-reflective coating)
Frame	anodized aluminium, sturdy hollow-chamber frame
Cells	6 × 10 polycrystalline silicon cells
Connection type	MC4 (IP65)

Warranties and certification:	
Product warranty	10 years[1]
Power warranty	25 years[1]
Certification	IEC 61215, IEC 61730-1/-2, ISO 9001, ISO 14001, OHSAS 18001

Packaging information:	
Number of modules per pallet	26
Number of pallets per 40' container	28
Number of pallets per lorry	32
Dimensions incl. pallet (L × W × H in mm)	1700 × 1100 × 1170
Gross weight incl. pallet (kg)	482
Stackability per pallet	2-fold

TECHNICAL DATA

IBC PolySol	255 ZX	260 ZX
Article number	2204100025 2204100027	2204100026 2204100028

Electrical data (STC):		
STC Power Pmax (Wp)	255	260
STC Nominal Voltage Umpp (V)	30.9	31.1
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STC Open Circuit Voltage Uoc (V)	37.8	38.1
STC Short Circuit Current Isc (A)	8.83	8.98
Module Efficiency (%)	15.8	16.1
Power Tolerance (Wp)	−0/+5	−0/+5

Electrical data (NOCT):		
800 W/m² NOCT AM 1.5 Power Pmax (Wp)	204.91	208.93
800 W/m² NOCT AM 1.5 Nominal Voltage Umpp (V)	30.86	31.26
800 W/m² NOCT AM 1.5 Open Circuit Voltage Uoc (V)	37.22	37.26
800 W/m² NOCT AM 1.5 Short Circuit Current Isc (A)	7.02	7.08
Relative Efficiency Reduction at 200 W/m² (%)	4.37	4.37

Temperature coefficient:		
NOCT (°C)	46	46
Tempcoeff Isc (%/°C)	+0.07	+0.07
Tempcoeff Voc (mV/°C)	−113.4	−114.3
Tempcoeff Pmpp (%/°C)	−0.39	−0.39

Operating conditions:	
Max. System Voltage (V)	1000
Application Class	A
Reverse Current Ir (A)	15
Current value string fuse (A)	15
Fuse protection from parallel strings	3

Mechanical properties:	
Dimensions (L × W × H in mm)	1639 × 983 × 40
Weight (kg)	18.5
Load capacity (Pa)[2]	5400
Front sheet (mm)	3.2 (low-iron photovoltaic glass and anti-reflective coating)
Frame	anodized aluminium, sturdy hollow-chamber frame
Cells	6 × 10 polycrystalline silicon cells
Connection type	MC4 (IP65)

Warranties and certification:	
Product warranty	10 years[1]
Power warranty	25 years[1]
Certification	IEC 61215, IEC 61730-1/-2, ISO 9001, ISO 14001, OHSAS 18001

Packaging information:	
Number of modules per pallet	26
Number of pallets per 40' container	28
Number of pallets per lorry	32
Dimensions incl. pallet (L × W × H in mm)	1700 × 1100 × 1170
Gross weight incl. pallet (kg)	482
Stackability per pallet	2-fold

Appendix D:

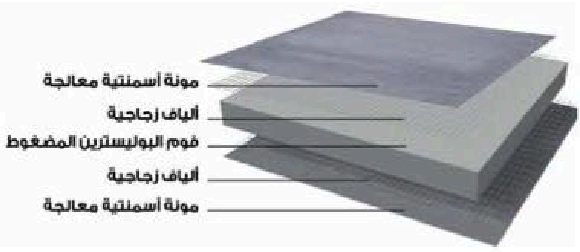
Marmox board brochure

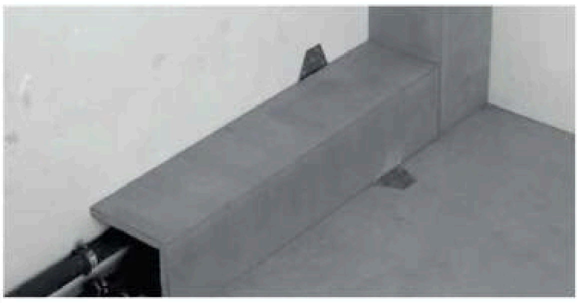
مارموكس بورد

ألواح مارموكس بورد. هى ألواح إنشائية خفيفة مصنوعة من فوم البوليسترين المضغوط والمسلحة من الوجهين بشبكة من الألياف الزجاجية والمغطاة بطبقة خفيفة من المونة الأسمنتية المعالجة، وتعتبر الحل الأمثل للعزل الحرارى والرطوبة فى نفس الوقت علاوة على ذلك أن طبقة المونة الأسمنتية المعالجة على وجهى الألواح قوية التلاصق مع جميع أنواع لواصق البلاطات، كما تصلح لجميع أنواع الدهانات.

مميزات ألواح مارموكس بورد :

- بمقاومة ضغط عالية.
- صلبة وقوية.
- عازلة للمياه.
- عازلة للحرارة حتى بالمناطق الرطبة.
- عازلة لصدمات الصوتية (الأرضيات فقط)
- سهلة التقطيع.
- خفيفة الوزن.
- صديقة للبيئة.





ألواح زوايا مارموكس بورد :

- يمكن تصنيع المارموكس بورد على شكل زوايا تصلح لكثير من الأغراض كتغطية المواسير فى الحمامات كما يمكن أستخدامها فى أغراض أخرى لتجليد الأعمدة أو أركان الحوائط حيث أنها ذات سطح قوى وعازل للمياه والرطوبة وتعتبر الحل الأمثل لسطح جاهز للتبليط مباشرة.

ألواح مارموكس بورد المشققة للأشكال الدائرية والمنحنية :

- يمكن تصنيع المارموكس بورد بشكل خاص يتماشى مع جميع التصميمات الدائرية والمنحنيات حيث يتم تحزيزها بشكل طولى أو عرضى حسب المطلوب من وجه واحد فقط، وتصلح لتجليد الأعمدة الدائرية أو أى أشكال تصميمية داخل الحمامات والغرف.

ماروكس بورد

أستخدامات ألواح ماروكس بورد :

- القواطيع بين الغرف وبعضها.
- الأسقف المستعارة.
- تجليد منطقة الدش بالكامل.
- تجليد الحوائط وخصوصاً المناطق الرطبة كالحمامات والمطابخ.
- العزل الحرارى للحوائط وأسفل التدفئة الأرضية.
- التشكيلات الديكورية داخل الغرف وخصوصاً أشكال دائرية ومنحنيات.

مقاسات وسماكات ألواح ماروكس بورد :

معامل التوصيل الحراري الكلي وات/ م٢ كيلفن	الـوزن (كـج)	الطـول (مـم)	العـرض (مـم)	السـمك (مـم)	الصنف
10	1.88	1250	600	4	ألـواح ماروكس بورد
7.00	1.95	1250	600	6	
3.50	2.22	1250	600	10	
2.70	2.30 / 4.60	1250 / 2500	600	12.5	
1.50	2.48 / 4.96	1250 / 2500	600	20	
1.00	2.74 / 5.48	1250 / 2500	600	30	
.70	3.00 / 6.00	1250 / 2500	600	40	
.57	3.26 / 652	1250 / 2500	600	50	
		1250	600	20 long	الألـواح المشققة
		2500	600	20 transv.	
		1250	600	30 long	
		2500	600	30 transv.	
		1250 / 2600	150 × 150	20	ألـواح الزوايا
		1250 / 2600	200 × 200	20	
		1250 / 2600	300 × 300	20	
		1250 / 2600	400 × 200	20	

Appendix E:

Tilefoam brochure

TILEFOAM

Thermal Insulating Tiles For Roofs &Walls

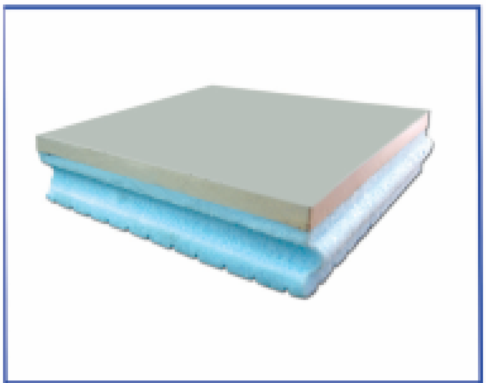
Description

TILEFOAM is an insulating tile made of high strength polymeric concrete layer bonded mechanically and chemically to extruded polystyrene foam layer .

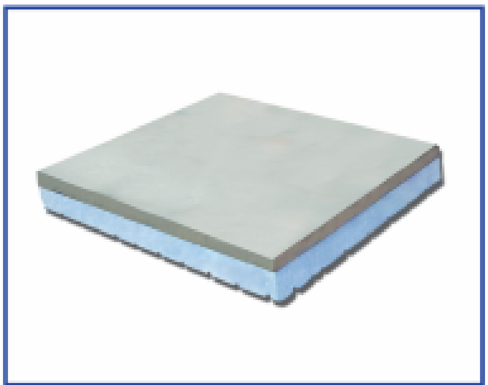
The top layer of polymeric concrete has high compressive, bending and abrasion strength and low water absorption.

The layer of foam which provides the insulation is characterized by its rigid and homogenous closed-cell structure, its waterproofness and its extraordinary high thermal insulating properties, which are maintained even under very humid/ wet conditions.

Suitable for internal and external use, TILEFOAM is an ideal covering where its finish gives an attractive appearance.



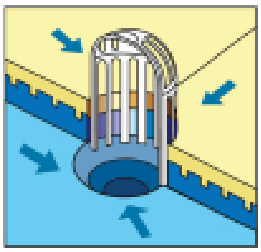
Tongue and Groove type



Straight Cut type

Advantages

-High thermal efficiency (Coefficient of thermal conductivity of the foam layer (0.032W/mK) (after ageing).
-Lower total thickness and reduction of permanent loads on roofs from 200 to 40 kg/m^2.
-Elimination of external vapour barrier.
-Reduced maintenance cost and easy lifting for inspection.
-Can be laid on any type of waterproofing material.
-Single-step fast application with consequent cost saving.
-Fast drainage of rain without the need for sloping roof.
-Several colours with attractive patterns.
-CFC and HCFC free.
-Eliminates the need for plastering when used for wall cladding.



Installing water drainage pipes

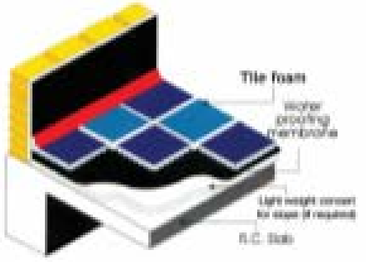
Technical Properties

Dimensions	30 x 30 cm (other dimensions upon request)
Foam Layer Material	Extruded polystyrene foam
Thickness of Foam Layer	2.0,3.0,4.0,5.0 cm
Coefficient of thermal conductivity of Foam Layer	0.032 W/ mK
Water absorption by submersion	Negligible
Fire classification (DIN 4102)	B 1 (self distinguishing)
Protective Layer	polymer cement concrete
Thickness of Top Layer	1 cm (and more at request)
Compressive strength (ASTM C 42) of Top Layer	400 - 600 kg/cm^2
Surface	Plain, or designed
Colours	Grey (other colours available upon request)

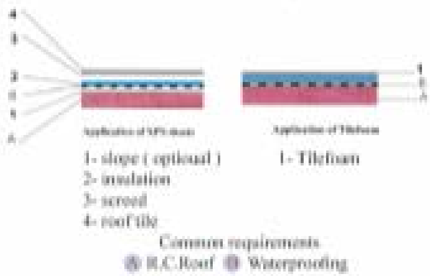
Application

The roof surface should be clean and free of all loose debris. If necessary the surface can be leveled using a cement mortar.
In large areas, expansion joints of 1cm width must be applied every 15m. The joint should be filled with suitable joint filling material.
Apply the waterproofing as specified.
Install water drainage pipes and seal around them.
Lay TILEFOAM using cement mortar.

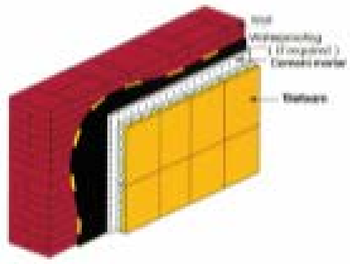
TILEFOAM for roofs



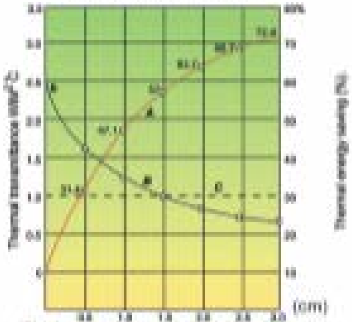
Tilefoam as a one step solution



TILEFOAM for walls



Thermal transmittance and thermal energy saving for hollow block roof, insulated by tilefoam



A: Thermal energy saving.
B: Thermal transmittance.
C: Max thermal transmittance according to the code.
b: Thermal transmittance for non-insulated roof.

Thickness of foam layer (Advefoam) (cm)	% of energy saved
1 cm	47.1%
1.5 cm	57.0%
2 cm	63.7%
2.5 cm	68.7%
3 cm	72.4%

Patterns and colours

- Pharaonic pattern
- Marbella pattern
- Sheva pattern
- Plain surface

Gray colour, other colours upon request