Renovating Strategy for Educational Buildings towards Low/Zero Energy in EMU

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ABSTRACT

Nowadays, most of the buildings are designed without considering the sustainability or responding to natural conditions which becomes a noticeable international trend. Recent global developments in awareness and concerns about environmental problems have led to reconsidering built environment approaches and construction techniques. One of the alternatives is the principle of low/zero-energy buildings. This study investigates the potentials of energy savings in an existing multi-story building in the Mediterranean region in order to achieve net-zero energy as a solution to increasing fossil fuel prices. The Colored building the Faculty of Architecture, Eastern Mediterranean University, North Cyprus was chosen as a target of this study to be investigated and analyzed in order to know the impacts of energy efficiency strategies applied to the building to reduce annual energy consumption. Since this research objective was to develop a strategy to achieve net-zero energy in existing buildings, case study and problem solving methodologies were applied in this research in order to evaluate the building design in a qualitative manner through observations, in addition to a quantitative method through an energy modeling simulation to achieve desirable results which address the problems. After optimizing the building energy performance, an alternative energy simulation was made of the building in order to make an energy comparison analysis, which leads to reliable conclusions. These methodologies and the strategies used in this research can be applied to similar buildings in order to achieve net-zero energy goals.

Keywords: net-zero energy buildings; renovating existing buildings; energy efficiency strategies; energy modeling simulation.

ÖZ

Günümüzde binaların çoğu sürdürülebilirliği dikkate almadan veya dikkat çekici bir uluslararası trend haline gelen doğal koşullara tepki göstermeden tasarlanmıştır. Çevre sorunlarıyla ilgili endişeler ve bilinçlendirme konusundaki son küresel gelişmeler, yapılı çevre yaklaşımları ve inşaat teknikleri üzerinde yeniden düşünmeye yol açmıştır. Bu çalışma, artan fosil yakıt fiyatlarına bir çözüm olarak net sıfır enerji elde etmek için, Akdeniz bölgesindeki mevcut çok katlı bir binadaki enerji tasarruf potansiyellerini araştırmaktadır. Yıllık enerji tüketimini azaltmak için bina için uygulanan enerji verimliliği stratejilerinin etkilerini bilmek için, araştırmanın yapılması ve incelenmesi amacıyla, Mimarlık Fakültesi, Doğu Akdeniz Üniversitesi, Kuzey Kıbrıs Renkli bina bu araştırmanın hedefi olarak seçildi. Bu araştırma amacı mevcut binalarda net sıfır enerji elde etmek için bir strateji geliştirmek olduğundan, Bu araştırmada, problemleri ele alan istenen sonuçların elde edilmesi için bir enerji modelleme simülasyonu yoluyla niceliksel bir yöntemin yanısıra gözlemlerle bina tasarımını niteliksel bir şekilde değerlendirmek için vaka analizi ve problem çözme metodolojileri uygulanmıştır. Bina enerji performansını optimize ettikten sonra, güvenilir sonuçlara götüren bir enerji karşılaştırma analizi yapmak için bina için alternatif bir enerji simülasyonu yapıldı. Bu metodolojiler ve bu araştırmada kullanılan stratejiler net sıfır enerji hedefleri elde etmek için benzer binalara uygulanabilir.

Anahtar Kelimeler: sıfır sıfır enerji binaları; mevcut binaları yenilemek; enerji verimliliği stratejileri; enerji modelleme simülasyonu.

Every effort in life needs motivation as well as guidance and support by those who are very close to our hearts and filling it with the most special gratitude feelings.

My humble work I dedicate to my sweet and loving parents,

Mr. Yahia AbuGrain & Mrs. Halima AbuGrain

For giving me their precious morals, emotions and support. They instilled in me their ethics, persistent determination to face life without limitations. This extended to my brother Suhaib and sisters Duaá and Aliaá who pillar strength in my life.

I also dedicate this work to For those who always support me in my darkest hours, in my deepest despair, in my tribulations, through my doubts ,and frustration, in my turbulence ,through my joy and my sorrow, to Nihad.

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PREFACE

There is no presence. There is no absence.
There is only the difference between them, always and already in movement.

Michael Benedikt

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Chapter 1

INTRODUCTION

Cyprus as one of the largest islands in the Mediterranean has no petroleum reserves and is completely dependent on imported energy from petroleum products. The energy statistics of North Cyprus over the past 20 years shows high increases in annual electricity consumption, and in all sectors energy is being provided from Cyprus Turkish Electricity Authority (KIB-TEK) customers put oppressive pressure for the maximization of the suppling capacity, which is costly due to the high price of fossil fuel (Ilkan, Erdil, & Egelioglu, 2005). This uncertain load increase and the rising cost of fossil fuels, requires serious attention and consideration especially to buildings optimizations towards sustainability and energy efficiency (Kolokotsa, Rovas, Kosmatopoulos, & Kalaitzakis, 2011).

1.1 Background

Existing buildings in most developed countries represents 40% of end use energy consumption while producing 36% of global CO^2 emissions industrial countries (Eichhammer, et al., 2009), regarding to this, the international environmental sustainability certificates of buildings, implements as a key feature, the environmental impact of the building over its life cycle. Presently, these certificates have international standards such as the American standards LEED (U.S. Green Building Council USGBC, 2009), or been optimized to the local criteria according to the region such as LIDERA in Portugal (LiderA, 2011), HQE in France (HQE Association), and BREEAM in United Kingdom (BREEAM, 2016). Furthermore, in most countries around 1% of new constructions is added to the existing building stock every year, while 1-3% of old buildings is been replaced by new-built which increase the consumption of national energy and produces more dioxide gas to the environment (The International Energy Agency (IEA)), (Barlow & Fiala, 2007) (Roberts, 2008). The regional director at building performance institute Europe (BPIE) highlight the sizable untapped underinvestment source of cost effective energy saving (Buildings Performance Institute Europe, 2013)*"I believe that renovation of buildings to high energy performance standards could be one of the most cost effective investments a nation can make, given the benefits in terms of job creation, quality of life, economic stimulus, climate change mitigation and energy security that such investments deliver".* Thus, reducing energy consumption and integrating renewable energy sources for energy savings has become an international trend as a strategy for reducing the level of peak demand from the electricity grid, in addition, in 2012 the energy efficiency directive (EED) set a headline target of 20% energy efficiency in Europe by 2020 for all building sectors (Directorate-General for Energy, 2017). Therefore, energy efficiency in buildings and net-zero energy buildings (NZEB) concepts have attracted intense attention from researchers, architects, and engineers.

Nowadays, various countries are trying to approach net-zero energy concepts in their buildings and are planning to achieve this goal within a certain time. Together with EED, the Energy Performance of Buildings Directive (EPBD) stated in their official journal that all new buildings in European countries should be NZEB by the end of 2020 (EPBD recast, 2010). Regardless of the new construction, existing buildings are the largest energy consumers which are still operating, but require renovating in order to decrease their energy needs; hence, EPBD set the existing and public buildings as a starting target in European countries (Buildings Performance Institute Europe, 2013), (Uihlein & Eder, 2010). In addition to the NZEB concept, the cost-optimal concept is introduced in the EPBD, which focus on the economic life cycle of the building. Following the European energy goals, Cyprus outlines the minimum requirements for the NZEBs (page 45 in ref. (EPISCOPE, 2014))

NZEB refers to a building consuming equal (or less) energy than what it produces within a single year. The idea of starting a time-period assessment for NZEB that refers to a yearly basis is critical, so as to allow variations in different seasons of the year. Therefore, the highest amount of energy needs in the winter (due to lower sun gains) for heating can be balanced at the end of year by energy delivered from renewable energy sources during the summer (Torcellini, Pless, Deru, & Crawley, 2006).

Many guidelines for early design stages have been set in order to achieve this goal for new construction (Biesbroeck, Klein, Versele, & Breesch, October 2010); different strategies and frameworks have been provided to achieve desirable results in existing buildings (Carmichael & Managan, 2013) and there are many examples of retrofit projects that achieve this goal. However, each project applies different strategies according to its type, local climate, and other measurements. In the case of North Cyprus, winter represents the peak energy demand load curve, which is basically consumed by residential sector (Cyprus Turkish Electricity Board, 2002) according to the working hours. Statics shows if 5% of the existing residential buildings implement stand-alone renewable energy production system, this will lead to 4% decrease in the peak demand (Ilkan, Erdil, & Egelioglu, 2005). In terms of public buildings, which is the focus of this research, main operating schedules is during the day time, where the maximum benefits can be obtained from photovoltaics to provide demanded energy. As such, it is important to regenerate the design of existing buildings which can play a key role in developing strategies towards the zero energy concepts in North Cyprus.

Renewable energy systems (RES) play a key role in the upgrading of energy performance of a building, and is an important element in NZEBs and can result to appositive energy building (Morelli, et al., 2012) (Adhikari, Aste, Pero , & Manfren , 2012). A research on residential buildings in Cyprus explores the influence of different renovation scenarios on energy savings (Serghides D. K., Saboohi, Koutra, Katafygiotou, & Markides, 3-8 August. 2014). The study proved that photo-voltaic PV systems has a high impact in greenhouse gases reduction in addition to the effectiveness of the insulation in energy savings.

The public buildings or (non-residential building) have been neglected in the previous studies about NZEB in North Cyprus although it will be operating for many coming years. Educational buildings which is the focus of this research is under the category of public buildings. Generally, educational buildings has a great potentials in energy reduction due to its limited daytime operational schedules which can get the maximum benefits from the solar energy, consists of holidays (off-time) during the year which save more energy annually and can be a great potential for investment in term of the produced energy from renewable systems during this time, in addition of creating an educational environment for the sustainability field related students. Thus, this research focus on renovating an existing educational building located in the Eastern Mediterranean University (EMU) into a NZEB taking it as a typology building, and investigate the renovation feasibility by analyzing the optimized solution. Hence a validated renovation strategy for public buildings towards low/zero energy can be developed.

1.2 Statement of the Problem

The problem of this research is the insufficient energy usage of existing educational buildings. Energy problems and sustainability issues is a worldwide discussion these days, Cyprus as many developing countries suffering from the increasing in the global fusel fuel prices despite the fact its only depending on the importing fossil fuel to cover its energy demands. A research in 2008 by (Erdil, Ilkan, & Egelioglu, 2008) stated that the energy peak demand would be increasing in North Cyprus till 2020 which is manly affected by buildings. The normal increasing of energy consumption consequently had negative impact on environment and economic.

As been mentioned, the studies towards energy efficiency stated in literature are only for designing new buildings (AlAjmi, Abouziyan, & Ghoneim, 2016) (F. Causone, 2014), or for residential buildings. However there is a different Sustainable building standards in different countries such as LEED, AECB and PassivHaus provide guidelines for engineers and Architects in terms of designing towards energy efficiency and Zero energy buildings, yet, there are few studies in design strategies and standards provided for renovating public buildings towards energy efficiency and environmental design in North Cyprus.

1.3 Research Aim and Questions

This research investigate the applicable passive design methods and principles that can be applied in the existent building and their impact in maximizing the energy efficiency in Mediterranean climate, in addition of potentials to integrate renewable energy technologies on the building to generate the demanded energy aiming to develop a specific strategy for renovating educational buildings towards zero energy building and sustainability concepts with energy efficient usage in Cyprus.

Further, this research aims to provide stakeholders involved in developing long-term strategies for building refurbishment with some key elements; firstly, the renovation meaning will be described in the next section and identify the main elements of the process for its elaboration. For this purpose, lessons have been gathered from existing strategies and programs in different areas (including technology and sustainable development) and analyzed their various stages (including initiation, development, and evaluation). Some key elements can already be drawn from this analysis.

Generally, this research arguing that public buildings sector has a higher impact in upgrading the energy efficiency of the country and represents the key role in making North Cyprus meet the EPBD requirements, the research questions are:

1. How public buildings in North Cyprus can meet the energy performance of building directive (EPBD) stated goals for 2020 towards low/zero energy building concept?
2. What is the energy savings from such a strategy? Can public buildings in N. Cyprus being renovate towards a positive energy buildings?

1.4 Research Significance

This research is targeted to prepare a roadmap or a strategy for renovating public buildings towards NZEB European standards in North Cyprus. Renovating public building towards NZEB or sure plus energy building is important in reducing total energy consumption of the country, therefore European countries make a higher priority in its researches for the improvement of the old building stock. Further, provided renovation strategies can bring many profits to the building sector and people such as:

- Renovation strategies can help designers and owners to set long-term objectives, with intermediate targets and action plans according to the available budget and owner's priorities, covering a range of government and market parties, and providing an agenda for all involved to work within.
- For the building owners, building renovations provide a positive return on investment, who cut their energy bills.
- Building renovations generate jobs, tax revenue and better housing for all parts of society.
- For decision and policy makers, this results of this research can be useful in set and planning for the future of energy of Northern Cyprus.

Additionally, this research is taking a public building in EMU as case study, the results can help in renovating similar buildings towards NZE and upgrade the general standard of the university and can be the start of align North Cyprus by other European countries that are moving towards net zero energy.

1.5 Research Methodology

This research will mainly adapt case study methodology in order to acquire solid conclusions. Problem solving and surveying methodologies will be used as well. The case study building was carefully chosen according to its space-related characteristics which represent a typical public building in North Cyprus. Firstly, the building has been surveyed and analyzed through observation, which is presented via photos and computer simulations via Autodesk Ecotect analysis (Autodesk, 2016) to find and define the problems statistically. The data has been analyzed using both qualitative and quantitative methods to accurately determine the energy problems. Secondly, an energy optimization of these problems has been done through an energy modelling simulation (eQuest energy simulation tool (James J. Hirsch & Associates, 2009) based on energy performance of building directive EPBD Directive 366/2014. Finally, the energy simulation results after optimization are discussed in terms of their energy impact and cost effectiveness to develop a strategy to achieve zero energy building.

1.6 Research Limitations

This research is focusing on developing a strategy for renovating public buildings towards NZEB in North Cyprus. The term of public buildings covers different type of buildings such as commercial, governmental and educational, this study is limited to educational buildings. The field study is located in Eastern Mediterranean University.

Moreover, evaluations and optimizations proposals are targeted to the energy consumption of the building (heating, cooling). Thermal insulation for roof and walls in addition to the windows insulation will be investigated in terms of energy and cost-effectiveness regarding to the heating and cooling consumption.

Furthermore, all the computational assessment methods have done with the existing situation of the building under a standard operation and the human behavior were excluded hence it’s difficult to be estimated in energy modeling software.

Chapter 2

THEORATICAL BACKGROUND

2.1 Terminologies

The following section is providing reliable definitions background and terminologies of zero energy and net zero building characteristics and types, renovation towards energy efficient concepts and European countries ‘standards for renovations towards zero energy building are addressed as well.

2.1.1 Zero Energy Buildings ZEB

The energy flow in the building and renewable energy source alternatives determines the net zero energy NZE boundaries. Based on the buildings’ energy consumption or/and generation, four methods are being used to describe NZEB (Srinivasan, Braham, Campbell, & Curcija, 2012); Net-zero energy emissions, net-zero energy cost, net-zero energy source and net-zero site energy. On the other hand, NZE can categorized according to the demand-site renewable energy source location; off-site/off grid supply options and on-site/on grid supply options.

In Net-Zero site energy method generated energy from the renewable systems must equalize the building yearly energy demanded. In Net-zero source energy concepts the energy generated from the renewable technologies has to consider primary energy transformation factors. Net-zero energy cost is taking into account the annual economic balance, meaning that the amount of payback money to the owner from renewable energy systems are equivalent or more than the amount of energy bills of the building from other power utilities. Finally, the method of Net-zero emissions building means that the yearly energy demanded of the building emissions must be equivalent to the emissions-free renewable systems that the facility generate or bought (Torcellini, Pless, Deru, & Crawley, 2006).

Furthermore, there are many definitions for NZEB; it depends on the specific goal of the project and the different points of views of the owners and the design team, the economic issues, and energy costs that are more important for the owners. However, the national energy members are interested in renewable sources of energy, and designers are more interested in requirements and energy codes (Torcellini, Pless, Deru, & Crawley, 2006). As a general definition, net-zero energy (NZE) is the annual energy balance between the operation/demanded energy and the generated energy from the renewable sources (Marszala, Heiselberg, Bourrelle, & Musall, 2011), and a net-zero energy building (NZEB) is a building that produces enough energy to sustain itself. Considering NZEB concept into renovating public building maximize the energy efficiency in existing building, in addition, since exiting buildings will last for more decades, optimizing towards NZE also share in the sustainable urban development.

2.1.2 Definition of Net Zero Energy Buildings According to Energy Performance Building Directive

The Energy performance for building directive EPBD stated in (EPBD recast, 2010) a general description of nearly zero energy buildings *"have very high energy performance while the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby"*. Regarding to this general definition, it's the responsibility of each country or European Union EU member state

MS to define the term according to their national, regional or local conditions as it is clearly stated by the Directive. In addition, each national definition should take into account the energy needs for cooling, heating, ventilation and lighting and expressed the primary energy use as a numerical indicator in kWh/m^2 per year.

2.1.3 Renovation and Sustainable Renovation

There is no specific description to define building changes, however, a wide range variety of partially terminologies are being in use like; reconstruction, re-habitation, transformation, retrofitting, renovation and many others terminologies (Rosenfeld & Shohet, 1999) (Stenberg, Thuvander, & Femenias, 2009) (Michaityte, Zavadskas, & Kaklauskas, 2008). Each terminology has a variety meanings and depends on the scale and the range of actions on the building, the scale and type of the building, and diversity of motivations and reasons of making an intercession, for example social uselessness, functional, facades aesthetics, technical or preservation (Ebbert, 2010).

There are wide range of changes that can be made to the building from major renovation with big modifications to the original building components, to minor restoration or repairs with slightest of interventions. At one hand when the objective of renovation is to preserve the original building the type of refurbishment only arrest decay (Feilden, 2007). On the other hand the entire building can be under a major replacement or reconstruction or deep renovation for example if the aim is to change the function of the building (Johnson & Wilson, 1982).

Though the terms like; modernization, preservation or rehabilitation are rather universally used, other terms have more interpretation. The term “renovation “is been used by some authors as an indication of a least possible interventions (Ebbert, 2010), though others use the same term as an indication of more consistent upgrading of the specific building (Douglas, 2006). Further, the term ‘retrofit ‘is been used by some authors to emphasize the action of upgrading the building to a higher standard (Jaggs & Palmer, 2000) (Flourentzou & Roulet, 2002), like in the case of upgrading the building to the sustainable standards (Femenías & Fudge, 2010).

The term alteration is been used in 2011 by the new Swedish planning and Building Act (SFS, 2010) as an indication for changes in building’s appearance, function, structure or cultural historic value (Boverket, 2011). In conclusion there are lack of universally agreed terminology or definition, in this research the term ‘renovation’ is been used as an indication of middle range to major interventions.

This research is focusing on the improvement of the environmental issues and energy savings, which refers to sustainable renovation that achieves the economic, environmental and social sustainability requirements in changes to buildings. Reducing the operation and maintenance costs are often influenced by economic return (Egmond, Jonkers, & Kok, 2005).

Yet, in terms of financial issues the building’s renovation towards energy efficient is considered to be more challenging due to the high initial cost and low return of investment because of the slow increase of energy costs, the value of the building according to the market and complications to transmission the costs upon rent (Femenías & Fudge, 2010).

2.2 Related Literature

2.2.1 Developing Energy Renovation Strategies in European Union

In order to reduce the greenhouse gas emissions and to reach the energy reduction goals many studies at the European level implemented in order to evaluate the renovation potentials of existing building stock. As mentioned before in the introduction chapter, the Energy Performance of Buildings Directive EPBD stated in their official journal that all new buildings in European countries should be NZEB by the end of 2020 (EPBD recast, 2010). Nevertheless of the new construction, existing buildings are the largest energy consumers which are still operating, but require renovating in order to decrease their energy needs; hence, EPBD set the existing and public buildings as a starting target in European countries (Buildings Performance Institute Europe, 2013), (Uihlein & Eder, 2010).

By implementing three different scenarios, the research (Eichhammer, et al., 2009) investigates the general saving potentials in buildings;

- Low policy intensity (LPI) from an economical perspective (the usual market conditions for consumers in terms of cost effectiveness).

- High policy intensity (HPI) from an economical perspective (country or region scale cost effectiveness).

- Technical and common practices potential

By investigating the three scenarios impact on energy reduction for 27 European countries (Eichhammer, et al., 2009), the realizable decreasing in 2030 (life cycle method) was for technical scenario which achieve 73% reducing in energy consumption, follows by the HPI scenario which achieve 57%, and the less scenario reduction was for LPI which was 41% in energy reduction.

In terms of environmental perspective, a research project at European scale done by (Nemry, et al., 2008) called environmental improvement potentials of residential buildings (IMPRO) investigates twenty five European countries ‘residential buildings for the environmental life cycle impacts . The research shows analyzed the lessening the gained of environmental impacts with the support of technical upgrading possibilities.

In terms of decision making towards sustainable renovations, studies (Thuvander, Femenías, Mjörnell, & Meiling, 2012) shows that major renovations in European countries are rarely if the energy improvements is the main aim, though it is one of several corresponding needs. Moreover, according to the same survey (Thuvander, Femenías, Mjörnell, & Meiling, 2012) many renovations are conceded without taking into account achieving energy efficiency in buildings.

Increasing comfort levels is the main motivation towards renovation in European countries, in addition to modernization and upgrading the building towards extending component life (Meijer, Itard, & Sunikka-Blank, 2009). (Gruis, Visscher, & Kleinhans, 2006) Discusses the social deterioration and its role in motivating policy makers towards large renovations in existing buildings. Recently, a combination of the social improvements with the environmental consideration in addition to the energy efficiency measures in order to address comprehensively the sustainable renovation (Stenberg, Thuvander, & Femenias, 2009).

2.2.1.1 Directive 2010/31/EU on the Energy Performance of Buildings

The leading governmental instrument at European Union to make buildings energy efficient is the directive on energy performance of building (2002/91/EC). The European countries according to this directive should apply the specific requirements of the energy performance for existing buildings, in addition to ensure their energy certification. On 2010 the recast (EPBD recast, 2010) was accepted to make the buildings' requirements of the energy performance in addition to make the previous requirements more clear.

The EPBD recast sets a target on 2020 and states that all new buildings by that date will be (nearly zero energy building) in addition to the existing buildings that is undergoing under major renovation.

The recast states general outlines for buildings 'energy performance, firstly the energy efficiency measures EEMs for the selected building should consider the indoor climate environment in addition to the climatic and local conditions and cost effectiveness (EPBD recast, 2010). The other buildings requirements should not be affected by these measures, such as circulations, planned function of the building and safety. Moreover, each country and region should calculate the building energy performance according to its local and environmental conditions, such as heating and air conditioning integration, thermal characteristics, the type of the renewable energy sources, daylighting, shading in addition to the passive cooling and heating elements (EPBD recast, 2010).

Regarding to the previous, NZEB concept is depending on the yearly energy performance of the building, therefore the methodology for buildings 'energy performance calculations should cover the yearly energy performance of the selected building, not only the season in which cooling is required or heating is required.

2.2.2 Building Renovation Objectives and Challenges

Existing building renovation towards energy efficiency faces many prospects and challenges, including human behavior, climate change, governmental policy change, services change, etc., which influence the renovation method selection and therefor the renovated project success (Ma, Cooper, Daly, & Ledo, 2012). Due to these challenges and interactions each type of renovation measure has a different influence on related building sub-systems, consequentially selecting of the renovation technique turn out to be very complex. At any process of sustainable renovation these considerations is a considerable technical challenge. On the other hand the economic issues and barriers, operation costs and perceived long payback time considered to be challenging in renovation existing buildings towards sustainability and/or energy efficient concept (Tobias & Vavaroutsos, 2012).

On the other hand, renovating existing buildings towards energy efficiency provides reliable chances for increasing staff productivity, improving energy efficiency, improving indoor thermal comforts and reducing maintenance costs (Sweatman & Managan, 2010). In addition to improving a country’s energy security, inventing job opportunities, reducing exposure to energy cost instability (Sweatman & Managan, 2010).

2.2.2.1 Building Renovation Problem

The problematic in the building renovation optimization is to assess, instrument and use the most economical renovation measurements to achieve improved energy performance while providing satisfactory thermal comfort levels, under a given set of operational restrictions (Ma, Cooper, Daly, & Ledo, 2012). Thus, there are two main renovation problems that should be considered in the optimization of an existent building; the stages of the renovation and the elements which influences the renovation (Ma, Cooper, Daly, & Ledo, 2012).

Cooper discussed in his review (Ma, Cooper, Daly, & Ledo, 2012) discusses the main key phases in the sustainable building renovation, which are; stage one is the building setup and pre-renovate survey, stage two is the energy audit and performance assessment, stage three is the identification of renovate alternatives, stage four is the site operation and commissioning, and the last stage is the validation and verification of energy savings. Fig.2 shows detailed this key phases.

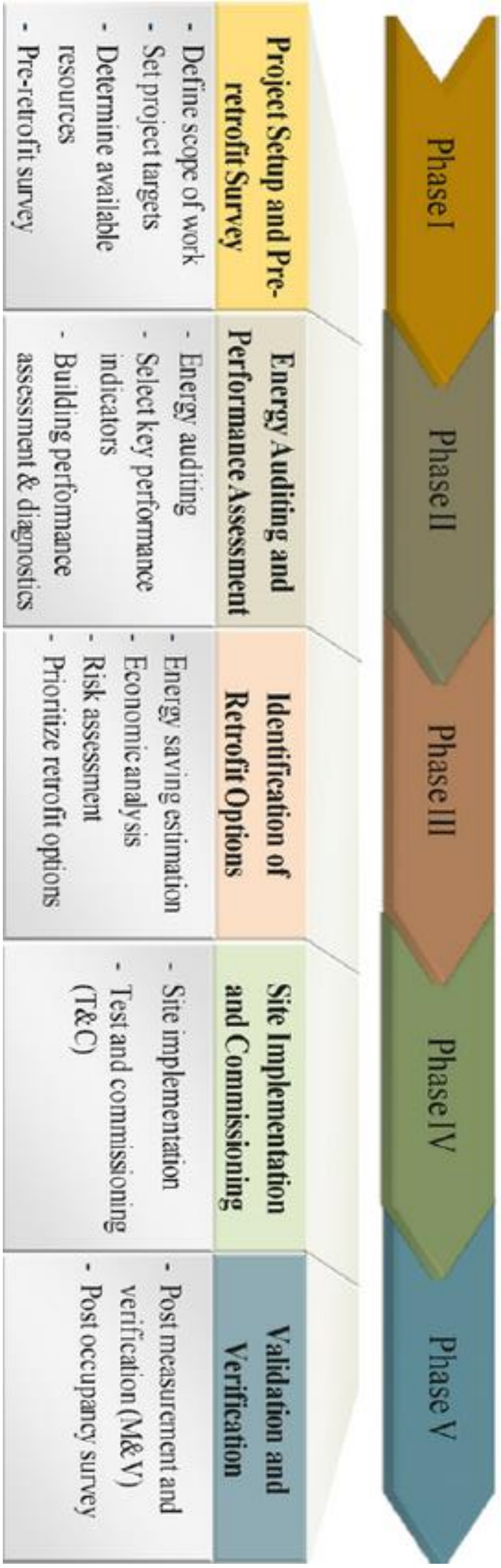


Figure 1: Key phases in a sustainable building retrofit programme (Ma, Cooper, Daly, & Ledo, 2012)

After taking in consideration the previous phases, and in order to make the renovation success, (Ma, Cooper, Daly, & Ledo, 2012) highlighted the key elements that influenced the building renovation. (fig.2) shows this elements which is including human factors, other uncertainty factors, governmental policies and guidelines, customer funds and prospects, renovation methods (passive/active strategies) and building specific information.

Governmental policies and how the polices has changing has been summarised in (Tobias & Vavaroutsos, 2012) (Baek & Park, 2012) such as European Union standards towards green buildings. Client’s concerns has been discussed in (Harris, Anderson, & Shafron, 2000). A several studies investigates occupants behaviour in its effect in energy savings (Owens & Wilhite, 1988) (Yohanis, 2012) (Santin, Itard, & Visscher, 2009).

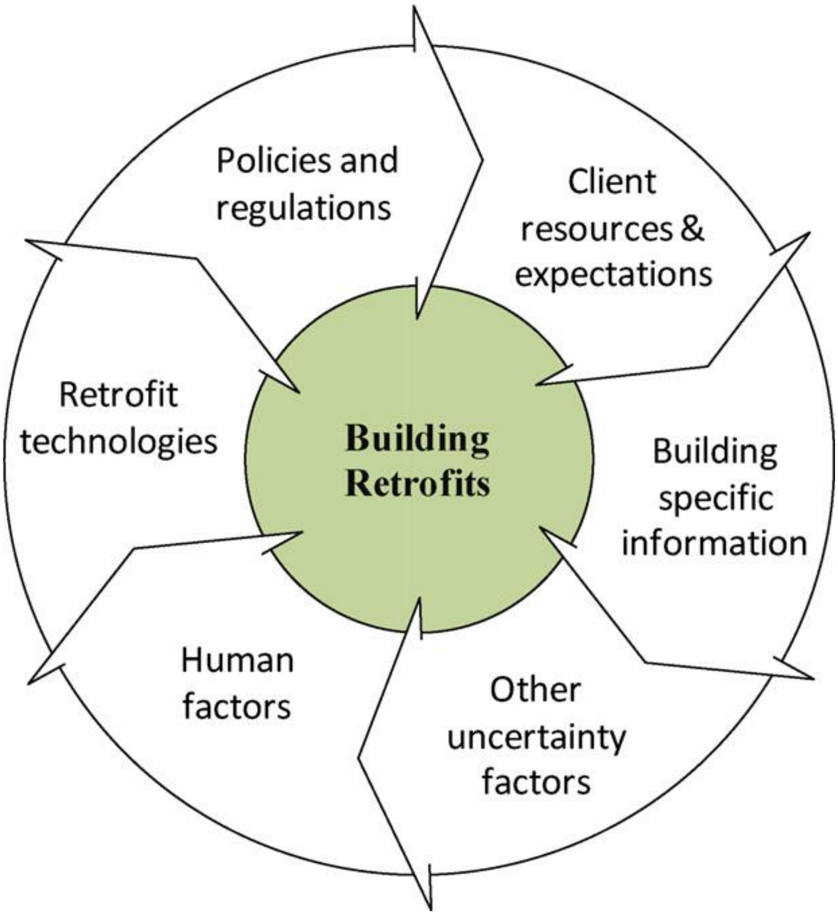


Figure 2: Key elements influencing building retrofits (Ma, Cooper, Daly, & Ledo, 2012)

2.2.3 The NZEB Objectives and Challenges

This following part highlights the parameters that influences the ability of buildings for reducing energy consumption and programmatic factors (architectural elements) for meeting the ZEB goal.

According to Professor François Grade's research about NZEB design (Garde, et al., 2014), there are two major factors that must be considered and analyzed in the early design phases to achieve NZEB targets:

1. Optimizing the passive solar energy concepts to reduce building energy consumption.

2. Generate sufficient electrical energy by renewable energy sources to reach energy balance.

Integration of passive techniques acts as a critical apparatus of ZEB design towards goals. It has direct influences on thermal balance and lighting loads that affects the electro-mechanical systems of the building. This creates noticeable indirect reduction in heating/cooling, lighting and ventilation energy consumption that sufficiently balanced by renewable energy systems (Garde, et al., 2014), thus, this research discuss the implementation of optimization of passive energy method to the case study in order to reduce the energy consumption.

2.2.3.1 The Problem with Net-Zero Buildings

The former member at the Leadership in Energy and Environmental Design LEED highlighted the net-zero neighbourhood/community concept in his online article (Malin, 2010), and discuss the problem of achieving zero energy for high rise buildings and found that achieving zero energy on low rise building on a low-rise density profile have greater potential towards zero energy while using onsite renewable energy devices.

Regarding to the previous, an argument rise up about the efficiency of built or renovate existing buildings towards zero energy or work through several buildings or communities or a campus. At the national scale, high energy efficient building standing alone is not useful or worth to invest for rather than a making the entire community or the neighbourhood as net-zero (Malin, 2010). Thus, this research take a public building in a university campus and to test the hypotheses of optimizing single building towards net-zero energy and its role in developing the campus energy efficiency even if some buildings are not or cannot achieve zero energy.

2.2.3.2 Number of Stories and Floor Area

In order to balance the consumed energy most buildings integrated solar photovoltaics (PV) in order to generate energy. The roof top area is the most applicable area for installing PV, therefore a multi-story or high-rise building is much less likely to accomplish net-zero than a single-story or low story buildings.

The United States department of energy (DOE) in a report in 2007 (Griffith, et al., 2007) with the national renewable energy lab (NREL) analyzed the possibility of achieving net-zero energy for buildings in the U.S by using energy technologies. The (fig.3) below illustrates the percentage of achieving net-zero with the relation of its number of stories. The results of the report shows that achieving net-zero is exceedingly hard for buildings of more than 4 stories. And if the building contains energy-sensitive data centers it gets harder.

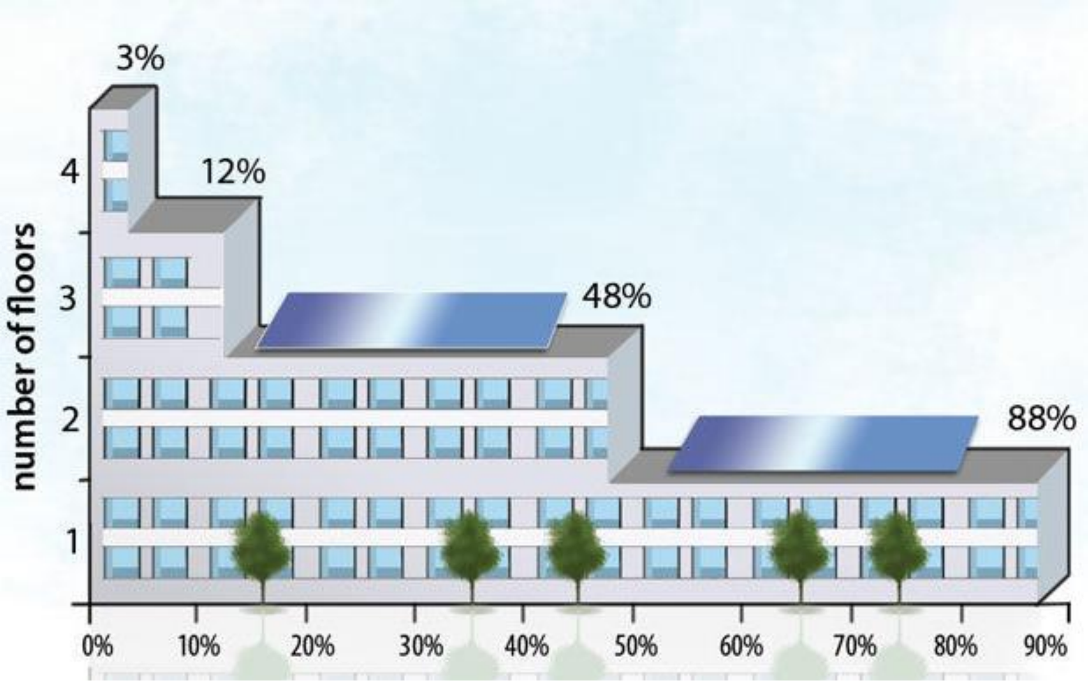


Figure 3: Percent of U.S buildings by floor area that could achieve net-Zero as a function of number of floors (Griffith, et al., 2007)

The report results shows that overall building mass is not an indication of if the specific building could reach ZEB or not.

2.2.3.3 Load Expansion & Cascading Usages of Energy Concept

The combination in society's residences can provision even more efficient usage of cascading energy consumption and infrastructure (Malin, 2010). For instance, public buildings like offices, educational and governmental buildings consume most of their energy during the day time, on the other hand the residential buildings consumes most of their energy during the night time. Accordingly, one cooling or heating plant or RES that is providing energy for both can be as size as plant providing energy for single building (Malin, 2010).

2.2.3 Zero Energy Building Covered Energy

Heating energy was the considerable share of energy in seventies and eighties in buildings, thus NZEB was known as the building which covers its space heating demand in addition to supply demanded domestic hot water DHW by applying energy conservation technologies such as heat recovery system, additional insulation or solar space heating (Esbensen & Korsgaard, 1977).

Other researches taking in consideration just the electric demand in NZEB concept, (Gilijamse, 1995) illustrates that the building should generate the demanded annual electricity while not consuming fossil fuels at all.

Recent researches takes in consideration both annual heating demand and electric consumption in terms of addressing NZEB energy efficiency (J Laustsen, 2008).

2.2.4 Passive Strategies towards NZEB

Integration of passive techniques acts as a critical apparatus towards zero energy building design goals. It has direct influences on thermal balance and lighting loads, which affects the electro-mechanical systems of the building. This creates a noticeable indirect reduction in heating/cooling, lighting, and ventilation energy consumption that is sufficiently balanced by renewable energy systems (Garde, et al., 2014).

The appliance of passive strategies constitutes many challenges correlated to the building type, climatic conditions, CO_2 emission levels, and optimum energy performance, consequently, by collaborative research with the Solar XXI project, built in 2006 at LNEG Campus in Lisbon (Gonçalves & Cabrito, 2006)], which claims to be an example of a low solar energy building integrating inert strategies for heating and geo-cooling systems to achieve NZEB (Gonçalves H. , 2010). Photovoltaic panels are integrated in the facade design with a heating system for thermal balance in winter. Otherwise, a geo-cooling system (ground tubes) assisted by night cooling approaches work together to cool the building in summer.

2.2.4.1 Optimize Passive Solar Architecture to NZEB

According to (Laura Aelenei, 2014) the principle of net-zero building recognized as natural building (i.e., the building produces energy on-site as much energy to contribute to grids as it consume on-grids), when energy efficiency measures are sufficiently incorporate supplementary renewable energy technologies. To achieve net zero energy performance, two essential steps must implemented:

- Minimize building energy demand. Optimizing passive solar energy would act an essential role to present a Net-ZEB design due to direct impact on electro-mechanical systems that covers needed loads. In addition, this would solve renewable energy generation challenges.
- Produce sufficient energy (i.e., electricity or heating power...) to balance building operation demand of energy.

2.2.4.2 Thermal Insulation

The understanding of the relation between thermal insulation and energy reduction has been developed expressively over time as well as the developing in heat insulation materials of the building envelope and integration techniques. Buildings that filling the existing European regulations or any other country would not have been imaginable with the old structures and materials of sixteen’s without expensive constructions.

Moreover, in new buildings the heat loss through the construction’s walls is considerably reduced although it’s in low-cost and simpler by using current materials, though, according to a recent report in Finland (Häkkinen, et al., 2012), renovating existing buildings just for the energy efficiency/saving purpose is rarely profitable. To make the renovating action feasible and profitable it has to be in addition to other renovation actions, like adding exterior insulation when re-rendering the façade or replacing damaged windows by modern ones.

The largest part of the building envelope is normally the external walls, consequently having a large impact on the heat gaining and losing of a building. There are different ways that additional thermal insulation could be integrated in a building (Häkkinen, et al., 2012). The main two types are; additional internal thermal insulation and additional external insulation. External insulation method is normally the easiest solution for renovating the thermal insulation of the external walls. When using this technique for adding more insulation to the building, the joints of the internal and external walls with the floor slabs will not need for an insulation due the existing water vapor barrier stays intact (Häkkinen, et al., 2012).

In terms of energy savings, the building energy consumption is influenced heavily by the thermal resistance (R-value) of the external walls, especially in high wall area ratio. Recent study (Christian & Kosny, 2006) founds that the whole wall R-value is not considered in most standards like ASHREE (ASHRAE Handbook of Fundamentals, 1993) and only using center-of-cavity R-values which not taking into account the interface connections and the framing factor, which leads to 25-50% lesser in thermal insulation comparing with whole wall R-value.

A recent research discussed walls insulation materials for energy savings (Sadineni, Madala, & Boehm, 2011) and founds that the phase change material PCM results high energy savings compared with other walls type. An earlier study (Athienitis, Liu, Hawes, Banu, & Feldman, 1997) about the inside thermal comfort founds that the temperature inside the room is being lowered by 4. C after optimizing the exterior walls insulation with PCM based wall linin material, which influence the heating energy consumption during the night. Moreover, (Kuznik & Virgone, 2009) founds the inside temperature reduced by 4-2.C after using PCM based composite wall boards as an insulation material. Thus, this material is recommended to be used as an insulation material for Mediterranean region due to its economical and its remarkable energy reduction results.

2.2.4.3 Daylighting and Shading Strategies

Since implementing the passive solar energy in the building influences the loads in the electro-mechanic system, passive strategies takes a vital position in NZEB design. Studies proved that efficient integrating of passive shading controls in the building envelope and building elements dramatically reduce the annual lighting energy demand by 40%, and this percentage increases to 60% if automated shading device have been integrated (Tzempelikos & Athienitis, 2007). Moreover, effective controlling of daylight can reduce 10-20% of the annual cooling/heating energy demand (Tzempelikos & Athienitis, 2007).

In general, the consideration of optimizing passive heating and cooling strategies are combined together in order to prevent glare by direct sunlight and overheating in cooler seasons. In addition, the thermal mass of the building provides a method to achieve passive cooling, which significantly reduces the cooling loads (Çomaklı & Yüksel, 2003) (Al-Turki & Zaki, 1991) for taking advantage of daylight and natural ventilation. Meanwhile, in hot seasons, distinguished by the use of the fresh air and the building's loss heat at night it is the non-use of the walls' thermal insulation that prevents heat loss during night time.

In terms of the indoor thermal comfort, a research done by (Da Silva, Leal, & Andersen, 2012) investigates the impact of shading control strategies and façade option on energy demand of the building in order to optimize the energy consumption. By using simulation based research done by (Mahdavi & Dervishi, 2011) compares different alternatives of lighting control in the relation with visual comfort and its influence on energy demand.

Moreover, a research (Nielsen, Svendsen, & Jensen, 2011) investigates alternative automated dynamic solar shading for altered facades in a simulation and taking in consideration daylight and it’s in impact in energy consumption. Other studies implemented experimental methods for studying the balance between daylighting benefits and energy requirements in term of solar gain and control by taking in consideration windows and glazing size and shading options to measure their impact in daylighting and energy consumption (Shen & Tzempelikos, 2012).

Furthermore, implementing exterior shading strategies reduces the peak energy consumption, which result reducing the relaying on electro-mechanical devices to achieve thermal comfort. Similarly, reducing the direct glare gains influenced positively in energy savings

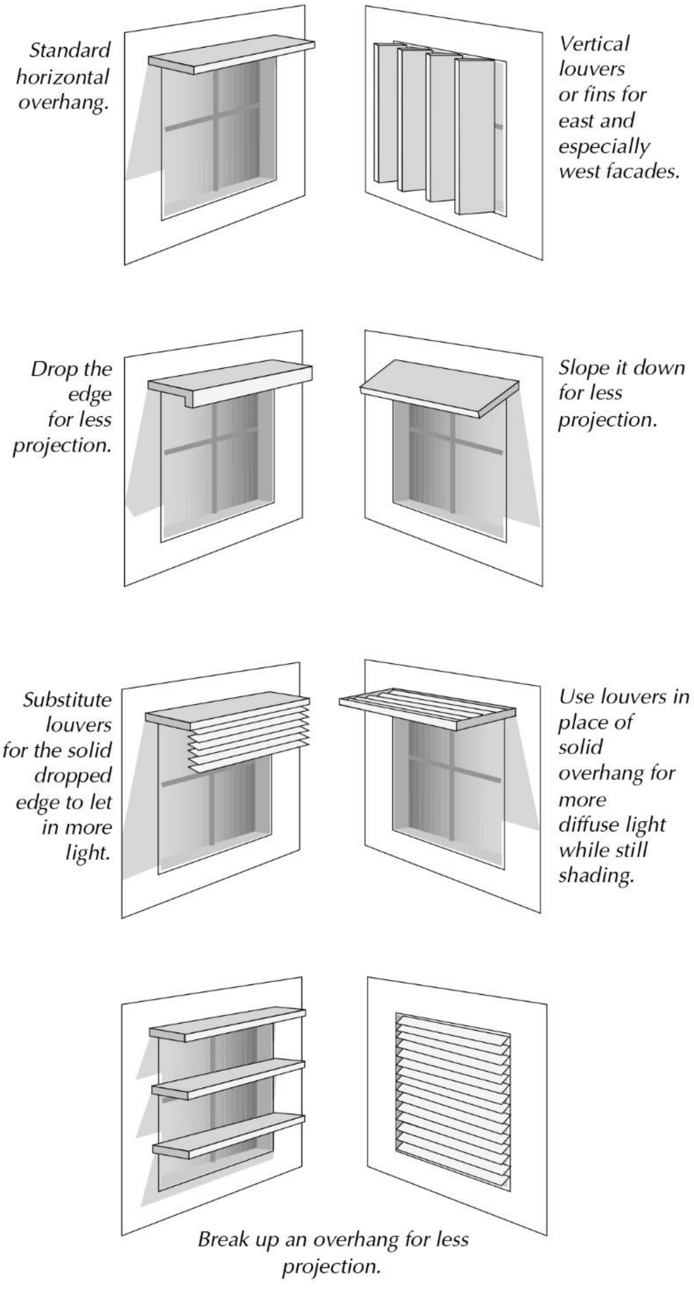


Figure 4: Samples of Basic External Shading Strategies for Side Windows (Retrieved from Robinson, A., & Selkowitz, S., 2013).

2.2.3.4 Fenestration (Windows Size and Glazing)

Furthermore, opening sizes and glazing specifications in the facade has a direct influence on the indoor thermal comfort in warm climate conditions (Alibaba & Ozdeniz, 2016), which affects the cooling and heating loads, and on the use of daylight which affects the lighting loads (Poirazis, Blomsterberg, & Wall, 2008).

In terms of the ventilation impact on building energy consumption, recent research using for dynamic thermal simulations EDSL Tas software found the percentage of the window openings' influence on the thermal comfort and energy consumption for cooling and heating for different seasons in a hot and humid climate (Alibaba H. , 2016). These results found that lowering the window to wall ratio (WWR) decreased the energy consumption and a large WWR increases energy consumption. However, a large WWR increases energy consumption in all climates (Susorova, Tabibzadeh, Rahman, Clack, & Elnimeiri, 2013)], the small WWR affects the daylighting efficiency (Juodis, 2011), and lighting consumption can be managed by using controllable electric lighting systems and optimum shading devices, especially for large glazing sizes (Johnson, et al., 1984). However, energy consumed, in this case by HVAC systems for heating and cooling, must kept in mind.

To conclude, The U-value and G-value of the glass are important factors in terms of cooling and heating energy consumption, and lowering the U-value respectively decreases the energy consumption for different WWR and increases the energy efficiency of the building (Grynninga, Gustavsena, Timeb, & Jelleb, 2013). Meanwhile, ten different glazing types were simulating in different climatic zones (Singh & Garg, 2009). According to this study, the solar heat gain coefficient (G-value) the thermal conductivity (U-value) of the window is not the only factors that influencing the annual energy savings, nevertheless it’s been affected by the climatic conditions, orientation and building characteristics like insulations levels.

Additionally, the Windows’s frames should be taken into account in losing and gaining of the thermal bridges, an early study by (Robinson & Hutchins, 1994) evaluate a different frames U-value and the advanced glazing technology and its impact on energy consumption. In the case of smaller windows size or small WWR the frame impact on energy consumption are more pronounced. The importance of the low-conductance window frames was highlighted by (Gustavsen, Arasteh, Jelle, Curcija, & Kohler, 2008).

After reducing building energy consumption, in order to balance the annual energy it is important to integrate a renewable energy technology device. In the following will highlight the RES role in zero energy buildings.

2.2.5 Renewable Energy Connection Type in ZEB

As been mentioned, net zero energy building concept indicates that energy generated from renewable energy technologies should covered the annual primary energy use of the building. Generally, the connection between the renewable energy source and the building is divided into two groups according to the integrated place of these technologies; on-site and off-site renewable energy supply (Marszal, Heiselberg, Jensen, & Nørgaard, 2012).

On-site renewable energy system supply (on-site RES) indicates that the building is connected or attached directly to the energy generation device, either integrated to the building or placed near to it. (fig.5)

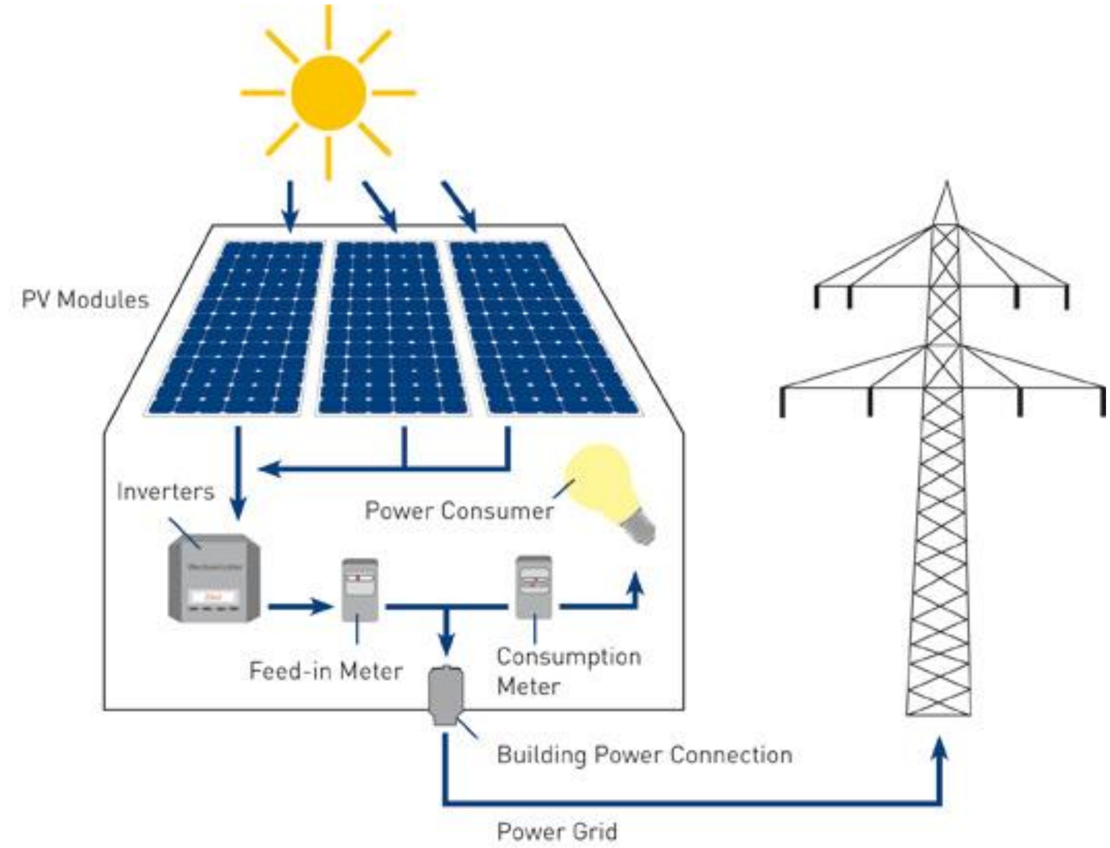


Figure 5: on-grid renewable energy supply (Green Sun Rising Inc. , 2015)

In off-site renewable energy system (off-site RES), the devices are placed outside the building’s boundaries, or the generated energy is been purchased to reach the zero energy goal without being connected to the grid. (fig.6)

According to (Marszala, Heiselberg, Bourrelle, & Musall, 2011) the limited area on the building envelope may be a barrier in applying on-site RES, though it is most popular alternative.

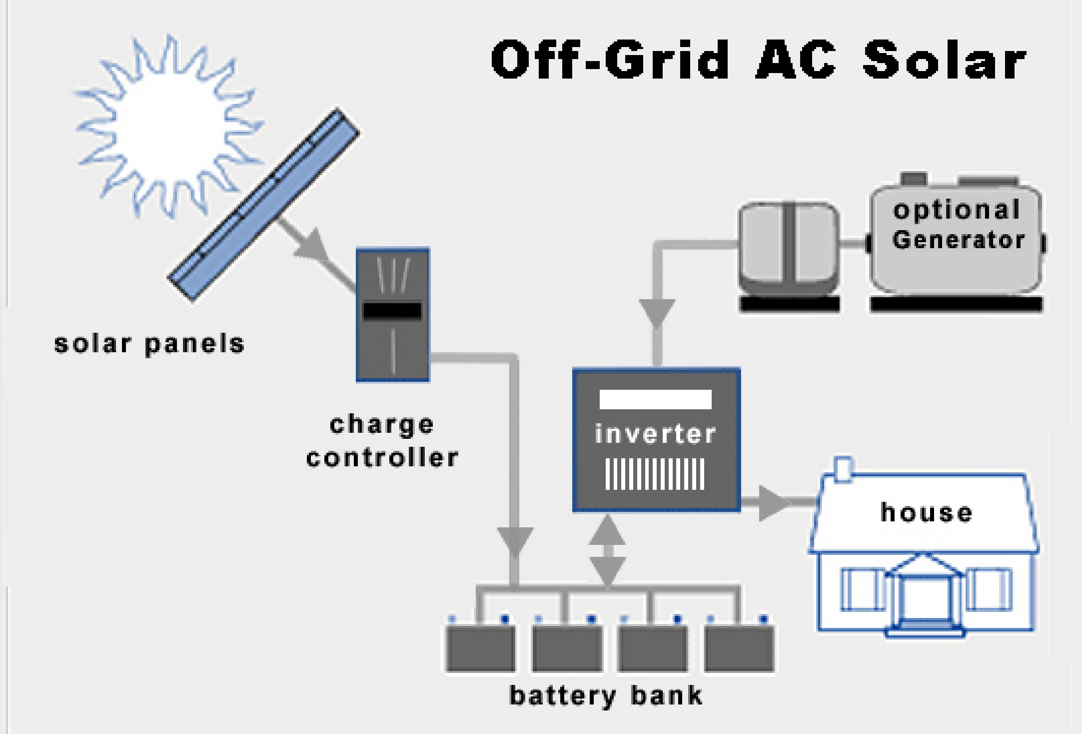


Figure 6: off-grid renewable system supply (Wholesale Solar, n.d.)

2.2.6 Renewable Energy Systems

Regarding to the previous, photovoltaic PV for electricity and solar thermal collectors panels STC for domestic hot water are the most renewable energy systems commonly used for on-site RES for meeting zero energy goals (Marszala, Heiselberg, Bourrelle, & Musall, 2011) (Voss & Musall, 2012). Additionally, (Marszal & Heiselberg, Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark, 2011) applied this approach in al life cycle cost LCC analysis in order to explore the financial relation between on-site RES and energy efficiency improvements for a multi-story zero energy building.

The study (Marszal & Heiselberg, Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark, 2011) founded that from a financial point of view, the NZEB’s cost optimized is a building with a great energy reduction in a year (20kWh/m^2.year) and integrated on-site RES.

For North Cyprus, most researches in terms of economical and availability perspectives, indicates that PV panels on-site and on-grid tied option is the best solution for generating demanded energy (electricity) to reach zero energy concept in North Cyprus (Causone, Carlucci, Pagliano, & Pietrobon, 2014) (Pathirana & Muhtaroglu, 2013). Moreover, (Pathirana & Muhtaroglu, 2013) analyzed different types of PV energy generation for off-grid and on-grid connection for North Cyprus, results shows that off-grid RES is not economically feasible for North Cyprus. Table 1 below illustrates different PV's type's energy generation costs in North Cyprus.

Table 1: different off-grid photovoltaics electricity generation costs in North Cyprus (Pathirana & Muhtaroglu, 2013).

PV panels	Cost of energy (electricity) generation ($/kWh)
Thin film Si	0.24
mc-Si	0.24
c-Si	0.25

Moreover, the results of the same research (Pathirana & Muhtaroglu, 2013) illustrates that on-grid RES generated energy price is less than the public grid price in Northern Cyprus. Table 2 below illustrates on-grid PV electric generation.

Table 2: different on-grid photovoltaics electricity generation costs in North Cyprus (Pathirana & Muhtaroglu, 2013).

PV panels	Cost of energy (electricity) generation ($/kWh)
Thin film Si	0.13
mc-Si	0.13
c-Si	0.14

Other renewable energy sources for Northern Cyprus has been investigated in (Biricik & Ozderem, 2011) such as wind turbines.

Regarding to the previous, this thesis is focusing on the electric consumptions only, according to the studies for the Mediterranean climate and especially for Northern Cyprus, PV solar panels are the common technology. And results (Bavafa, 2015) shows that on-grid PV for energy generation is economically feasible. And Mono-crystalline PV panels is recommended due to its operational and maintenance availability in Northern Cyprus.

2.2.7 Zero Energy Buildings in Mediterranean Climate & North Cyprus

Subtropical climate is the main climate type at the Mediterranean climate and the lands around Mediterranean Sea including Northern Cyprus (Peel, Finlayson, & McMahon, 2007), consists of very warm summer and relatively mild winter.

Due to the high solar radiation and the long day range, the most challenging issue is the building cooling during summer season (Pagliano, Carlucci, Toppi, & Zangheri, 2009). On the other hand, during winter, heating requirements can be achievable by means of the passive strategies due to the plentiful solar radiation during the day time (Pagliano, Carlucci, Toppi, & Zangheri, 2009).

In addition to the thermal insulation in 2.2.4.2 section, studies shows that by using the floor slab's thermal mass the heat energy consumption can be reduced especially if it is integrated together with the thermally insulated walls (Serghides & Georgakis, 2012).

In terms of reaching zero energy concept for Mediterranean climate, an experimental research (Causone, Carlucci, Pagliano, & Pietrobon, 2014) implement passive strategies targeting reduces the cooling energy consumption and integrate PV and STC to balance the annual energy consumption.

Regarding to the current situation in Turkish Republic of Northern Cyprus TRNC towards zero energy concept, buildings are mostly designed and built based on traditional methods which dramatically increasing the energy demand regardless to the esthetic issues (Bavafa, 2015). Recent researches in TRNC was discussing pre-design stages and provide alternatives for external walls insulation materials, thermal mass, U-values, WWR options and layers (Baglivo, Congedo, & Fazio, 2014) (Stazi, Tomassoni, Bonfigli, & Di Perna, 2014) . Other researches investigates the renovating strategies impacts on energy savings (Serghides D. K., Saboohi, Koutra, Katafygiotou, & Markides, 2015) (Serghides D. , 2014) although all these attempts was for low rise residential buildings.

Regarding to the previous, and in order to achieve E.U zero energy targets (EPBD recast, 2010), the published Directive 366/2014 specify NZEB energy minimum requirements for Cyprus (table3) (Atanasiu, et al., 2014) These energy requirements are for Southern Cyprus, thus, this thesis applied the same provided energy specification requirements as a standard reference, due to the same climatically conditions and buildings architectural type and characteristics.

Table 3: NZEB requirements for public buildings in Cyprus

Technical specifications - Construction Element	**U-Value (W/m^2k)**
Flat roof	0.40
External walls	0.40
Double glazed windows	2.25
Energy performance specifications	**Minimum requirements**
Total annual energy consumption	125 kWh/m^2a
Renewable energy percentage of the total primary energy consumption	25%

2.2.8 Tools and Methods for Assessing Sustainable Renovation

From a sustainable or environmental perception there are a wide-ranging international methodologies for evaluating or categorizing buildings. There are methods focuses on local conditions and others taking in consideration global aspects. In United Kingdom the building research establishment environmental assessment technique (BREEAM, 2016) considered to be the first standard since 1990 for environmentally evaluating renovation of existing buildings. Other international standards LEED was implemented for United States (Council, U. G. B., 2013), CASBEE for Japan (Council, J. G. B., & Japan Sustainable Building Consortium, 2013), DGNB for Germany, etc.

On the EU level, the SurPerBuildings standard (SuPerBuildings, n.d.) Assessments the existing evaluation tools according to three aspects; socially, economically and sustainability. The study (Malmqvist, et al., 2011) in Swede made a comparison for unique characteristics of the environment assessment tool.

A great sustainability list indicators integrated together in the OPEN HOUSE project (Thuvander, Femenías, Mjörnell, & Meiling, 2012). A research highlight renovation methodologies standards and specify the best criteria for building renovation tool (Sidwell, et al., 2004). The highlighted methods rarely in relation to the procurement method or construction management (Sidwell, et al., 2004).

2.2.9 Renovation's Life Cycle Cost Methodologies

The cost optimal concept where introduced together with the NZEB concept in the EPBD (EPBD recast, 2010), which is concerning about the cost of the energy efficiency measures EEM throughout the predictable economic life cycle of the building (Cambeiro, Armesto, Barbeito, & Bastos, 2016).

The life cycle cost LCC method is an important to be highlighted due to its key role in the selection of the renovation type for owners or policy makers.

In terms of renovation procedures, LCC evaluates the building performance in terms of its cost, including maintenance, disposal, and development (Cambeiro, Armesto, Barbeito, & Bastos, 2016). Different researches shows that LCC methodology established as a clear terminology in ISO 15686-5 (Langdon, 2006) (Marszal & Heiselberg, Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark, 2011). (Tanasa, Sabau, Stoian, & Stoian, 2014) And (Marszal, Heiselberg, Jensen, & Nørgaard, 2012) compared different on-site photovoltaics panels LCC. A research done by (Sesana & Salvalai, 2013) highlighted on life cycle methods and financial possibility for NZEB.

In order to select a specific renovation measure or alternatives passive design strategies, economic analysis can provide an indication of whether the renovation measurement are energy efficient cost wise or not (Ma, Cooper, Daly, & Ledo, 2012).

Many studies (Kreith & Goswami, 2008) (Krarti, 2016) presents a range of financial analysis methodologies which can be implemented to assess the cost-effective feasibility of building renovation measure, such as benefit-cost ratio (BCR), simple payback period SSP and net present value NPV.

The cost effective variability for alternative renovation options by implementing NPV method discussed in (Verbeeck & Hens, 2005). Net present value NPV considered as the preferable method for optimal building energy valuation (Remer & Nieto, 1995). The method of life cycle cost assessment was applied by (Kaynakli, 2012) for selecting the optimal thermal insulation thickness for energy savings calculations. A combination of four methods where used in (Nikolaidis, Pilavachi, & Chletsis, 2009).

This thesis was not applied of the previous methods in its analysis and focuses on energy consumption. Yet, the previous studies shows that cost-effective assessment methodologies helps the decision makers or/and the designers in the selection of the optimal building design renovations.

2.2.10 Measurement of Energy Savings

After implementing passive strategies or energy efficiency measurements EEMs to an existing building in order to optimize its energy consumption, energy savings been determined by measurement and verification M&V process by an energy management program (Cowan, et al., 2001). M&V key goal is to calculate actual energy savings after implementing renovation actions. After calculate the energy difference between the after renovation consumption and before renovation energy consumption energy savings can be determined by Eq.1;

$$E\text{sving} \ = E\text{pre-retrfo} - E\text{post-retro} \ \pm E\text{adjust} \quad (1)$$

$E_{\text{saving:}}$ the amount of energy saving.

$E_{\text{pre-retro:}}$ base-line run which is the existing energy consumption before renovation (calculated or being estimated)

$E_{\text{post-retro}}$: the amount of energy consumption after optimization (calculated or being estimated)

E_{adjust}: is the difference between the energy consumption in the existing situation and after optimization consumption, which is affected by any changes in non-energy renovation factors.

According to the worldwide protocol (Cowan, et al., 2001) there are 4 M&V preferences for the estimation and calculate renovation energy savings, preference A: renovation isolation – all parameter measurement, preference B: renovation isolation – key parameter measurement, preference C: standardized energy simulation and preference D: entire building. Detailed methodologies of M&V studied in (Cowan, et al., 2001) (AEPCA, 2004).

Many researches applied M&V to calculate energy savings, Mozzo in his research (Mozzo, 1999) argued the significance of M&V in performance contracting projects. (Lee, 2000) illustrates in his investigation about determine yearly energy savings associated with lighting renovation applying long and short term monitoring a three case studies using M&V. and many other early studies discussed different aspects of M&V in their calculations and analysis for renovation (Roosa, 2002) (Kromer &

Schiller, 2000) (Erpelding, 2008).

Regarding to the previous, the results of these researches specified that M&V is an effective method for estimating, calculating and measure energy savings accomplished after applying renovations measures, thus this method is applied in this research for the verifying energy savings after optimizations.

2.2.11 Building Simulation Software/Programs

Due to the fact that calculating an accurate real energy consumption of an existing building is quite difficult, because of the human factors and difficulties in collecting the information of loads in addition to the time factor, computer programs can provide a reliable energy quantification and estimation and help decision makers in selecting the renovation measures.

Different renovation measures performance is been assessed through energy modelling and simulations. Different input parameters affect the accuracy of the building energy simulations, such as building type (educational, commercial or residential), construction type, building envelope geometry and orientation, location, mechanical loads and users or building operating schedules.

A comparative study done by (Crawley, , Hand, Kummert, & Griffith, 2008) for twenty building energy simulations codes, such as; HEED, Ecotect, eQuest, EnergyPlus, TAS, etc., and discussed each software capability.

EnergyPlus was implemented for simulating the renovation affect for historical and an office building (Chidiac, Catania, Morofsky, & Foo, 2011) (Ascione, De Rossi, & Vanoli, 2011). TRNSYS software applied by (Santamouris, et al., 2007) to examine energy and environmental performance of sustainable roofs in an educational building. eQuest is been used by (Aksamijaa, 2015) for multiple design considerations were investigation for renovation towards NZEB, correspondingly, (Zmeureanu, 1990) used DOE-2 energy simulation software to investigate energy savings after building renovation.

Building information modelling BIM is a useful tool in optimizing building performance towards energy efficient by creating models of existing building, offering clear renovation alternatives, a comparison of different EEMs energy savings and analysis (Tobias & Vavaroutsos, 2012).

2.2.11.1 Autodesk Ecotect Software

Autodesk Ecotect® (Autodesk, 2016) performs various thermal calculations and visualize results like daylight factor, materials thermal behavior, and indoor environment, and analyze it on annually bases by using weather data of the specific location of the selected design.

Additionally to its standard graph analyses reports, results and tables reports can displayed directly within the spaces for accurately measures or mapped over building model envelope (Crawley, , Hand, Kummert, & Griffith, 2008).

2.2.11.2 Equest Energy Simulation Software

eQuest® energy tool calculate the energy consumption under the existing condition of the building, and provide annual energy brake down and gives the possibility to adapt and comparisons the selected energy efficiency measurement EEM on annual bases (James J. Hirsch & Associates, 2009).

The input data drives the operator through the procedure of creating a building model.

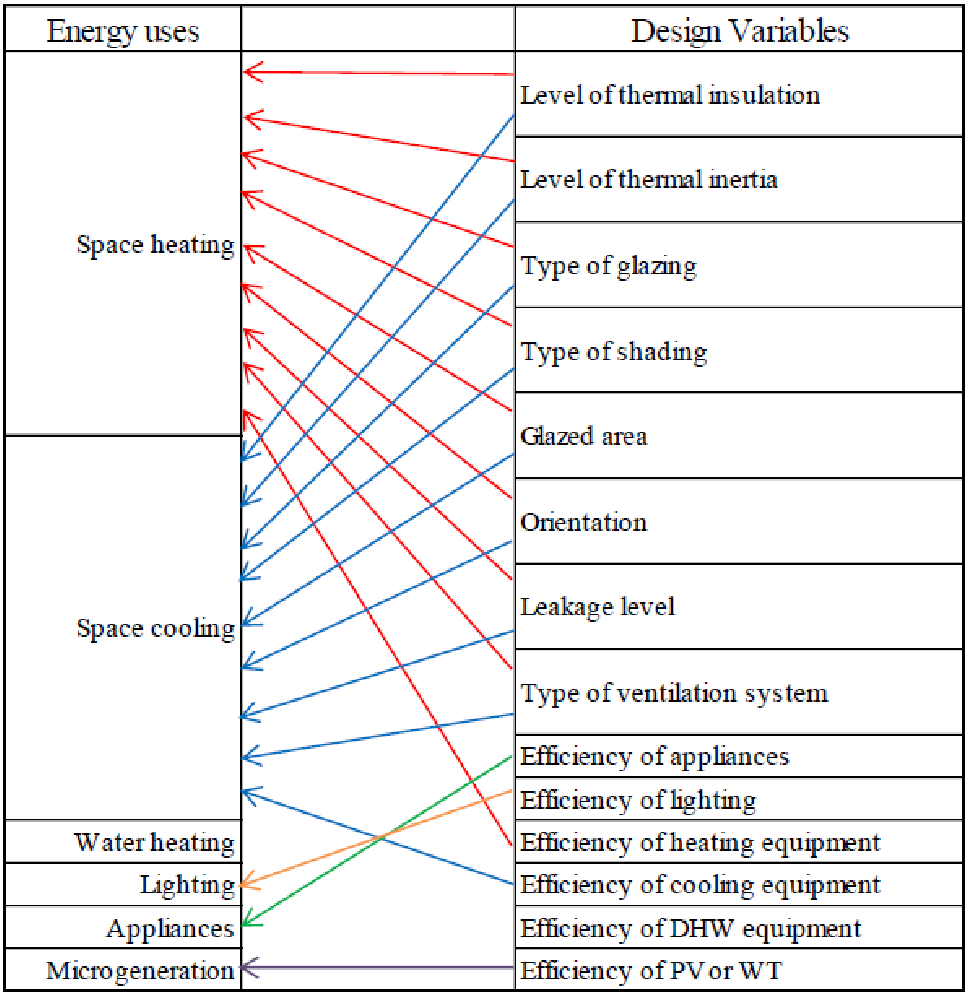
Within eQUEST, DOE-2.2 implements an hourly simulation of the building based on building operational schedules, openings/doors/ windows and glass sizes, walls layers characteristics, occupants quantities, plug loads, and ventilation (Crawley, , Hand, Kummert, & Griffith, 2008).

2.3 Sorting of Design Alternatives towards NZEB

Renovating towards NZEB design strategies applies the same principles of reducing energy consumption that is applied for new buildings. However these principles essentially related to the loss of freedom regarding some design features (e.g. the building solar orientation and building geometry shape, even some elements of the envelope) and the cost-effectiveness of measures regarding the replacement of building components that are still functional. Regarding to the building energy consumption for space cooling & heating, lighting, water heating,etc. Each end use can be influenced by a number of design variables, and typically each design variable has a wide range of possible values or choices. Table 4. That follows shows the dependence of each end use on each design variable.

Each combination of design variables will lead to a certain total yearly energy consumption, which in turn will require a certain amount of building-integrated renewables to offset the demand on a yearly balance basis. It therefore is of interest to characterize the full spectrum of possible combinations of variables, in order to identify those that have expected lower initial costs and those that have lower life-cycle costs.

Table 4: Energy uses versus design variables



Complying with the focus of this thesis and limits, reducing energy consumed for heating and cooling design alternative will be investigated in an existing building in the following section. Firstly the case study will be evaluated in terms of its envelope elements that influences the energy consumption, secondly an alternative design possibility will be suggested according to data evaluated, and lastly, these alternatives will be re-evaluated in order to identify their energy and cost-effectiveness.

Chapter 3

EDUCATIONAL BUILDINGS: FIELD STUDY EVALUATION

3.1 The Method of Data Collection

This research explores the validity and the feasibility of building renovation towards net-zero energy building (NZEB) in an existing educational building in Eastern Mediterranean University (EMU) in Turkish Republic of North Cyprus (TRNC).

In order to acquire the accurate data from the case study, main data about the existing building characteristics had been collected through observations, interviews, surveying and computer simulations through a qualitative method. Moreover, due to the lack of data about the existing energy consumption, an estimation calculation had been conducted through an international energy tool simulation in a quantitative method. Other data will be collected from internet sources, books, scientific papers, etc.

3.1.1 Data Evaluation Method

According to several aspects that related to the building energy demand/consumption such as building form, orientation, location, building envelope characteristics, transparent sizes and operation schedules, evaluation has been conducted through a field study to the colored building area at the faculty of architecture in EMU, the case study has been surveyed, real measurements of the building has been taken, computer simulated.

3.2 Case Study (Faculty of Architecture in EMU)

The case study is a multi-story educational building reprehensive of its typology for the educational buildings in EMU. Generally, educational buildings has a great potentials in energy reduction due to its limited daytime operational schedules which can get the maximum benefits from the solar energy, consists of holidays (off-time) during the year which save more energy annually and can be a great potential for investment in term of the produced energy from renewable systems during this time, in addition of creating an educational environment for the sustainability field related students. Thus, the results and strategies cost-effectiveness towards ZEB in this case study with respect to the local climate in North Cyprus can be applied to all the similar educational building and consequence to high-energy savings in terms of national level.

3.2.1 Location Data Findings

The case study is located in Cyprus-Famagusta, one of the largest islands in the Mediterranean Sea (35° Latitude, 33° Longitude) (Fig.7). With a humid-hot climate, the temperature rises above 30 °C in the hottest months during the typical summer season, and the temperature decreases to 3 °C in the winter season (Fig.8), as stated in the Cyprus meteorological station report about Famagusta (Climatemps.com, 2015).

According to its location, Famagusta has high solar energy during winter (5.26 kWh/m²/day), which rises to 7.12 kWh/m²/day during the summer season.

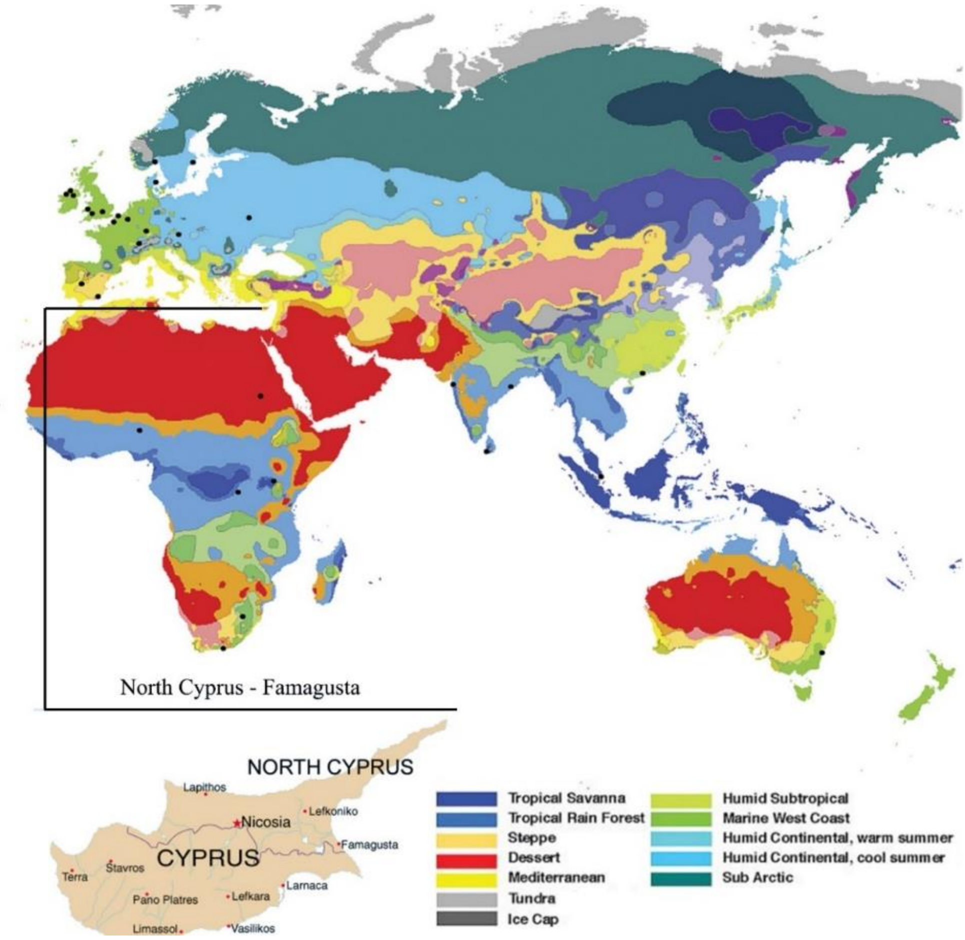


Figure 7: Cyprus Climate Map in Koppen Classification - Case Study Location (Kottek & Rubel , 2017)-edited by (Mohamedali, 2017)

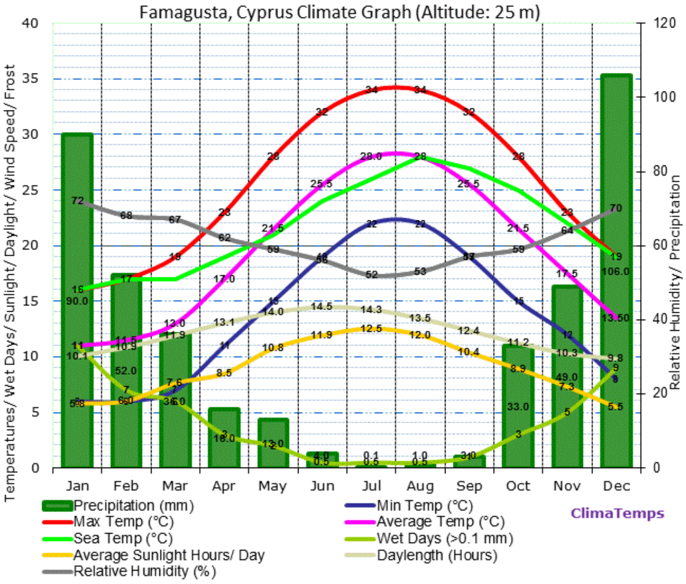


Figure 8: The annual graph of Famagusta's climate (ClimaTemps.com, 2015)

3.2.2 The Colored Building

Located at (35°146N 33°910E)**,** it is oriented 30° to the North and 60° to the East (fig.9). The colored building is an educational building with a rectangular shape and has three floors, built up approximately 1,500 m^2 and 4,483 m^2 total built-up area. The ground floor containing a library, offices, seminar room, cafeteria, and studio (fig.10). The two typical floors above mainly containing studios for architectural students, the top roof has a 150 m2 skylight aperture in the building atrium (fig.11). The building annual operational schedules is consists of 3 semesters (fall, spring and summer), on daily bases starts from 8:30 am to 4:20 pm, 5 days per week/ semester. The buildings is using packaged HVAC system for air conditioning with separate outdoor and indoor units, the building characteristics and the observation findings are described in the following part.

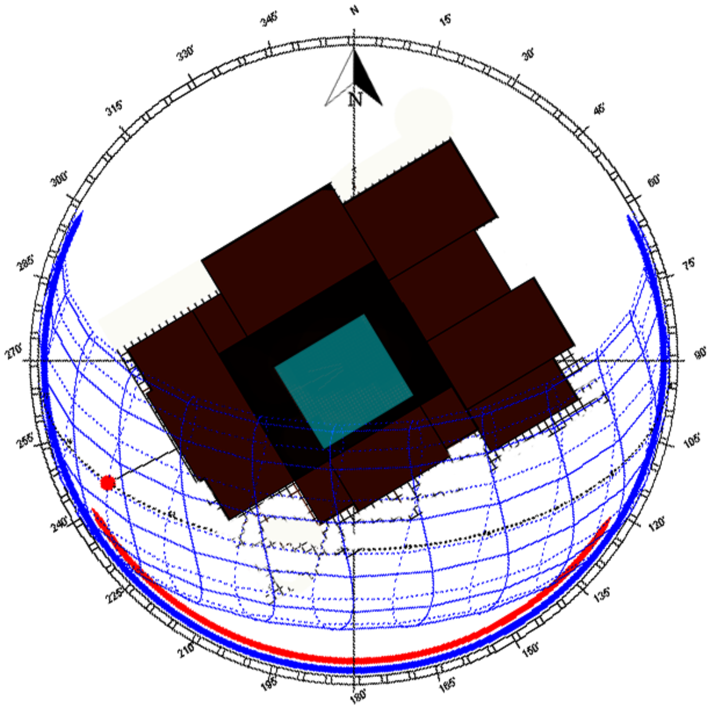


Figure 9: colored building orientation (by Author)

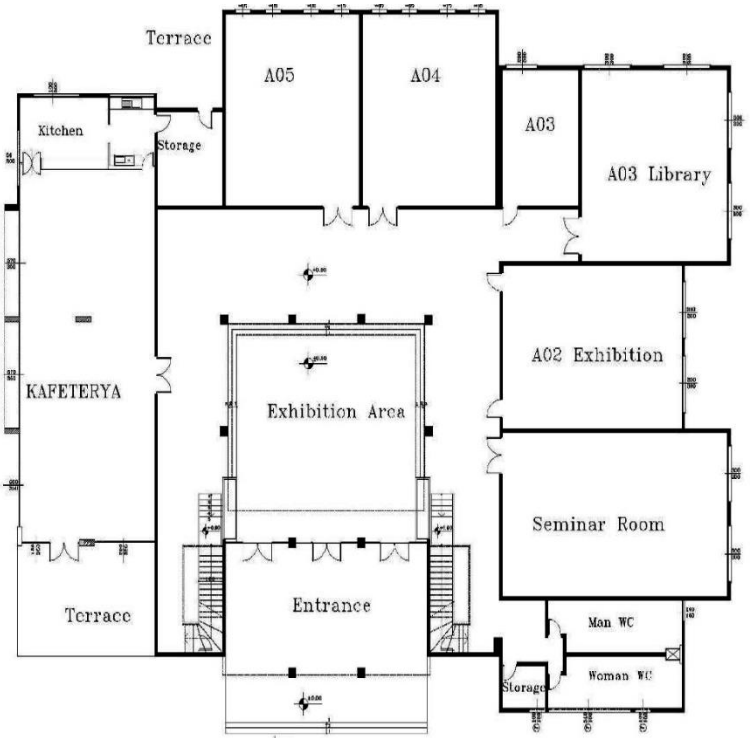


Figure 10: Ground floor plan of the coloured building

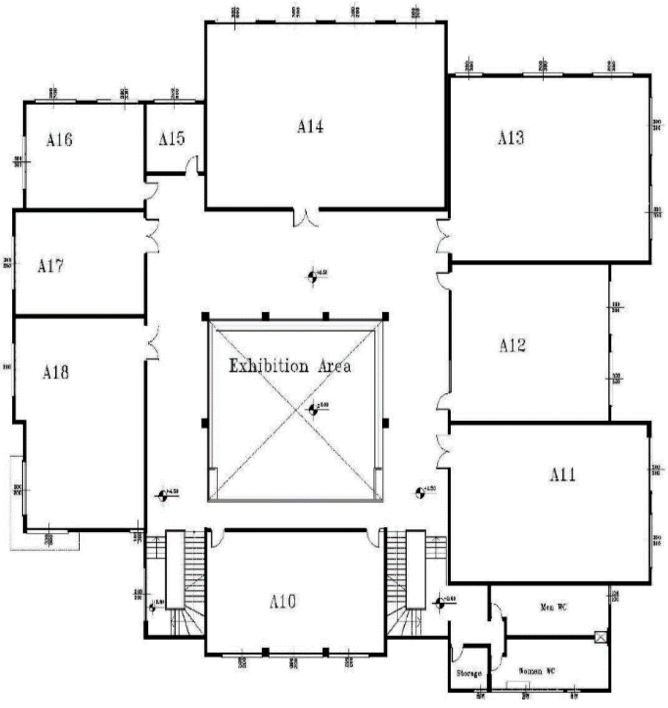


Figure 11: Typical floor of the coloured building (first + second)

3.2.3 Observation-based Evaluations

Observations and surveys have been conducted through several visits to the case study building in order to identify the main problems in the building that influences the energy consumption, As shown in Table 1 below, through description of the case study design elements, the building has been evaluated based on NZEB design strategies highlighted in literature review and elements that affect the energy efficiency of the building.

Table 1: Data Collected by Observation from Field Study (Faculty of architecture)[1].

Part	Field of Study Observation Photos	Observed Facts	Indicators / Author evaluation
North West Facade		The Colored Building elevations have the same treatments facing all directions, with large parts of windows, and no shading devices have been used on exterior facades. Windows to wall ratio is 31.2% The geometry layout provides shades to parts small parts during the day	The large windows increase interior daylighting efficiency, though this causes overheating in summer, which leads to an increase in cooling energy demand.
South West Facade		The building is surrounding by trees at the south west elevations, which drops some shade on parts of the building. Windows to wall ratio is 30.8% Though, at midday on the facades that face the sun direction, radiation shines vertically on glazing parts.	This causes overheating in the summer, which increase the cooling energy demand.

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[1] All photos has been taken by the author unless it's been mentioned.

South Est Facade		The building is surrounding by trees at the south east elevations, which drops some shade on parts of the building. This façade had the lowest windows to wall ratio which is 20.2%	This protects from overheating in the summer, which influences the cooling energy demand.
North Eest Facade		North East façade received the less sun radiation during the year. Windows to wall ratio is 41.3%	The windows sizes provide needed sun radiation during winter which influences the heating consumption.
Interior		Typical interior window blinds are being used for the studios' windows internally due to the lack of exterior shading devices to protect the users from overheating and glare. Artificial lighting is being used during the day.	These is insufficient shading because they obstruct daylight and the visual efficiency of users, increasing the lighting demand (Tzempelikos & Athienitis, 2007)
Atrium		A large skylight is placed in the atrium of the building to provide enough daylight to corridors and inside deep spaces, though lamps are being used during the day.	This insufficient usage of artificial lighting increases lighting energy consumption and causes overheating of the atrium and corridors during the summer.

The main observed finding is that there are insufficient usage of artificial lighting, lack of external shading devices and no insulation material for windows and wall. In addition the large windows are responding to the deep studio spaces daylighting, although it provide over sun radiation during the summer, and lose heat during winter which influences the heating and cooling consumption.

3.2.4 Simulation Software Employed

3.2.4.1 Autodesk Ecotect®

The case study has been analyzed via computer software tool Autodesk Ecotect® (Autodesk, 2016) according to its exact location, original orientation and Famagusta weather conditions for the purpose of accurate and quantitative analysis. By entering the building envelope parameters, material specifications and windows size and transparency, the program provide accurate data for sun path diagrams, annual daylighting illumines, the annual passive heat gain and lose percentages from the building envelope, which helps to evaluate the building elements that influence the energy efficiency of the building.

3.2.4.2 Equest Energy Tool

The actual electric consumption for the coloured building was hard to acquire due to its electric meter is connected with 4 other buildings, and their electric bills is all together not separately. In order to estimate the annual energy consumption breakdown, the case study has been simulated with eQuest energy simulation tool which is developed from DOE-2 and Energy plus qualified energy simulation engines with graphics and wizards built on top of it (James J. Hirsch & Associates, 2009). The building geometry as in Ecotect® software has been input, Famagusta weather data in addition to the internal loads and operating timetables on annually, weekly and daily bases, artificial lights efficiency, in addition to the HVAC operating schedules, more detail about the input data illustrates in the table below (table 4)

For the colored building, the daily working hours considered to start form 9 AM to 5 PM five days a week (Monday – Friday) for the entire year. The air conditioning thermostat has been set to 25C in summer and 18C in winter. The windows are 4 mm thickness single glass with PVC frames in all orientations, window to wall ratios (WWR) are (31.2, 20.2, 30.8, 41.3) for North-West, South-East, South-West and North-East facades respectively for the colored building. Table5 shows the construction thermal characteristics for both buildings and estimated air conditioning thermostats and operation schedules.

Table 5: Building envelope characteristics and annual operation schedules

Construction Element	**Layers (outside to inside)**	**U-Value (W/m^{2}k)**
Roof	Water insulation R. F. concrete Plaster	3.10
External Walls	Plaster Brick (20 cm) Plaster	2.00
Floor slabs	Ceramic tiles Concrete screed R. F. concrete Plaster	2.77
Windows	single clear glass (4 mm thicknesses, 50 mm PVC frame)	6.00
Operating schedules Weekdays (Monday – Friday)	12 months	8:30 AM – 4:20 PM
Air conditioning thermostat	Start cooling above 25 ℃ (summer) Start heating below 18 ℃ (Winter)	

3.2.4.3 Climate Consultant

Climate Consultant software (Milne, 2017) has been used in order to evaluate the case study facades based on the annual sun path. The software provide a graphical illustration for the Famagusta weather data and carry out a simple analysis to suggest the suitable strategies for a particular climate. Moreover, the software provides analyses for optimizing the horizontal shading angle HSA and vertical shading angle VSA for each façade according to its annual hot and cold hours based on (ANSI/ASHRAE/IES Standard 90.1-2010, 2010) standard, which has been used to provide shading devices strategies for the case study.

3.2.5 Simulation-Based Evaluations

3.2.5.1 Building Facades Shade Analysis

According to the building orientation angle 30º to North (fig.12), the sun radiation hits all facades in different portions annually. By using climate consultant software, and based on the yearly hot hours (hot > 27ºC) that sun radiation is overheating the façade (shade is needed), and yearly cold hours (cold <20ºC) that sun is providing sunlight to warm the facade (sun is needed), each façade has been simulated individually.

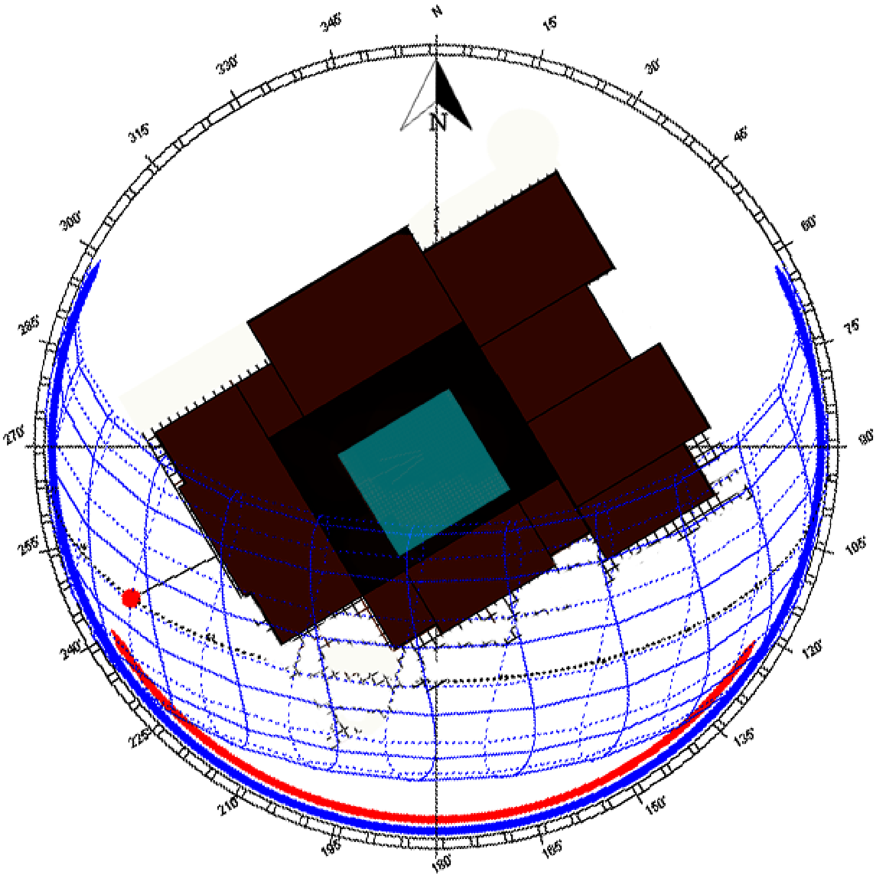


Figure 12: Building orientation to the Famagusta sun path

Table 5 below shows the different building façade's annual hours above 27ºC and comfortable hours and hours above 20ºC. Regarding to these numbers, the building orientation provides balanced sun radiations for the four facades between annual hot hours when shade is needed and annual cold hours when sun radiation is needed. Although, towards more cooling energy reduction, shading devices is needed to respond the annual hot hours.

Table 6: Colored building facade's annual hours (hot >27ºC>comfort<20ºC<cold)

Façade direction	Annual Hours > 27ºC (shade needed)	Annual Hours > 20ºC (shade helps)	Annual Hours < 20ºC (sun needed)
South-East	973	1,132	1,706
South-West	941	898	1200
North-West	533	519	246
North-East	559	744	708

3.2.5.2 Daylight Levels Analysis

The analysis of daylighting has been conducted according to the sun path during the year and the transmittance and sizes of the windows in all orientations. The results shows more than 1100 lux illuminance of daylighting in the interior spaces in the colored building (fig.13*)*, the yellow color range shows a high level above that required (Light, C. E. N., 2011), due to the lack of exterior shading devices and the large window to wall ratios (WRR) on facades, especially of the southwest facade, which faces the most sun radiation during the summer season and causes overheating to the interior spaces according to (Alibaba H. , 2016).

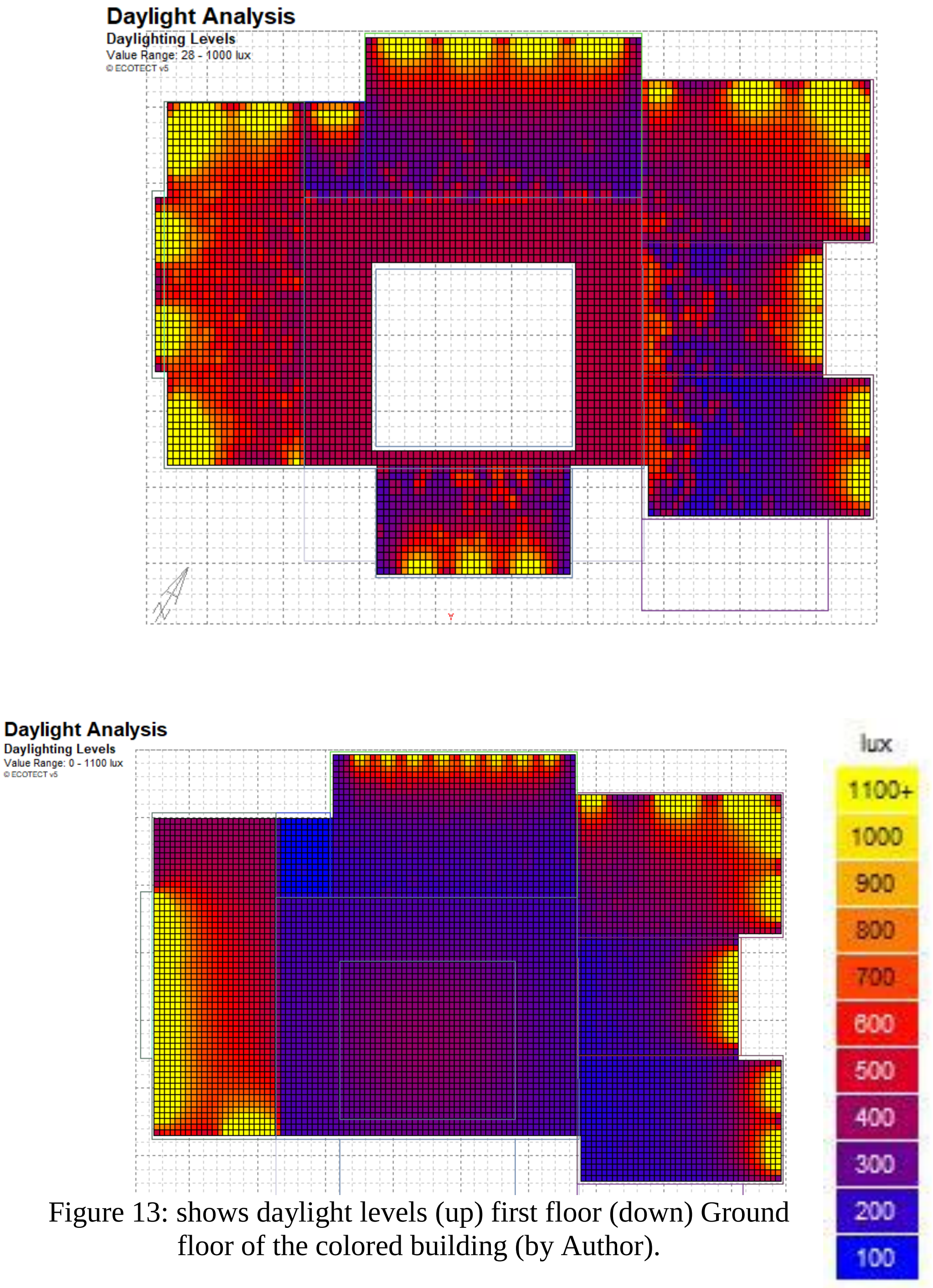


Figure 13: shows daylight levels (up) first floor (down) Ground floor of the colored building (by Author).

The skylight in the atrium provides acceptable daylight levels (Light, C. E. N., 2011) (red color range) to the deep spaces in the building such as the corridors during the day. On an annually basis, this shows that the artificial lights are not required during the day.

3.2.5.3 Heat Gains and Loss Breakdown

Accordingly, electric energy demand for heating/cooling increases due to the following building envelope solar gain breakdown chart, (Fig.14) shows where the heat loss or gain for the colored building:

- About 45% (red color) of the building thermal loss in winter is caused by material conductivity because of the poor thermal insulation while just 7.5% of the total gain is from the same factor in summer.

- Opening sizes, which have a direct impact on ventilation, are major factors causing a 49% drop (green color) in total thermal loss during the winter, 9.2% of gaining heat during summer.

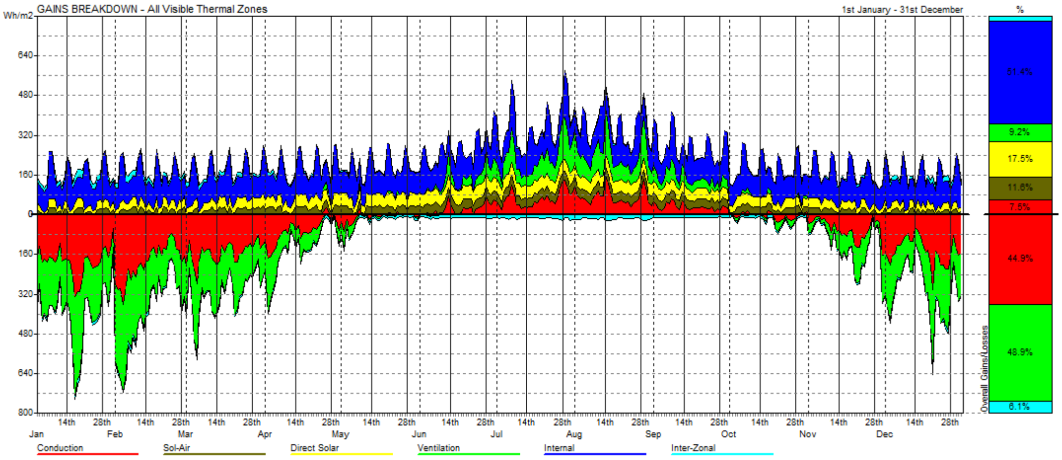


Figure 14: Shows the yearly heat gains breakdown of the colored building.

3.2.5.4 Existing Electric Consumption

The case study has been simulated under its existing situation in order to estimate its existing energy consumption. The annual energy consumption calculated for the colored building was 130.26 kWh/m^{2}y, (table6). The monthly electric consumption is shown in (fig.16) below. The lowest energy consumption for the colored buildings was observed was during April. The highest calculated energy consumption was on August.

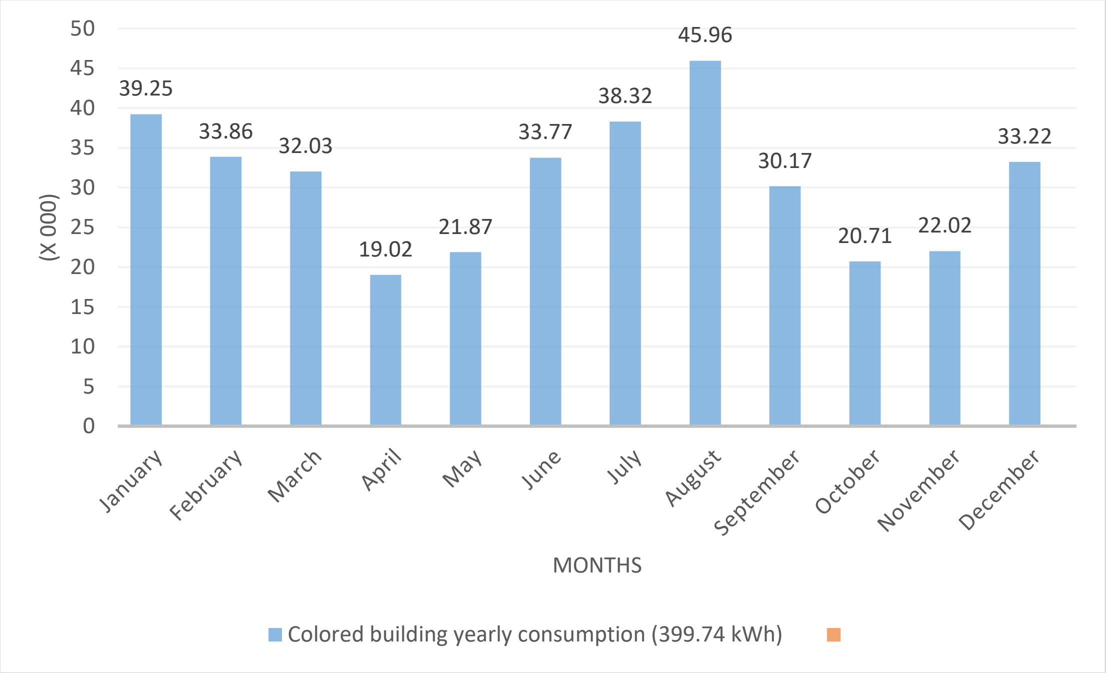


Figure 15: Monthly electric consumption profile (kWh).

The major 130.20 kWh/m^{2}y energy consumption calculated for the colored building was attributed to the high demand on cooling (table 6). The energy consumption for cooling is 46.44 kWh/m^{2}y and 36.49 kWh/m^{2}y for heating, in terms of lighting is about 2.4 kWh/m^{2}y.

Table 7: Existing Electric Consumption on annual bases

Building	**Energy Consumption for Cooling**	**Energy Consumption for Heating**	**Energy Consumption for Lighting**	**Final Energy consumption**
	kWh/m^{2}y	kWh/m^{2}y	kWh/m^{2}y	kWh/m^{2}y
Colored building	46.44	36.49	2.4	130.20

3.2.5.5 Observation Indicators

Based on the surveys to the case study and as shown in the table 1 above, no insulation material is installed in the building walls, in addition to a large single glass windows in all the building facades with no external shading devices. This poor insulation causes overheating during summer and increasing the cooling consumption as well as increasing in heating demand and consumption in winter to provide thermal comfort for occupants. Meanwhile, the skylight in the atrium provide equivalent daylight to the deep spaces and corridors of the building, though it can provide a warm environment during winter, though during mid-day during summer it causes overheated as well as increasing in cooling consumption.

3.2.5.6 Computer Simulations Evaluation Summary

After evaluating the existing design elements that affect the building energy performance and existing energy consumption, the results can be summarized in the following points:

- Daylight plays an important role in decreasing electric consumption, analysis shows high daylight levels in the colored building especially at the south-west part of the building due to the lack of the exterior shading devices, causing an overheating to the interior spaces which increases the cooling demand during summer and indicates that the artificial lighting is being used inefficiently.
- Insulation materials that have been used for windows and walls are insufficient and increase the annual energy demanded for heating due to the high loss of heat during winter through walls and windows, and increases the cooling demand due to the small loss of heat in summer.
- Highest energy consumption observed during august for cooling, while for

heating is on January.

The following section discussed the optimization measurements and its energy impacts in order to formulate a strategies towards zero energy for colored buildings.

Chapter 4

RENOVATING STRATEGY FOR THE BUILDING TOWARDS ZERO ENERGY

4.1 The Standard NZEB Renovation Scenario

In terms of having cost-effectiveness and energy efficient measures for evaluations in this research, it is applying several energy efficient measurements EEMs based on Cyprus energy performance of building directive EPBD Directive 366/2014 requirements for NZEB (table 7) as follow:

Table 8: NZEB requirements for non-residential buildings in Cyprus

Technical specifications - Construction Element	U-Value (W/m^{2}k)
External walls	0.40
Rooftop	0.40
Double glass windows	2.25
Energy performance specifications	**Minimum requirements**
Total annual energy consumption	125 kWh/m^{2}a
Renewable energy percentage of the total primary energy consumption	25%

4.2 Finding Alternative Strategies

Among infinite design possibilities, many strategies can be adapted and integrated in the building to reduce energy consumption in a way to coup the challenges presented in the coloured building. Suggested strategies should be oriented by the evaluation indicators which have found during the data collection, analysis and evaluations have done for the current situation in the building. Regarding these aspects, the indicators can be summarised as follow:

- Building is oriented towards 30º to north, which exposed all orientation to unwanted sun radiation during the summer which influenced the cooling consumption, yet it provides sun radiation during the winter which influenced the cooling consumption

- Large windows in all facades with no external shading devices integrated provides high daylight values to the interior spaces.

- In term of insulation, windows are single glasses (high U-values) and no thermal insulation has been used for walls and roof.

- The passive heat losing during winter is more than the passive heat gain during summer through the building envelope.

Regarding to these indicators, there are supplementary considerations during proposition strategy as initial climate analysis can be made to delimit a series of possibilities for intelligent envelope elements based on the psychometric chart for bioclimatic design. Climate analysis using specialized software for the location is possible, given the existence of electronic yearly data.

The psychometric analysis for Famagusta city, executed using the Climate Consultant 6 software program, revealed a series of general strategies as illustrated in (Fig.49) which shows the comfort hours of the building according to its location, and the passive design alternatives that increases the comfort hours and relatively decrease the usage of mechanical systems which reduce the total energy consumption.

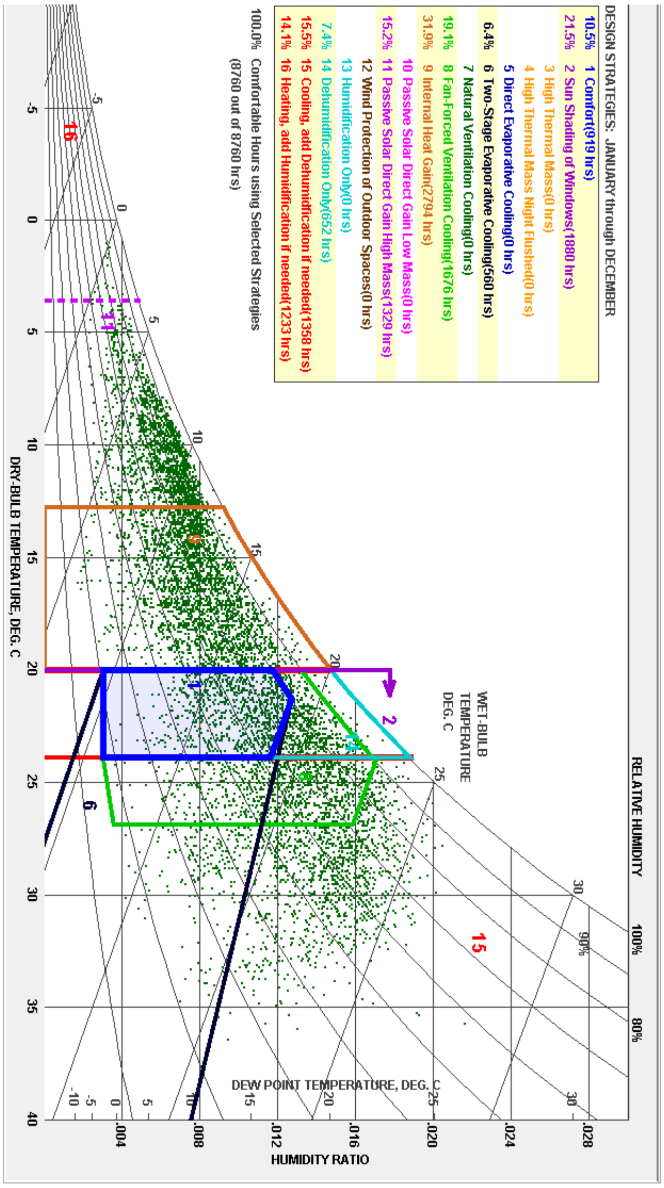


Figure 16: Psychometric analysis for Famagusta. Performed using Climate Consultant v 6.0 (by Author)

Initial costs (IC) and life cycle cost (LCC) is another aspects in terms of each strategy cost-effectiveness. And helps to identify which strategy is optimum to be implement to the case study.

Regarding to these considerations, and hence this research is focusing on the renovation of the building envelope, the following strategies will be investigated in term of their energy and cost effectiveness in the case study; thermal insulation for walls and roof, windows insulation and shading strategies. Each alternative consists of two variables in order to ensure enough variety in the range of the variables and to not inflating unnecessarily the search space. The next section provides a description of the alternatives implemented for each variable.

4.2.1 Exterior Walls and Roof Thermal Insulation

The existing U-value of the external walls = 2.17 W/m^2K, and for roof = 2.52 W/m^2K. In order to reduce building energy demanded for cooling/heating and responding to the EU requirements for NZEB, maximizing the embodied energy preservation by integrating additional insulation materials to the existing walls and roof is needed.

In terms of insulation location (outside or inside), eQuest energy simulation software has limits in calculation energy reduction with relation to the building thermal insulation. It only calculates the material’s U-values. The position of the insulation is not significant regarding to the heating savings, yet positioning the insulation to the outside face of the roof or the wall lowering the condensation risk, in addition to save the cost of renovating because interior spaces cost more in installing regarding to the re-installing the plugins, light fixtures, moving the furniture in addition of the space will not be used till the end of the renovation process.

Regarding to the previous, and hence this research is investigating the cost effective of the insulation material regarding to its energy savings, Thermal insulation was characterized by two levels – alternatives. These levels of thermal insulation are represented by the U-value, for walls it ranges from to 0.40 W/m^{2}K (maximum U-value according to EU NZEB requirement for walls) and 0.20 W/m^{2}K also considered as minimum insulation. For roof, ranges from 0.40 W/m^{2}K (maximum U-value according to EU NZEB requirement for roofs) and 0.167 W/m^{2}K also considered as minimum insulation.

Accordingly, using expanded polystyrene panels as an insulation material, 70 mm, and 150 mm is the thickness resulting 0.40 W/m^{2}K, 0.167 W/m^{2}K respectively. The same concept is applied to the wall insulation, 150 mm, 68 mm, is the thickness resulting 0.20 W/m^{2}K, 0.40 W/m^{2}K, respectively. These values illustrates in the table below

Table 9: Alternative suggested thermal insulation thicknesses and U-values for walls and roof

Element	Insulation Thickness	U-value (W/m^{2}K)
Expanded polystyrene above roof	70 mm	0.40
	150 mm	0.167
Expanded polystyrene installed externally for wall	68 mm	0.40
	150 mm	0.20

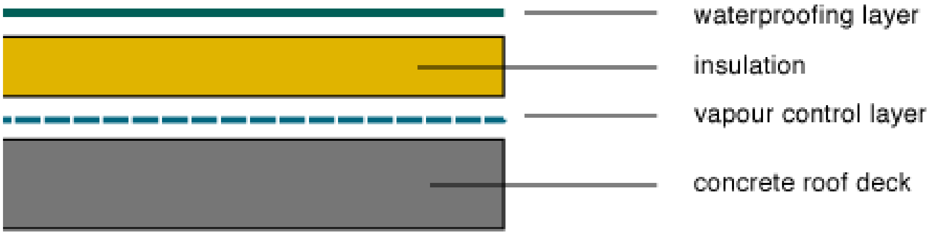


Figure 17: Roof section showing the layers of the roof after insulation (U-value depends on the thickness of the insulation) (GreenSpec, 2017).

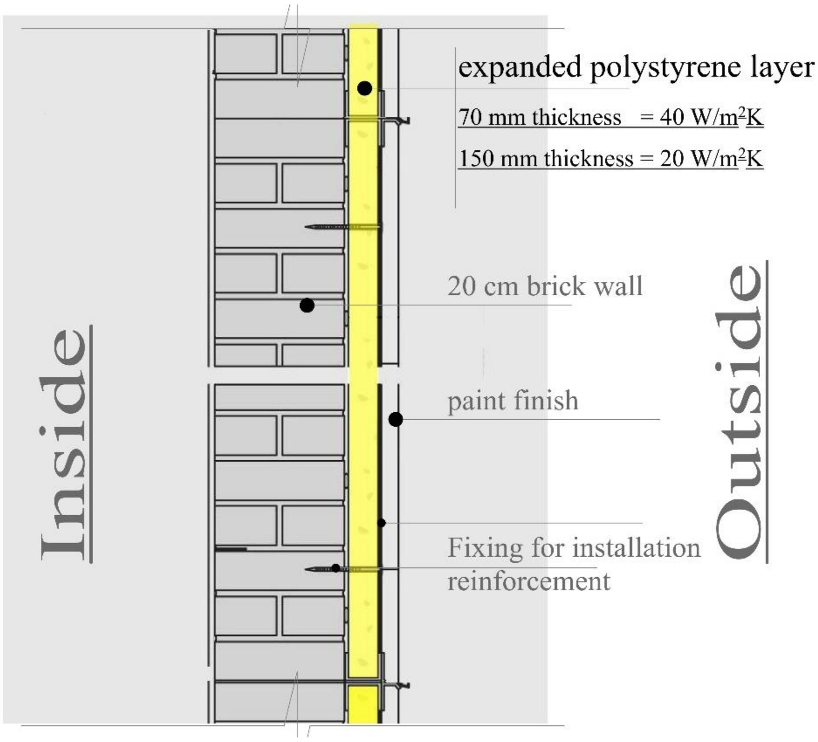


Figure 18: Optimized external wall section (by Author).

4.2.2 Windows Optimization

The existing U-value of windows = 6.00 W/m2K. Referring to the EPBD Directive 366/2014, lowering the U-value of the windows by replacing them with double or triple low-E glass minimize the heat loss of the building and save reliable energy according to (ANSI/ASHRAE/IES Standard 90.1-2010, 2010). Moreover, according to ASHRAE, solar heat gain coefficient SHGC of windows influencing the energy consumption as well. The recommended value for SHGC is 0.25 for Mediterranean climate (zone 3) for all facades (ANSI/ASHRAE/IES Standard 90.1-2010, 2010). High

SHGC windows should be used in north facing windows to maximize solar heat gains during winter for saving heating energy, and low SHGC windows should be used in south facing windows in order to prevent the solar radiation during summer and avoid over heating in order to save cooling energy consumption.

Regarding to the previous recommendations, the suggested windows optimization is oriented towards the existing situation of the building in addition to the indicators found during observation and evaluations. Same windows size has been used for investigating their cost-effective by increasing their U-values to meet the minimum requirements stated above, by using two alternatives: double low-E coating glazing aluminum frames with thermal insulator spacer (filled with Aragon) (U-value: 1.5 W/m^{2}K, SGHC: 0.48, VT: 0.57), and triple low-e coating glass with aluminum frames with thermal insulator spacer (filled with Aragon) (U-value: 1.2 W/m^{2}K, SGHC: 0.48, VT: 0.57).

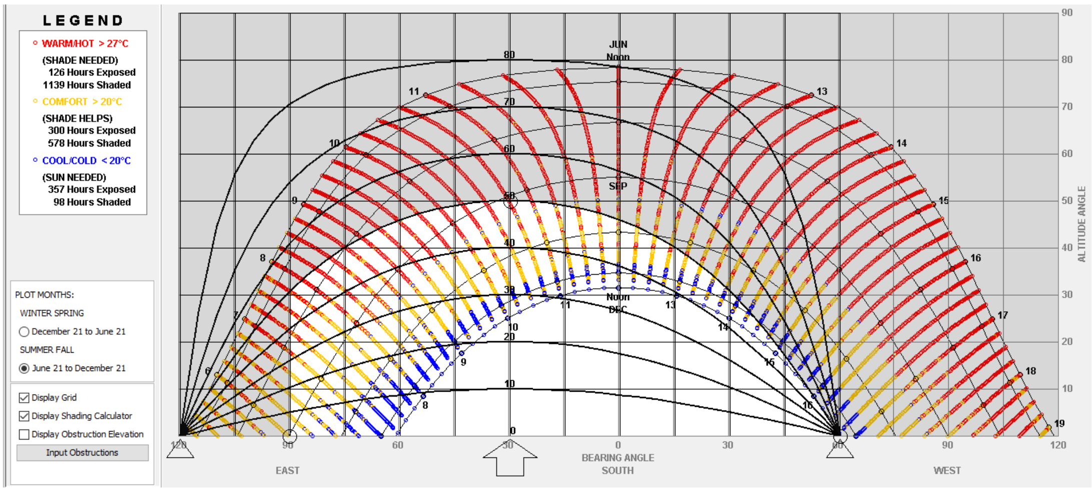
4.2.3 Exterior Shading

Suggestion measure is based on the solar latitude and building orientation. Moreover, due to the focus of this research is on energy consumption, the proposed shading is based on summer sun location in order to prevent over heating which influencing the cooling consumption. As it is been mentioned in observations, there are no integrated external shading devices on the building windows which provide insufficient daylighting due to the building orientation. The horizontal and vertical shading devices provides acceptable protection from sun radiation.

Towards designing for more energy savings, therefore each façade shading proposed strategy is responding to the hours shaded needed during summer (May to September) and to the hours sun is needed during winter (October to April). In terms of finding the shading devices optimum length, simulation done by climate consultant simulation tool which provide the vertical shading angle VSA and horizontal shading angle HSA for the four facades based on the ASHREA standard thermal comfort hours during the year (ANSI/ASHRAE/IES Standard 90.1-2010, 2010) according to the weather conditions of North Cyprus.

4.2.3.1 South-East Façade Shading Strategy

The building South-East façade is oriented 31º to south and 51º to east direction. According to the simulation, the optimum vertical shadow angle VSA found was 50º and the optimum horizontal shadow angle was 60º, optimizing the shading devices towards these sun radiation angles results to increasing of 87 % protection from unwanted sun radiation and cover 31 % of wanted sun radiation during the year comparing to the existing situation. Figs. (18-19) shows the detailed hours of shaded/sun radiation needed and the VSA and HSA angle selected for South-East façade.



LEGEND

∘ WARM/HOT > 27°C
(SHADE NEEDED)
126 Hours Exposed
1139 Hours Shaded

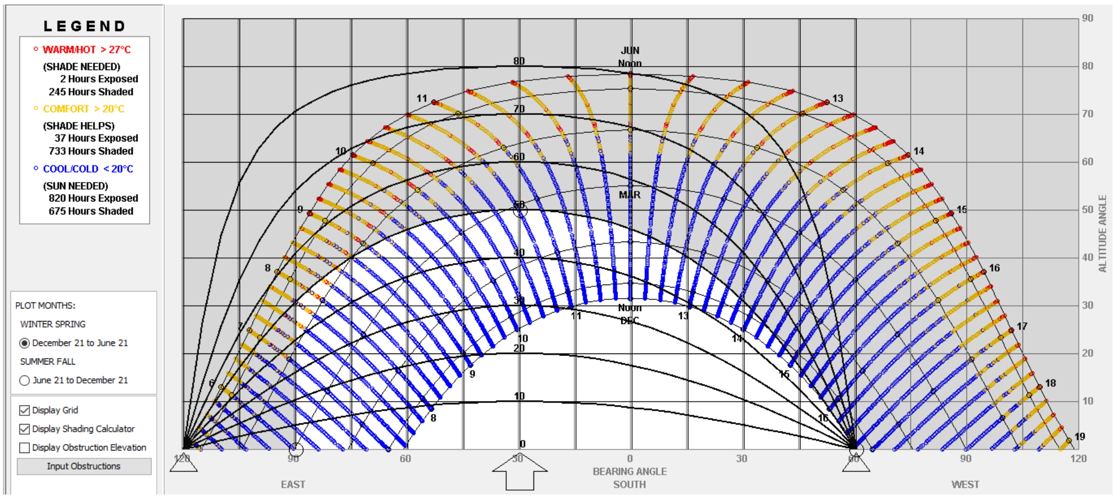
∘ COMFORT > 20°C
(SHADE HELPS)
300 Hours Exposed
578 Hours Shaded

∘ COOL/COLD < 20°C
(SUN NEEDED)
357 Hours Exposed
98 Hours Shaded

PLOT MONTHS:
WINTER SPRING
○ December 21 to June 21
SUMMER FALL
● June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 19: sun shading chart for south east facade from June to September



LEGEND

- ○ WARM/HOT > 27°C
  (SHADE NEEDED)
  2 Hours Exposed
  245 Hours Shaded
- ○ COMFORT > 20°C
  (SHADE HELPS)
  37 Hours Exposed
  733 Hours Shaded
- ○ COOL/COLD < 20°C
  (SUN NEEDED)
  820 Hours Exposed
  675 Hours Shaded

PLOT MONTHS:
WINTER SPRING
● December 21 to June 21
SUMMER FALL
○ June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation
Input Obstructions

Figure 20: sun shading chart for south east facade from September to June

According to the previous, and responding to the South East windows (2.00 m. height * 3.00 m. width) fig.20. Using 600 mm length fixed over hanged shading devices and 300 mm length vertical fins for the south-east windows facades is suggested (fig. 21)

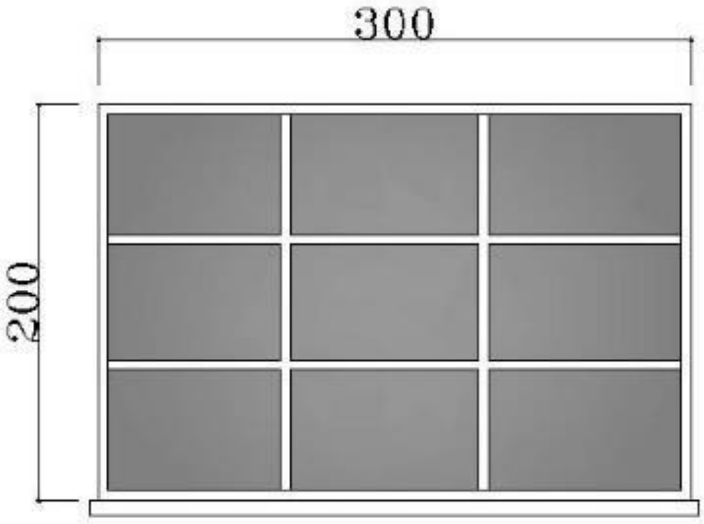


Figure 21: Existing South-East windows elevation

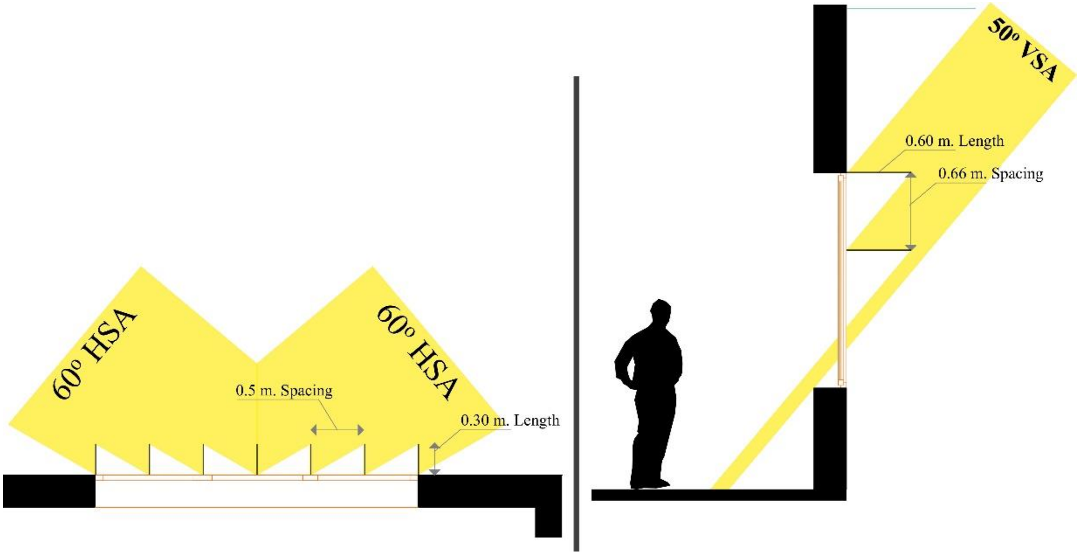
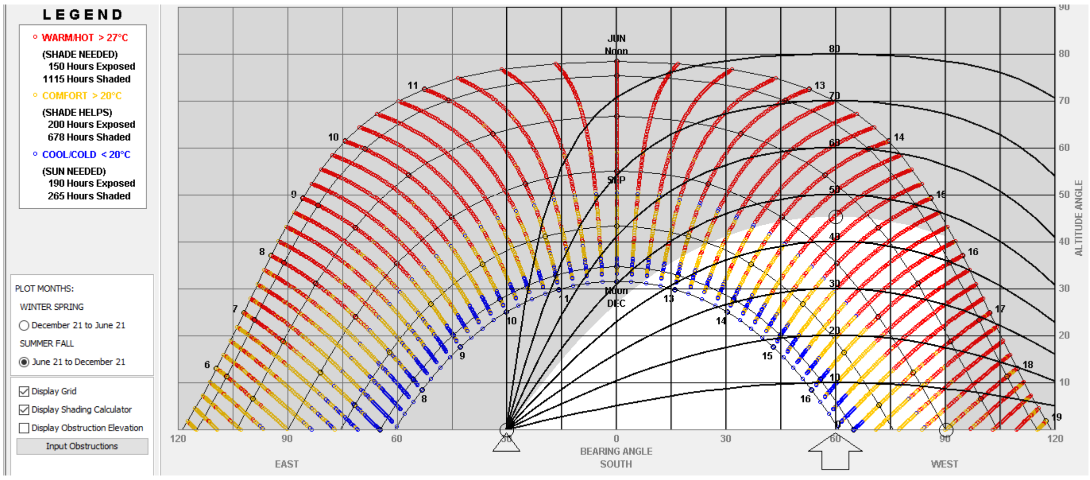


Figure 22: Optimized shading device strategy detail responding to the preferable (summer & winter) sun radiations for South-East façade, HSA 60º, VSA 50º. (Left) plan view (right) section (by Author).

4.2.3.2 South-West Façade Shading Strategy

The South-West façade of the building is oriented 59 º to south and 31º to west. According to the simulation, the optimum vertical shadow angle VSA found was 45º and the optimum horizontal shadow angle was 30º, optimizing the shading devices towards these sun radiation angles results to increasing of 84 % protection from unwanted sun radiation and cover 40 % of wanted sun radiation during the year comparing to the existing situation. Figs. (24-25) shows the detailed hours of shaded/sun radiation needed and the VSA and HSA angle selected for South-West façade.



LEGEND

WARM/HOT > 27°C
(SHADE NEEDED)
150 Hours Exposed
1115 Hours Shaded

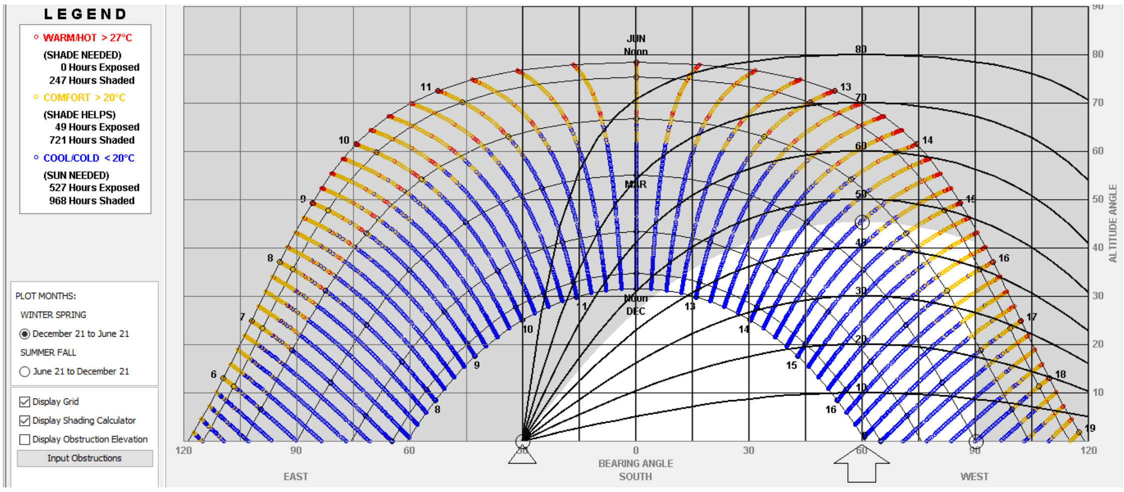
COMFORT > 20°C
(SHADE HELPS)
200 Hours Exposed
678 Hours Shaded

COOL/COLD < 20°C
(SUN NEEDED)
190 Hours Exposed
265 Hours Shaded

PLOT MONTHS:
WINTER SPRING
○ December 21 to June 21
SUMMER FALL
● June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 23: Sun shading chart for south west facade from June to September



LEGEND

WARM/HOT > 27°C
(SHADE NEEDED)
0 Hours Exposed
247 Hours Shaded

COMFORT > 20°C
(SHADE HELPS)
49 Hours Exposed
721 Hours Shaded

COOL/COLD < 20°C
(SUN NEEDED)
527 Hours Exposed
968 Hours Shaded

PLOT MONTHS:
WINTER SPRING
● December 21 to June 21
SUMMER FALL
○ June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 24: Sun shading chart for south west facade from September to June

According to the previous, and in response to the visual human eye range and typical South-West windows dimeters fig. 26, using 430 mm length fixed over hanged shading devices angled 35 ° to horizon and 860 mm length vertical fins for the south-east windows facades is suggested as seen in fig. 27.

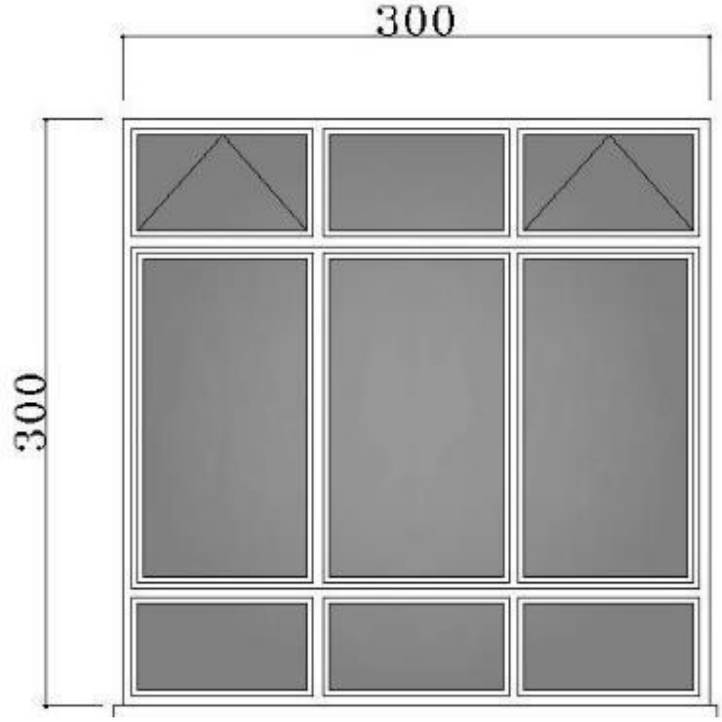


Figure 25: Existing South-West windows elevation

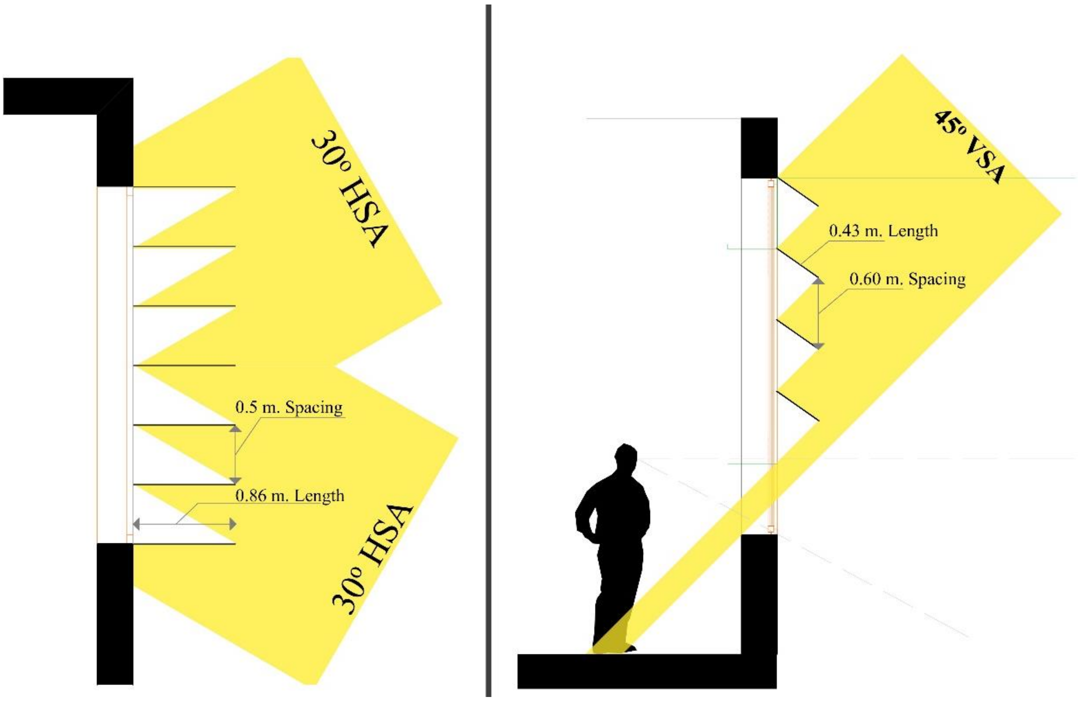
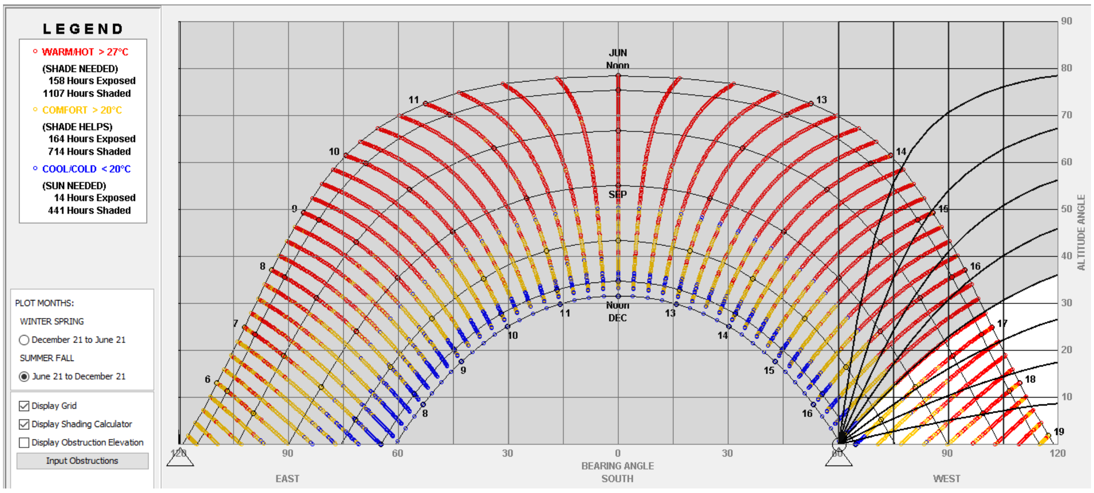


Figure 26: Optimized shading device strategy detail responding to the preferable (summer & winter) sun radiations for South-West façade, HAS 30º, VSA 45º. (Left) plan view (right) section (by Author).

4.2.3.3 North-West Façade Shading Strategy

The North-West façade of the building is oriented 31 ° to North and 59° to West direction. According to the simulation, the optimum VSA found was 40° without needing for vertical fins, optimizing the shading devices towards these sun radiation angles results to increasing of 65 % protection from unwanted sun radiation and cover 39 % of wanted sun radiation during the year comparing to the existing situation. Figs. (28-29) shows the detailed hours of shaded/sun radiation needed and the VSA selected for North-West façade.



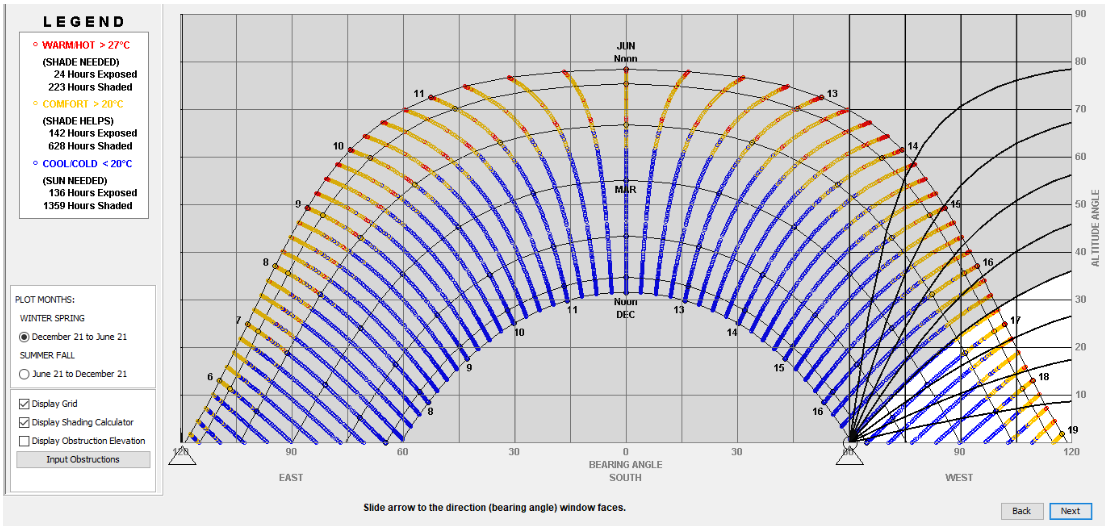
LEGEND

- WARM/HOT > 27°C
  (SHADE NEEDED)
  158 Hours Exposed
  1107 Hours Shaded
- COMFORT > 20°C
  (SHADE HELPS)
  164 Hours Exposed
  714 Hours Shaded
- COOL/COLD < 20°C
  (SUN NEEDED)
  14 Hours Exposed
  441 Hours Shaded

PLOT MONTHS:
WINTER SPRING
○ December 21 to June 21
SUMMER FALL
● June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 27: Sun shading chart for North West facade from June to September



LEGEND

- WARM/HOT > 27°C
  (SHADE NEEDED)
  24 Hours Exposed
  223 Hours Shaded
- COMFORT > 20°C
  (SHADE HELPS)
  142 Hours Exposed
  628 Hours Shaded
- COOL/COLD < 20°C
  (SUN NEEDED)
  136 Hours Exposed
  1359 Hours Shaded

PLOT MONTHS:
WINTER SPRING
● December 21 to June 21
SUMMER FALL
○ June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation

Slide arrow to the direction (bearing angle) window faces.

Figure 28: Sun shading chart for North West facade from September to June

According to the previous, use of 470 mm length fixed over hanged shading devices angled 35 ° to horizon is suggested as seen in fig 30.

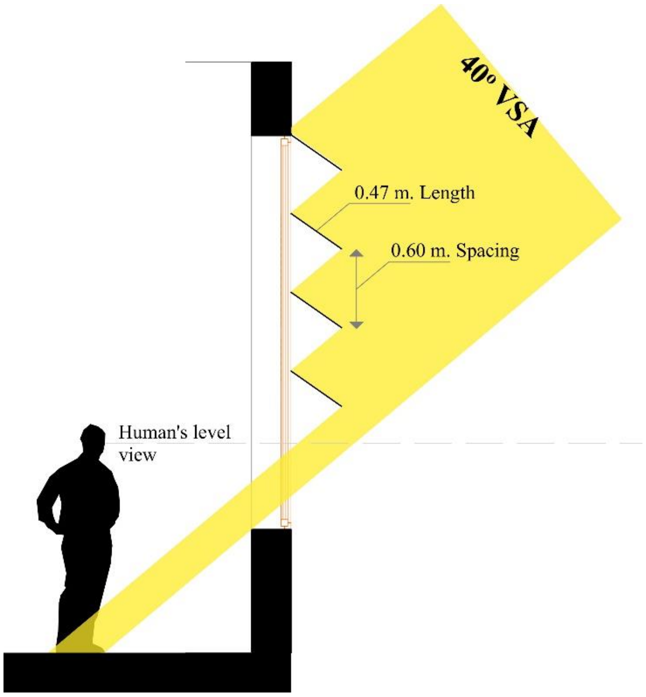
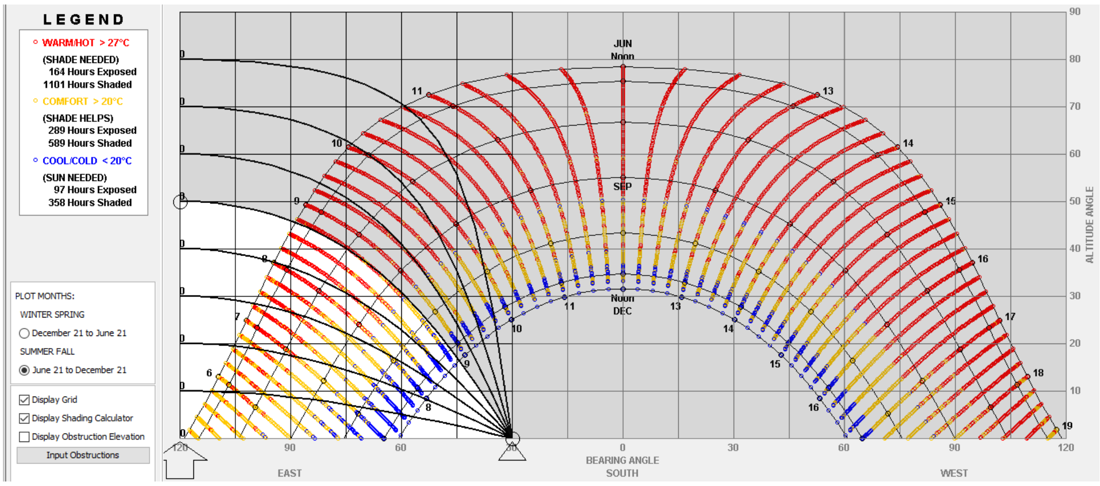


Figure 29: Optimized shading device strategy detail responding to the preferable (summer & winter) sun radiations for North-West façade, VSA 40º. (Left) plan view (right) section (by Author).

4.2.3.3 North-East Façade Shading Strategy

The North-East façade of the building is oriented towards 59º to North and 31º to East direction. According to the simulation, the optimum VSA found was 50º without needing for fins, optimizing the shading devices towards these sun radiation angles results to increasing of 66 % protection from unwanted sun radiation and cover 42 % of wanted sun radiation during the year comparing to the existing situation. Figs. (31-32) shows the detailed hours of shaded/sun radiation needed and the VSA angle selected for North-East façade.



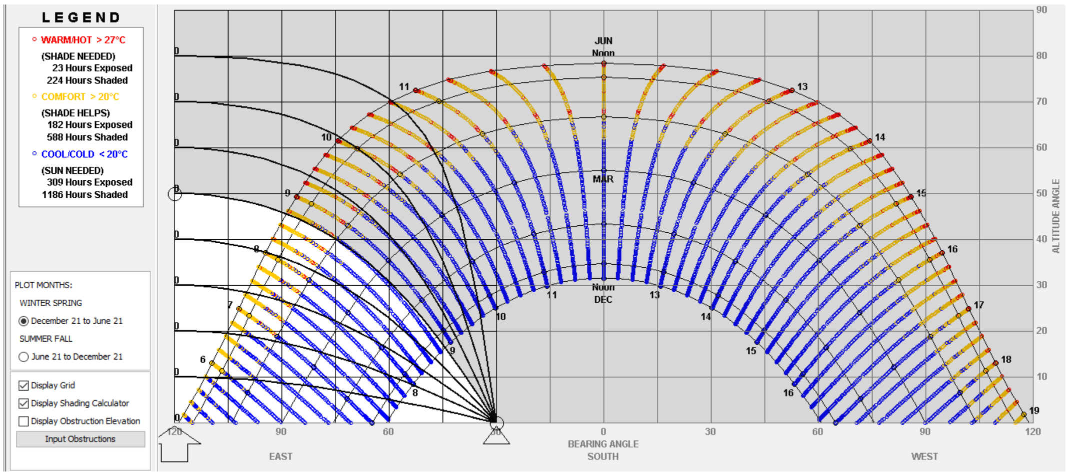
LEGEND

- WARM/HOT > 27°C
  (SHADE NEEDED)
  164 Hours Exposed
  1101 Hours Shaded
- COMFORT > 20°C
  (SHADE HELPS)
  289 Hours Exposed
  589 Hours Shaded
- COOL/COLD < 20°C
  (SUN NEEDED)
  97 Hours Exposed
  358 Hours Shaded

PLOT MONTHS:
WINTER SPRING
○ December 21 to June 21
SUMMER FALL
● June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 30: Sun shading chart for North east facade from June to September.



LEGEND

- WARM/HOT > 27°C
  (SHADE NEEDED)
  23 Hours Exposed
  224 Hours Shaded
- COMFORT > 20°C
  (SHADE HELPS)
  182 Hours Exposed
  588 Hours Shaded
- COOL/COLD < 20°C
  (SUN NEEDED)
  309 Hours Exposed
  1186 Hours Shaded

PLOT MONTHS:
WINTER SPRING
● December 21 to June 21
SUMMER FALL
○ June 21 to December 21

☑ Display Grid
☑ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 31: Sun shading chart for North east facade from September to June.

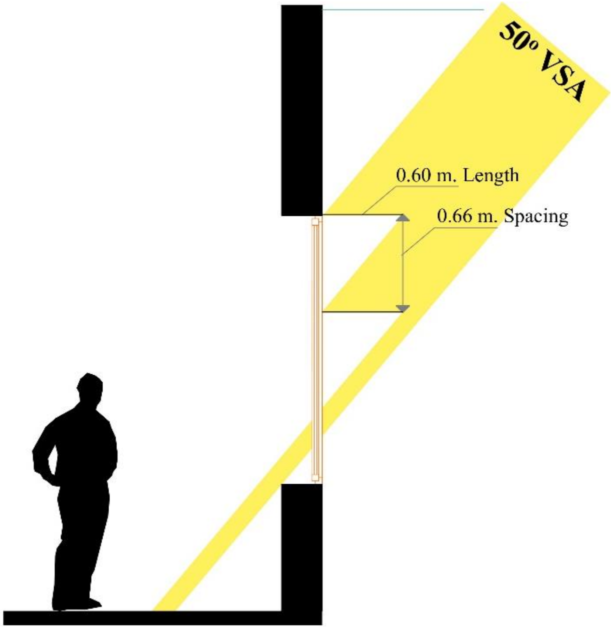


Figure 32: Optimized shading device strategy section detail responding to the preferable (summer & winter) sun radiations for North-East façade, VSA 50º. (By Author).

4.2.3.4 Skylight

It’s been considered to provide shading devices at the skylight in the building atrium in order to decrease overheating in the building and reduce the cooling demand during the summer. Due to the skylight orientation, optimizing the shading devices towards South east results to increasing of 87 % protection from unwanted sun radiation and cover 31 % of wanted sun radiation during the year comparing to the existing situation. According to the simulation, the optimum VSA found was 50º without needing for fins.

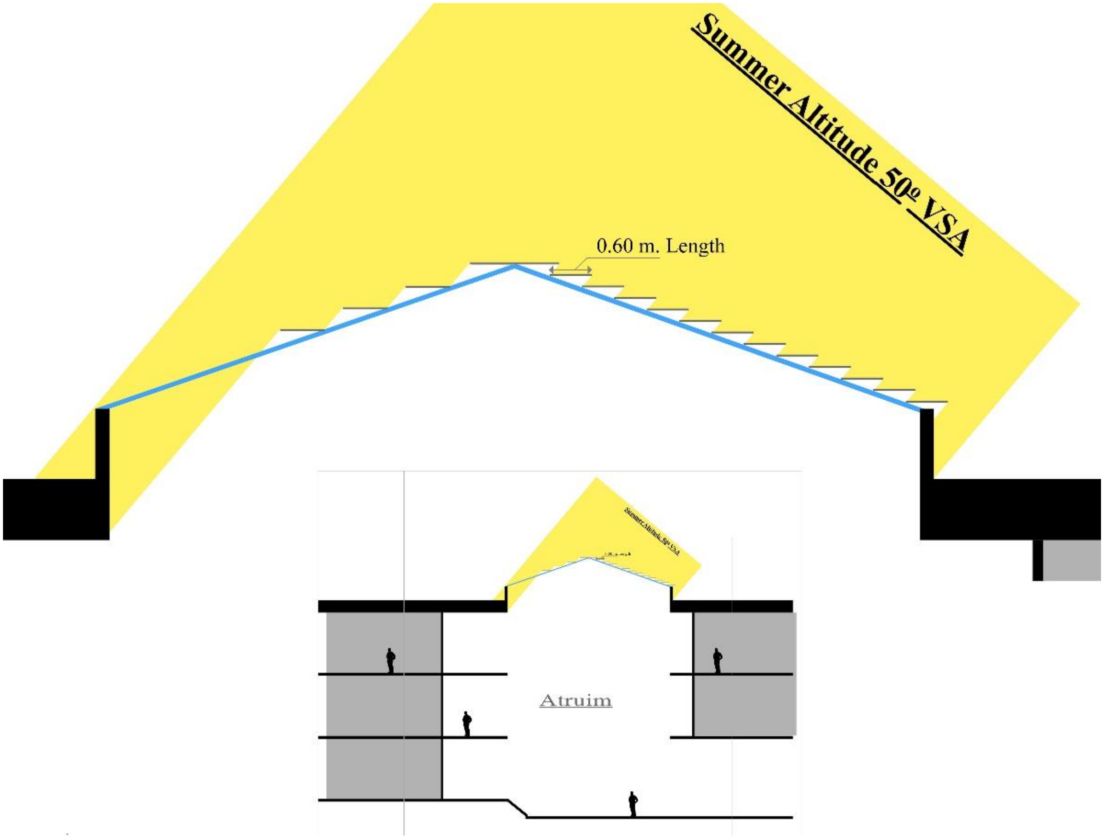


Figure 33: Building Cross Section Illustrate the Predicted Behavior of Shading Strategies from South East orientation.

4.3 Impact of the Optimization Alternatives and their Cost-Effectiveness

In order to meet EU NZEB requirements, the alternative energy efficiency measures were separately simulated to find their influence on energy consumption, which were the replacement of windows, adding an insulation to the walls and on roof and the installation of vertical and horizontal shading devices for all windows. The skylight shading devices was tested under an estimation condition if the atrium is been air conditioned. An investigation of the impact of each energy efficiency measurement mentioned above was acquired in order to identify the most cost-efficient and energy efficient measure. Energy savings calculated for each measure are on annually bases.

By conducting an energy comparison between the baseline run (existing energy consumption) and alternative runs after optimizations the results shows significant savings in energy consumption after each optimization item (table 10). It was found that the most energy effective measure is the placement of the roof thermal insulation among investigated measures and the most conducted savings was for heating energy consumption. Insulating the roof with (150mm – 70 mm) expanded polystyrene) results to (42,770 – 37,930 kWh/year) energy savings respectively.

Replacing the existing windows with highest insulating ones, found to be the second energy effective measure after the roof insulation, and the most conducted savings was for cooling consumption savings. Triple low-e glass filled with Aragon results to (23,470 kWh/year) energy savings and double glazing results (21,400 kWh/year) energy savings.

Thermal walls insulation results energy savings less than the windows replacement, the most energy savings was conducted to the heating energy consumption. Insulating with (68 mm) thickness of expanded polystyrene externally results (17,610 kWh/year) and insulating with (150 mm) results to (19,610 kWh/year).

Integrating shading devices to the windows results the minimum energy savings per year reach to (9,740 kWh) and the most savings conducted for cooling savings. Integrating shading devices to the skylight results to (8,990 kWh) savings per year. Table 10 and (fig.33) below illustrates detailed energy savings for each measures.

Table 10: Annual energy efficiency measures alternatives energy savings.

Element	**alternatives**	**Total savings (kWh)**	**Cooling savings (kWh/m^{2}y)**	**Heating savings (kWh/m^{2}y)**
	68 mm (0.40 W/m^{2}K)	**17,610**	0.30	5.32
	150 mm (0.20 W/m^{2}K)	**19,610**	0.33	6.06
	70 mm (0.4 W/m^{2}K)	**37,930**	2.18	9.63
	150 mm (0.20 W/m^{2}K)	**42,770**	2.32	10.89
	Double clear glass low-e	**21,400**	4.00	0.71
	Triple clear glass low-e	**23,470**	3.92	1.50
Installation of shading devices	For South-East and South West facades	**9,740**	2.77	-
Shading devices for the skylight	South east orientation	**8,990**	2.14	-

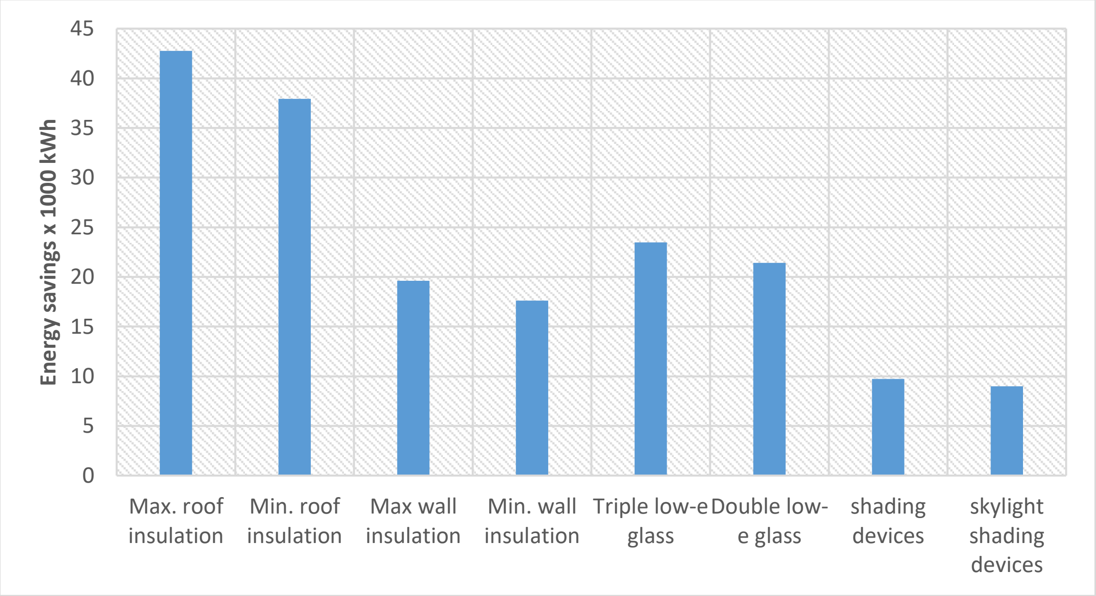


Figure 34: Yearly energy savings for the energy efficiency measures.

4.3.1 Energy Efficacy Cost-Effectiveness

In addition to energy efficiency measures energy savings evaluation, an economic analysis using the life cycle cost LCC method has been conducted for each scenario to investigate their cost-effectiveness in term of their life service.

Simple payback period method will be used in order to determine the length of time it will take to recover the initial amount invested for each measurement. Minimum years indicate the better investment or the better energy efficient measure to be chosen. The initial cost of each scenario and annual saving cost are the variables in this method according to the following equation:

$$payback\ time\ (years) = initial\ cost\ \$ \div annual\ energy\ savings\ cost\ \$$$

In addition, for determine the feasibility of the energy efficient measure or the renovation measure, Net Present Value (NPV) method has been used to evaluate each renovation measure. NPV consider the time value of money (e.g. money is losing its value over time because of the discount amount of interest rate). Generally, higher NPV indicates higher profits regarding the life time of the measure. The NPV value calculate the sum of savings of the service year and refer it to the present value according to the following equation:

$$NPV = PV\ saving\ \$\ in\ yr\ 1 + PV\ saving\ in\ yr\ 2 + \cdots + PV\ saving\ in\ N - IC\ \$$$

(2)

Where:

NPV: net present value $

PV: present value of the money $

N: year considered

IC: initial cost $

Complying with the objective of this research to find optimum strategy for renovation within the design alternative mentioned before, additional design alternative developed from the combination of these measures based on their individual NPV values. Twenty year life cycle costs are calculated with the 10% interest rate, 10% electricity escalation rate, and initial costs of the measures. The maintenance cost was considered as 1% per year. For more details refer to (appendix A)

From (fig.34) the external thermal insulation for roof and walls shows less than 6.5 years payback periods, followed by the integrating of shading devices with 9.2 payback period. Followed by the windows replacement which shows more than 10 years payback periods,

In terms of roof insulation, the thermal external insulation with (70 mm thickness) expanded polystyrene (here will refer as minimum insulation) shows 3.2 year as a payback period and the thermal external insulation with (150 mm thickness) (here will refer as high insulation) shows payback period 4.2 years. For walls insulation minimum insulation shows 5.3 payback year and 6.1 payback year for the higher insulation level. In terms of the windows replacements, double glass replacement shows 10.1 years and triple glass shows 11.5 years as a payback period. (fig.34) shows the payback period by years for each measurement.

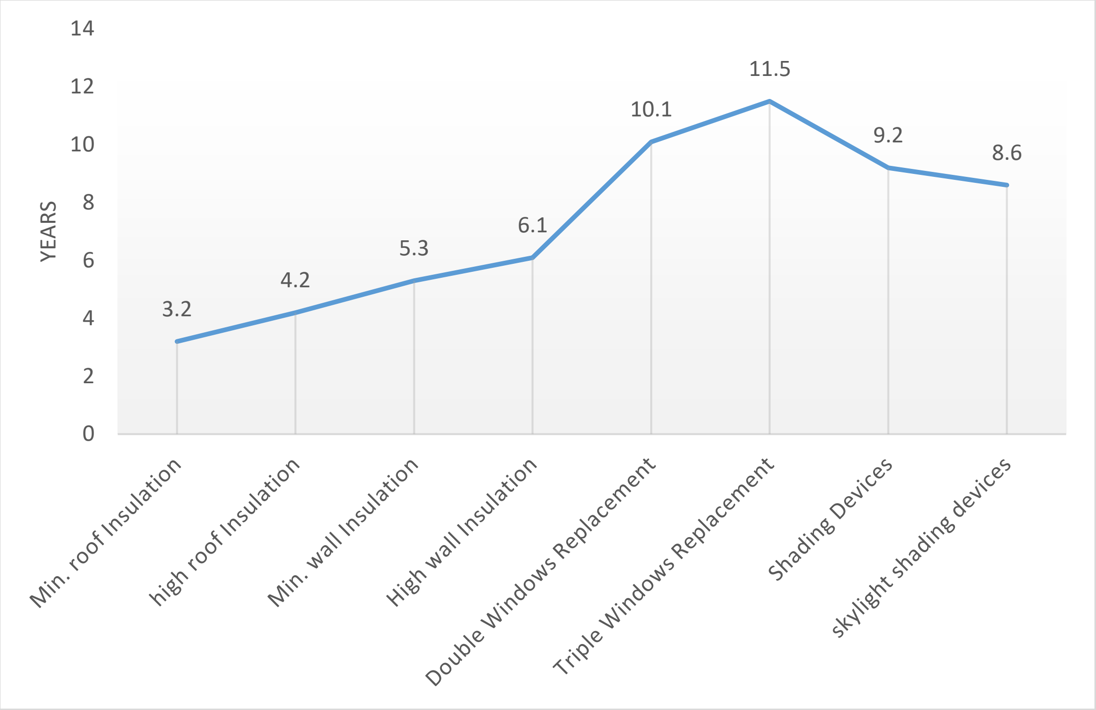


Figure 35: Payback period for the energy efficient measurements. (High payback means bad investment)

In terms of NPV, (fig.35) shows the different NPV of the energy efficient measurements, its proven that thermal insulation for the roof accounts for the higher savings in comparison with other measurements, the higher insulation saves (131,595 $) for the next 20 years and the less insulation saves (124,402 $) for the same period. For external wall insulation, the higher insulation saves (53,044 $) for the 20 year and the less insulation saves (50,613 $) for the same period.

For the windows replacement, double glass shows higher saving than the triple glass savings due to the high initial cost of the triple glass, for double glass (41,260 $) savings for the 20 year and (38,783 $) savings account for the triple glass for the same period. Therefore replacing with triple low-e glass is not recommended due to its high initial cost. Installing shading devices for south east and south west façade has (20,436 $) for the 20 years (Fig.37) shows the relation between NPV and payback period for the energy efficient measures.

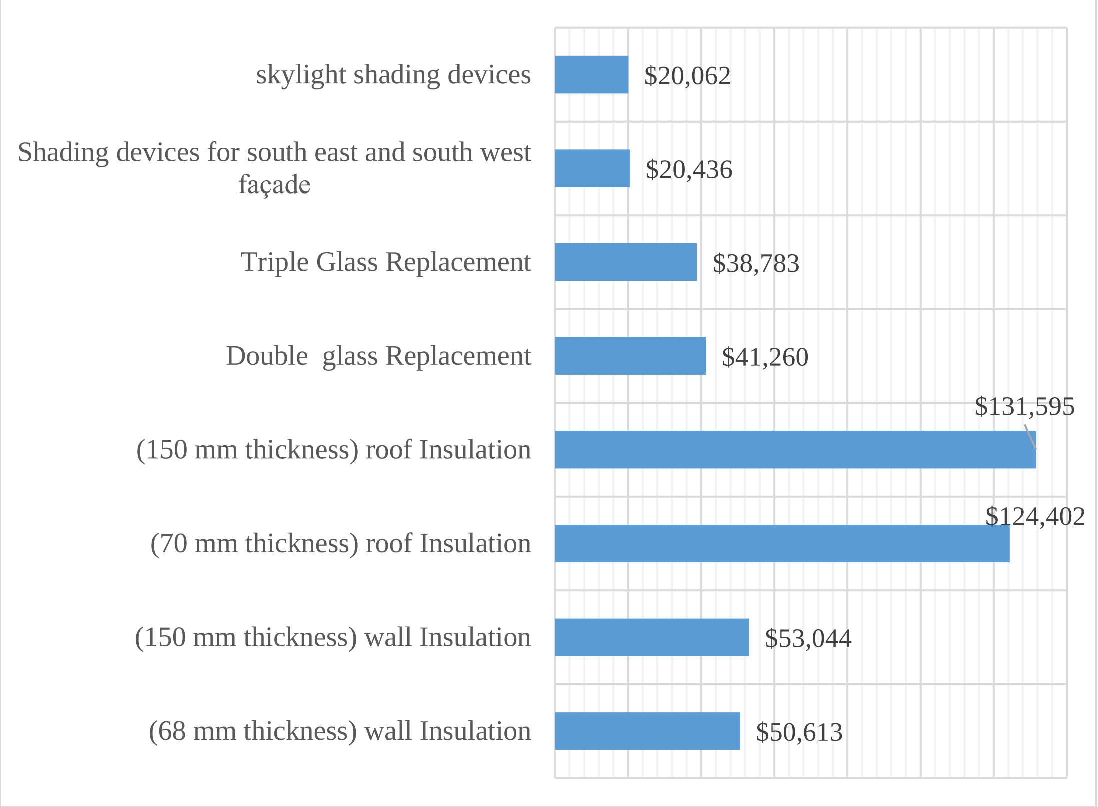


Figure 36: different NPV of the energy efficient measurements for 20 years (high NPV indicate as good investment).

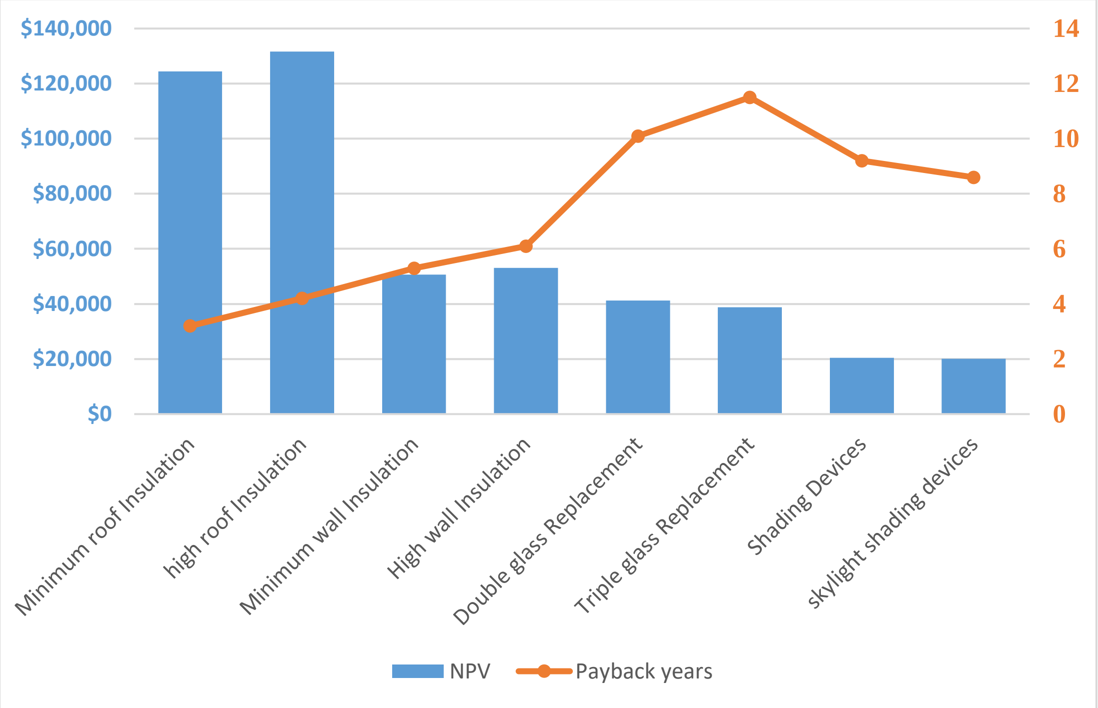


Figure 37: shows the relation between NPV for 20 years and payback period for the energy efficient measures.

Regarding to the previous, an alternative design measurement developed from the combination between these measurers based on their payback period and the NPV for each alternative. Firstly, two alternatives was developed from a combination of two alternatives together, secondly tow alternative was developed from a combination of three measures together, which results in total as 6 alternatives shown in the following table:

Table 11: combination design alternatives.

Combination type	Low NPV and short payback period	High NPV and longer payback period
Combination of two alternatives	Minimum insulation for walls + windows replacement (double glass)	High insulation for walls + windows replacement (double glass)
	Minimum insulation for walls + minimum insulation for roof	High insulation for walls + high insulation for roof
Combination of three alternatives	Minimum insulation for walls + minimum insulation for roof + windows replacement (double glass)	High insulation for walls + high insulation for roof + + windows replacement (double glass)

The results indicate that all design alternative have less than 7.5 years as payback period. In terms of the combination of two alternatives, high thermal insulation for walls and roof results as a higher investment profit with (197,155$) for 20 years and 4.6 years as a payback period. Adding high insulation for walls and replacing the windows results to (111,503$) NPV for 20 years and 7.4 years as payback period and adding minimum insulation for walls and with windows replacement results to (105,952$) NPV for 20 years and 7.3 years as a payback period. (fig.37) shows the relation between the NPV and payback period for the alternatives.

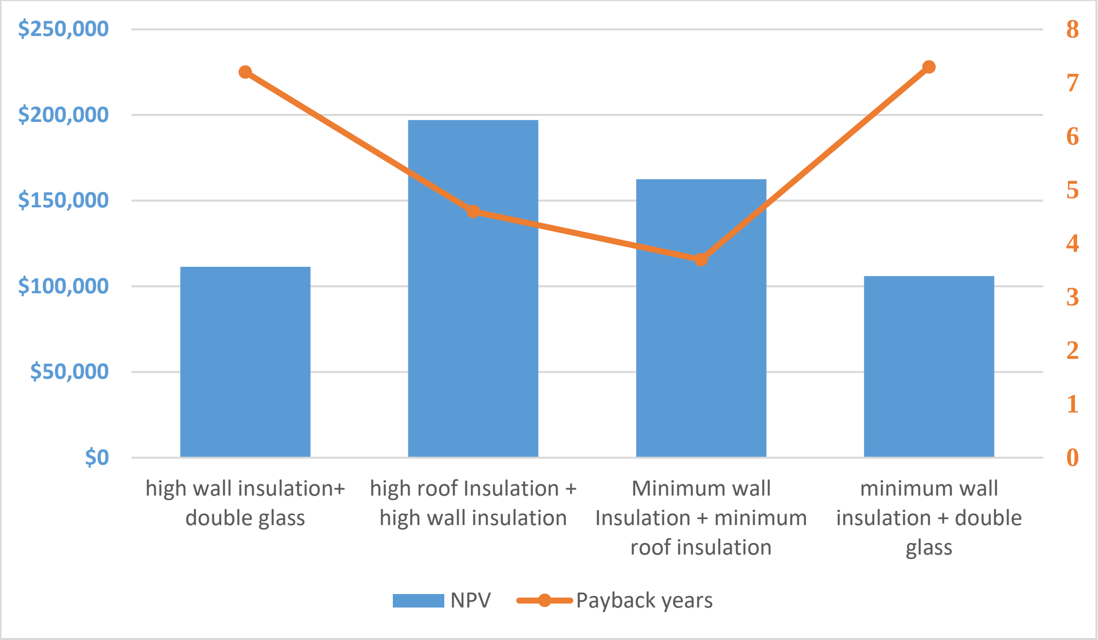


Figure 38: Shows the relation between NPV for 20 years and payback period for the combination alternatives.

In terms of the combination of the three alternative together, high thermal insulation for roof and walls and replacing the existing windows with double glass window proven to be the higher NPV with (289,934$) savings for 20 years and 5.2 years as payback period. Adding low thermal insulation for roofs and walls and replacing the windows with double glass result to (269,354$) NPV for 20 years and less payback period which calculated as 4.7 years. The following figure 38 shows the each alternative NPV and payback period.

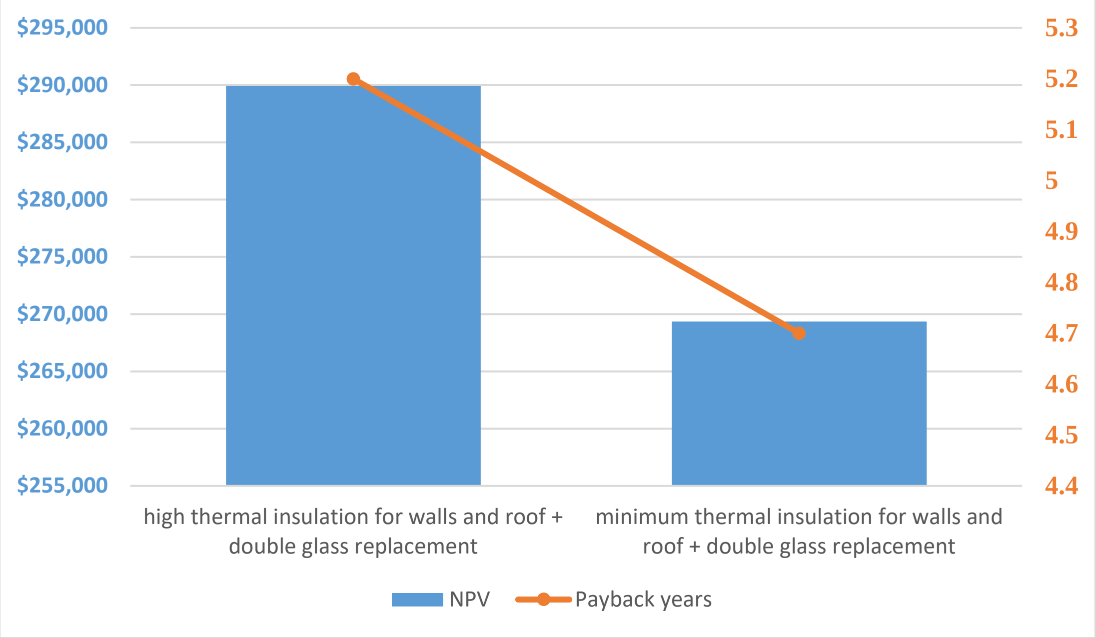


Figure 39: Shows the relation between NPV for 20 years and payback period for the combination alternatives.

After discussing the design alternative for reducing energy consumption, and in order to achieve NZEB renewable energy system is required in order to balance the energy consumption of the building on annually bases. The following discuss the integrating of renewable energy to the colored building and its economic feasibility.

4.3.2 Renewable Energy Systems Role

No renewable energy systems are integrated the buildings envelope, which play a key role in achieving net-zero energy after optimizing the energy efficiency of the building.

Based on the colored building location (35º. 8'44" North, 33º. 54'35"East) and North Cyprus annual solar radiation (fig. 39) shows the monthly and annul sun radiation, and in response to the building orientation to the sun path, the optimum PV integration is on the roof, with a slope inclination 30º and oriented 30º to the south (parallel with the building orientation).

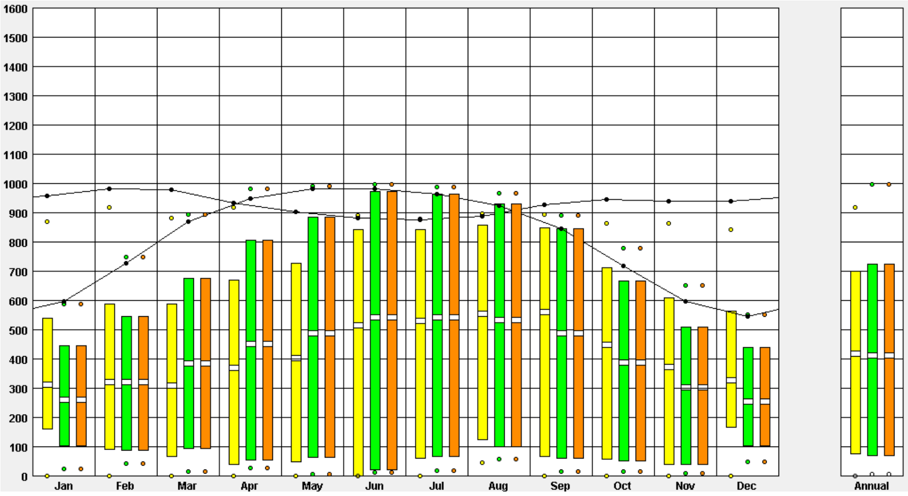


Figure 40: Variation of the annual solar irradiation in Colored building (at latitude 35º) (climate consultant software). (🟨 Direct normal, 🟩global horizontal, 🟧 total radiation)

Available roof top area for integrating the PV is (777 m^2) (fig.40), according to the PV panel (1.2 m^2) and it’s tilted angle (30º), and taking in consideration avoiding the shades and walking corridors, 500 panel can be integrated to the roof (fig.41), annual energy can be integrated from one panel based on the solar radiation on the building is (286 kWh) (Appendix P). According to these considerations, integrating PV panels on this area provides (143,000 kWh) on annul bases.

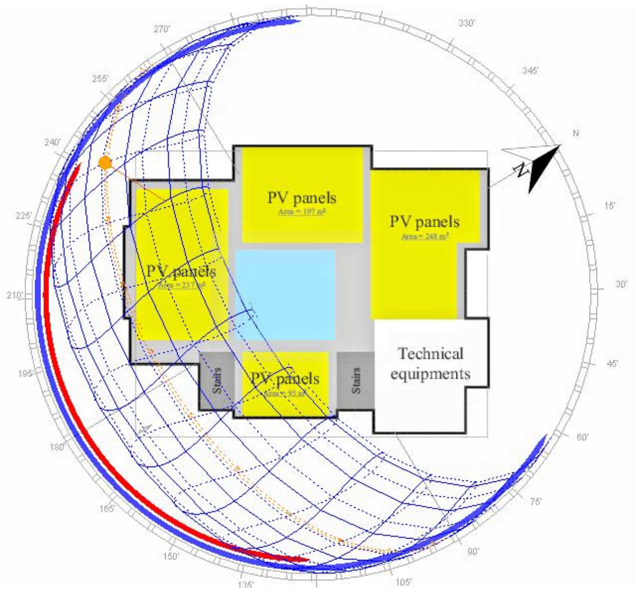


Figure 41: shows the integration locations and the sun location to the roof top of the colored building.

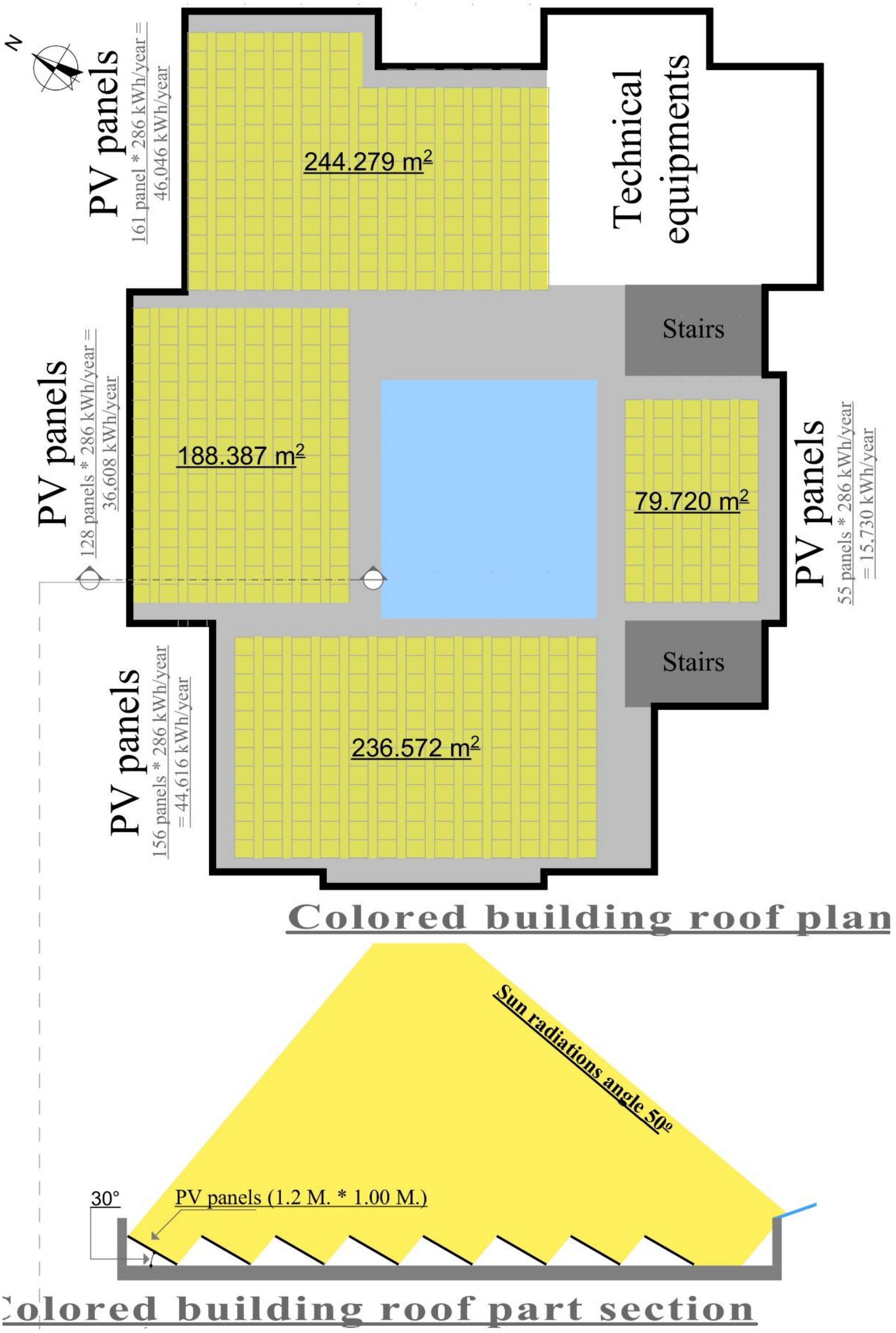
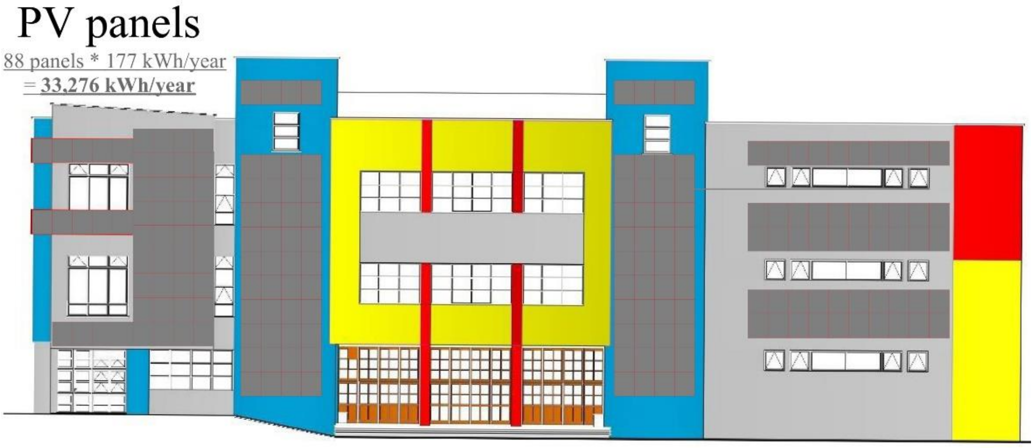


Figure 42: shows the integration locations and available areas on the roof top of the colored building with the number of the PV panels and their annual electricity generation.

In terms of facades, PV panels consider to be integrated to the South-east and South-West facades, regarding to the orientation the PV efficiency decreases, for the South-East façade the panel can produce (177 kWh/year) and for South west façade the panel can produce (166 kWh/year) (Appendix Q, R.) According to the PV panel (1.2 m^2) 188 panel can be integrated to the south-east façade, and 168 panel can be integrated to the south west facade (fig.42), annual energy can be integrated from one panel based on the solar. According to these considerations, integrating PV panels on both facades provides (61,164 kWh) on annul bases.

South-West Elevation



South -East Elevation

Figure 43: shows the PV integration location on colored building facades

4.3.1.1 Feasibility of Integration PV

As stated in literature review section (2.2.6), off-grid system is not cost-feasible for North Cyprus, the grid connected system generate cheapest energy in comparison with energy cost from the grid. Therefore, Grid – tied PV system is a suitable alternative to against the conventional grid electricity generation in Northern Cyprus.

An investigation done by (Pathirana & Muhtaroğlu, 2013) for the feasibility of PV panels in North Cyprus, implied that the final price of generated electricity by grid-tied PV systems in Northern Cyprus is (0.13 $- 0.14 $ / kWh). In comparison of current price of grid electricity, produced electricity from grid-connected PV system is less than public grid price which is accounts as (0.195 $/kWh) (Pathirana & Muhtaroglu, 2013). (Table 11) shows the electricity generation costs by different grid-tied technologies in Northern Cyprus putting in consideration the PV system cost and the life time (20 years) and interest rate in Cyprus (10%) according to the same study (Pathirana & Muhtaroglu, 2013).

Table 12: Electricity Generation Costs for Different on-grid PV Types in N. Cyprus (Pathirana & Muhtaroglu, 2013)

PV Technologies	c-Si	mc-Si	Thin film Si
Cost of Electricity Generation from PV panel (**$/kWh**)	0.14	0.13	0.13
Cost of electricity from general grid (**$/kWh**)		0.195	

Based on these calculations, integrating PV panel on building's roof and south-east and south west façade generate (204,164 kWh) annually, which costs according to the table above (26,541$/annually), the same amount of electricity from the general grid will cost (39,811$/annually). From these calculations PV integration saves (13,270 $)

annually. The NPV of renewable electricity supply systems accounts to approximately (331,647 $) during 25 years (appendix P).

4.4 Comparison of Energy Optimization Measures with the Existing Building Situation

The colored building estimated energy consumption was calculated as (140.65 kWh/m^{2}year). Adding additional external insulation for the existing walls and roof with (150 mm thickness expanded polystyrene) and replacing the existing windows with double low-e glazing filled with Aragon and integrating PV panels to the roof proved to be the most energy and cost efficient renovation measurement.

The optimization measurement reduce the energy consumption to (105.40 kWh/m^{2}y) which is below the minimum requirements of the EU for NZEB in Cyprus which is accounts as (125 kWh/m^{2}y) (EPISCOPE, 2014). Moreover the PV panels produces (195,805 kWh) annually which is account for almost 50% of energy consumption after renovation measures. Table 13 illustrates all design alternative measures considered and their investment costs, annual energy savings, energy savings cost, NPV for 20 years and their payback period.

Table 13: Design alternative measures' energy and economic impacts

Energy efficient measure	alternatives	Initial cost $	Annual savings (kWh)	Annual savings cost $	NPV	Payback periods (years)
	68 mm thickness expanded polystyrene for walls (0.40 W/m^{2}K)	18,066$	17,610	3,434$	50,613	5.3
	150 mm thickness expanded polystyrene for walls (0.20 W/m^{2}K)	23,436$	19,610	3,824$	53,044	6.1
	70 mm thickness expanded polystyrene above roofs (0.4 W/m^{2}K)	**23,517$**	**37,930**	**7,396$**	**124,402**	**3.2**
	150 mm thickness expanded polystyrene above roofs (0.20 W/m2K)	35,208$	42,770	8,340$	131,595	4.2
	Double clear glass low-e coated with aluminium frames with thermal insulation spacer filled with Aragon	42,200$	21,400	4,173$	41,260	10.1
	Triple clear glass low-e coated with aluminium frames with thermal insulation spacer filled with Aragon	52,750$	23,470	4,576$	38,783	11.5
	Installation of shading devices All windows	17,550$	9,740	1,899$	20,436	9.2
	Skylight shading devices	15,000$	8,990	1,753$	20,062	8.6
	150 mm exp. Pol. for walls Dbl. clr. glass low-e (Aragon filled)	65,636$	45,420	8,856$	111,503	7.4
	150 mm exp. Pol. for walls 150 mm exp. Pol. above roofs	58,644$	65,590	12,790$	197,155	4.6
	68 mm exp. Pol. for walls Dbl. clr. glass low-e (Aragon filled)	60,266$	42,620	8,310$	105,952	7.3
	68 mm exp. Pol. for walls **70 mm exp. Pol. above roofs**	**41,583$**	**57,590**	**11,230$**	**162,595**	**3.7**
	70 mm exp. Pol. above roofs 68 mm exp. Pol. for walls Dbl. clr. glass low-e (Aragon filled)	83,783$	90,550	17,657$	269,354	4.7
	150 mm exp. Pol. for walls **150 mm exp. Pol. above roofs** **Dbl. clr. glass low-e (Aragon filled)**	**100,844$**	**100,200**	**19,539$**	**289,934**	**5.2**

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Cyprus, one of the largest islands in the Mediterranean has no petroleum reserves and is completely dependent on imported energy from petroleum products. The uncertain load increase and the rising cost of fossil fuels, requires serious attention and consideration especially to buildings optimizations towards sustainability and energy efficiency. Therefore, renovating towards energy efficient towards net-zero energy buildings (NZEB) concepts have attracted intense attention from researchers, architects, and engineers.

From general theoretical background in chapter 2, renovating buildings technologies for energy efficient or towards zero energy building consists of two steps;

- Reducing the existing energy consumption through passive and active design strategies which takes advantage of the heat transfer processes contributing to the thermal balance of a building.

- Integrate renewable energy sources to balance the energy demand after energy efficient measurements.

Following is the summary of building renovation technologies:

1. Demand side management (reducing energy consumption):

Passive Solar design strategies:

- Passive solar heating systems, which (in the Northern hemisphere) include south facing glazing to let the sunlight in and thermal mass to absorb, store and distribute heat.

- High level of thermal Insulation helps the building to preserve the heat and at the same time it prevents the building from releasing the unwanted heat

- High airtightness: Infiltration leads to enlarge energy losses; an energy efficient building should have between 0.35 and 0.5 ach-1 (air changes per hour) if mechanical ventilation is not present, and below 0.35 ach-1 is there is mechanical ventilation

- Maximum usage of natural daylighting

- Solar heat gain

- Windows replacement with multiple glass (double or triple glazing).

- Glazing area should not exceed 40% of the façade area

- Advanced low-U value and high solar factor windows specified for each climate Use low U-value of 1.5 W/m^{2}K or less.

- Use of windows with lower SHGC, less than 0.7

- Solar protection: Window overhangs, which if properly designed provide shading that prevents solar gain or heat during the summer while during the winter that the sun is lower the solar and heat gains are more. Controllable external shading can also be a good solution

Active design strategies:

- High Efficiency of lighting
- High Efficiency of heating equipment
- High Efficiency of cooling equipment
- Mechanical ventilation equipment
- Efficiency of appliances
- Advanced sensors,
- Energy control (zone heating and cooling) and monitoring systems

2. Supply side management (balancing the demanded energy):

- Developing on-grid integrated solar photovoltaics PV systems,
- Solar hot water

- Wind energy turbine

- Geothermal energy

- Integrate solar façade as shading and/or as additional insulation

This research investigated the feasibility of reducing energy consumption of an existing educational building in EMU through optimizing its envelope characteristics in order to develop a strategy for achieving net-zero energy concepts, in addition to evaluate the cost-effectiveness of the energy efficiency measurements and integrating renewable energy sources to balance the energy demanded. Educational buildings has a great potential in energy reduction due its limited daytime operational schedules, in addition of getting the maximum benefit from the solar energy.

The faculty of architecture lecture hall (colored building) is a rectangular shape building consist of three floors founds to be oriented 30º to North, the built up area is approximately 1,500 m^2 and 4,483 m^2 total built-up area. It contains large studios areas, in order to provide enough daylight levels to the deep spaces, a large windows (WWR) is been used in all facades without any insulation which caused overheating during summer and led to using of inside curtains due to the lack of exterior shading devices, which can reduce the glare but not the heat entered which influence the cooling consumption. The large skylight in the atrium provides daylighting to the deep spaces and the corridors without a controlling system which led to an excessive overheating during summer to the atrium. In addition of the poor insulation of walls and roof.

The existing energy consumption calculated is (130 kWh/m^2.year). By investigating the impact on energy consumption of two design alternatives of external thermal insulation for walls and roofs, windows replacements with two alternative more insulated glazing, and adding exterior shading devices for the windows and to the skylight, in addition of integrating PV panels to the building roof and south facing facades, the results indicates that the optimizing or renovating the colored building towards near zero energy building is energy and economically feasible, with a payback period of less than 4 years. The general results found that this building can reach (105 kWh/m^2.year) energy consumption which is below the EU standards for zero energy buildings, and the PV panels energy generation can cover more than 75% of the annual energy consumption after renovation.

5.1 Main Findings

The research concluded that external thermal insulation for roofs with (70 mm thickness) expanded polystyrene is the most effective renovation measurement, it results to 25% savings from heating energy during winter, with a 3 years as payback period and save almost (125,000 $) from energy saving over 20 year of service.

Following by a combination of insulating the roof with (70 mm thickness) and walls with (68 mm thickness) with expanded polystyrene which result to 15% from heating energy and provide less than 4 years as a payback period and save (163,000$) over 20 years of service.

Maximum saving found to be using thermal insulation of (150 mm thickness) expanded polystyrene for walls and roof and replacing the existing windows with double low-e coating glazing with aluminum frame with thermal insulator spacer filled with Aragon, which result to 55% of heating energy and 17% of cooling energy. The savings reach to (290,000$) over 20 years but more payback period counted to 5 years.

If the renovation action conducted only windows replacement, the saving in terms of energy is high, but due its high initial cost it takes longer payback time and less money savings so it’s not recommended measurement unless it’s being combined with the walls insulation which results higher savings in terms of money and energy savings.

Furthermore, integrating on-grid system PV panels to the building roof and south- east and south west facades provide (204,164 kWh) annually with a less price than the electric provided from the grid results to (331,647 $) savings in electricity bills over 25 years.

In terms of the annual operating schedules, in the case of building is not operating during summer season (July, August), shading strategies for windows and the skylight is not needed. Only the thermal insulation for roofs and walls should be considered.

5.2 Recommendations

- Further studies on automated shading devices.
- Further studies about daylight sensors to increase the lighting efficiency.
- Upgrading the existing lighting and HVAC system in terms of energy efficiency for more annual energy savings.
- Provide opening to the skylight for the stack ventilation on the building atrium.
- Further studies on integrating the PV panels as an additional insulation material to the walls and roofs
- Further studies on integrating PV panels as shading devices

REFERENCES

Adhikari, R. S., Aste, N., Pero , C. D., & Manfren , M. (2012). Net Zero Energy Buildings: Expense or Investment? Energy Procedia, 14, 1331-1336.

AEPCA. (2004). A Best Practice Guide to Measurement and Verification of Energy. South Melbourne, Australia: Australian Energy Performance Contracting Association.

Aksamijaa, A. (2015). Regenerative Design of Existing Buildings for Net-Zero Energy Use. Procedia Engineering, 72 – 80.

Alibaba, H. (2016). Determination of Optimum Window to External Wall Ratio for Offices in a Hot and Humid Climate. Sustainability, 8(187), 1-21. Retrieved 2016, from http://www.mdpi.com/2071-1050/8/2/187/htm

Alibaba, H. Z., & Ozdeniz, M. B. (2016). Energy Performance and Thermal Comfort of Double-Skin and Single-Skin Facades in Warm-Climate Offices. Journal of Asian Architecture and Building Engineering, 15, 635-642. Retrieved from https://www.jstage.jst.go.jp/article/jaabe/15/3/15_635/_pdf

Al-Turki, A., & Zaki, G. M. (1991). Cooling load response for building walls comprising heat storing and thermal insulating layers. Energ. Convers. Manage., 235–247.

ANSI/ASHRAE/IES Standard 90.1-2010. (2010). Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Ascione, F., De Rossi, F., & Vanoli, G. (2011). Energy retrofit of historical buildings: theoretical and experimental investigations for the modelling of reliable performance scenarios. Energy and buildings, 1925-1936.

ASHRAE Handbook of Fundamentals. (1993). American Society of Heating and Refrigerating, Air Conditioning Engineers. Atlanta, Georgia.

Atanasiu, B., Arcipowska, A., Kontonasiu, E., Stegnar, G., Rakušćek, A., & Šijanec, M. (2014). Inclusion of New Buildings in Residential Building Typologies—Steps Towards NZEBs Exemplified for Different European Countries. Institut Wohnen und Umwelt GmbH.

Athienitis, A., Liu, C., Hawes, D., Banu, D., & Feldman, D. (1997). Investigation of the thermal performance of a passive solar test-room with wall latent heat storage. Building and Environment ;):., 5(32), 405–10.

Autodesk. (2016). Autodesk Ecotect Analysis. Retrieved from Autodesk web site : http://www.autodesk.fr/adsk/servlet/pc/index?siteID=1157326&id=15362643

Baek, C. H., & Park, S. H. (2012). Changes in renovation policies in the era of sustainability,. Energy and Buildings, 485–496.

Baglivo, C., Congedo, P. M., & Fazio, A. (2014). Multi-criteria optimization analysis of external walls according to ITACA protocol for zero energy buildings in the mediterranean climate. Building and Environment, 82, 467-480.

Barlow, S., & Fiala, D. (2007). Occupant comfort in UK offices—How adaptive comfort theories might influence future low energy office refurbishment strategies. Energy Build., 39, 837–846.

Bavafa, M. (2015). Evaluation of Developing Net Zero Energy Buildings in Northern Cyprus. MS.c Thesis, Eastern Mediterranean University, Department of Architecture, North Cyprus, Gazimagusa.

Biesbroeck, K., Klein, R., Versele, A., & Breesch, H. (October 2010). Design processes for Net-Zero Energy Buildings. In SB 10 conference. Retrieved from https://www.irbnet.de/daten/iconda/CIB21669.pdf

Biricik, & Ozderem, O. (2011). OVERVIEW OF ENERGY SYSTEM AND MAJOR POWER QUALITY PROBLEMS IN NORTH CYPRUS. International Journal onTechnical and Physical Problems of Engineering, 71-75.

Boverket. (2011). Regelsamling för Byggande, BBR 2012. Boverket: Karlskrona.

BREEAM. (2016). BREEAM International Non-Domestic Refurbishment. United Kingdom: BREGlobal Ltd. Retrieved March 22, 2017, from http://www.breeam.com/domrefurbmanual/#resources/output/bre_printoutput/breeam_domestic_refurb_manual_2012.pdf

Buildings Performance Institute Europe. (2013). A guide to developing strategies for building energy renovation. Buildings Performance Institute Europe (BPIE). Retrieved October 20, 2016, from http://bpie.eu/wp-content/uploads/2015/10/Developing-Building-Renovation-Strategies.pdf

Cambeiro, F. P., Armesto, J., Barbeito, F. P., & Bastos, G. (2016). Perspectives on Near ZEB Renovation Projects for Residential Buildings: The Spanish Case. energies, 628.

Carmichael, C., & Managan, K. (2013). Reinventing Existing Buildings:Eight Steps to Net Zero Energy. U.S.A, Milwaukee: institute for building efficiency an initiative of johnson controls.

Chidiac, S. E., Catania, E., Morofsky, E., & Foo, S. (2011). Effectiveness of single and multiple energy retrofit measures on the energy consumption of office buildings. Energy, 5037-5052.

Christian , J. E., & Kosny, J. (2006). Thermal Performance and Wall Ratings.

Climatemps.com. (2015). Retrieved April 24, 2016, from Famagusta Climate & Temperature: http://www.famagusta.climatemps.com/

Çomaklı, K., & Yüksel, B. (2003). Optimum insulation thickness of external walls for energy saving. Appl. Therm Eng., 23, 473–479.

Council, J. G. B., & Japan Sustainable Building Consortium. (2013). CASBEE, Comprehensive Assessment System for Built Environment Efficiency.

Council, U. G. B. (2013). LEED Reference Guide for Building Design and Construction, LEED V4 . Washington DC, USA: USGBC.

Cowan, J., Kromer, S., Claridge, D., Franconi, E., Haberl, J., Hepner, M., & Schiller, S. (2001). International performance measurement & verification protocol: Concepts and options for determining energy and water savings (No. LBNL--48675; DOE/GO-102001-1187). Berkeley, CA (US): Ernest Orlando Lawrence Berkeley National Laboratory.

Crawley, , D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2008). Contrasting the capabilities of building energy performance simulation programs. Building and environment, 661-673.

Cyprus Turkish Electricity Board. (2002). 2002 annual report. Nicosia, Cyprus Turkish Electricity Board. North Cyprus.

Da Silva, P. C., Leal, V., & Andersen, M. (2012). Influence of shading control patterns on the energy assessment of office spaces. Energy and Buildings, 50, 35-48.

Directorate-General for Energy. (2017). Directorate-General for Energy. Retrieved March 22, 2017, from Directorate-General for Energy: http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive

Douglas, J. (2006). Building adaptation. Amsterdam: Routledge. Retrieved March 9, 2017, from https://books.google.com.cy/books?hl=en&lr=&id=gaqwsLs23mgC&oi=fnd&pg=PP2&ots=EbQC-KUVtM&sig=FWP7EJjYV1hQZkwKL7y-Qramcy8&redir_esc=y#v=onepage&q&f=false

Ebbert, T. (2010). Re-Face: Refurbishment Strategies for the Technical Improvement of Office Façades. TU Delft, Delft University of Technology, Building Technology. The Netherlands: Thiemo Ebbert.

Egmond, C., Jonkers, R., & Kok, K. (2005). A strategy to encourage housing associations to invest in energy conservation. . Energ. Pol., 2374–2384.

Eichhammer, W., Fleiter, T., Schlomann, B., Faberi, S., Fioretto, M., Piccioni, N., . . . Resch, G. (2009). Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. Final Report for the European Commission, Directorate-General Energy and Transport. Retrieved March 22, 2017, from https://ec.europa.eu/energy/sites/ener/files/documents/2009_03_15_esd_efficiency_potentials_final_report.pdf

EPBD recast. (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, 18(06). Retrieved April 25, 2016, from http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

EPISCOPE. (2014). Inclusion of New Buildings in Residential Building Typologies. Darmstadt / Germany: Institut Wohnen und Umwelt GmbH.

Erdil, E., Ilkan, M., & Egelioglu, F. (2008, August). An experimental study on energy generation with photovoltaic (PV)- solar thermal hybrid system. Journal of Energy, 33(8), 1241-1245.

Erpelding, B. (2008). Monitoring chiller plant performance. ASHRAE Journal, 48-52.

Esbensen, T. V., & Korsgaard, V. (1977). Dimensioning of the solar heating system in the zero energy house in Denmark. Solar Energy, 195-199.

European Commission, Joint Research Centre. (2017, September 26). Photovoltaic Geographical Information System - Interactive Maps. Retrieved from Photovoltaic Geographical Information System - Interactive Maps: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=africa

Feilden, B. (2007). Conservation of historic buildings. . United Kingdom: Routledge.

Femenías, P., & Fudge, C. (2010). Retrofitting the city: Re-use of non-domestic buildings. Int. J. Urban Des. Plan., 117–126.

Flourentzou, F. J., & Roulet, C. A. (2002). TOBUS software—An interactive decision aid tool for building retrofit studies. Energy Build., 193–202.

Garde, F., Lenoir, A., Scognamiglio, A., Aelenei, D., Waldren, D., & Rostvik, H. N. (2014). Design of Net Zero Energy Buildings: Feedback from international projects. Energy Procedia, 61, 995–998.

Gilijamse, W. (1995). Zero-energy houses in the Netherlands. Building Simulation, 95.

Gonçalves, H. (2010). Solar XXI : em direcção à energia zero : towards zero energy. Lispona, Portugal. Retrieved May 1, 2016, from http://repositorio.lneg.pt/bitstream/10400.9/1322/1/BrochuraSolarXXI_Maio2010.pdf

Gonçalves, H., & Cabrito, P. (2006). A passive solar Office Building in Portugal. PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture. Geneva, Switzerland.

Green Sun Rising Inc. . (2015). Green sun rising. Retrieved from Green sun rising: http://www.greensunrising.com/solar-pv.htm

GreenSpec. (2017). Concrete flat roof insulation. Retrieved from GreenSpec: http://www.greenspec.co.uk/building-design/concrete-flat-roof-insulation/

Griffith, B., Long, N., Torcellini, P., Judkoff, R., Crawley, D., & Ryan, J. (2007). Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector. Colorado: National Renewable Energy Laboratory (NREL). Retrieved from http://www.osti.gov/bridge

Gruis, V., Visscher, H., & Kleinhans, R. (2006). Sustainable Neighbourhood Transformations. Delft University Press. doi:IOS Press: Delft, The Netherland

Grynninga, S., Gustavsena, A., Timeb, B., & Jelleb, B. P. (2013). Windows in the buildings of tomorrow: Energy losers or energy gainers? Energy Build., 16, 185–192. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378778813001059

Gustavsen, A., Arasteh, D., Jelle, B. P., Curcija, C., & Kohler, C. (2008). Developing Low-conductance Window Frames: Capabilities and Limitations of Current Window Heat Transfer Design Tools — State-of-the-Art Review. journal of building physics , 131-153.

Häkkinen, T., Ruuska, A., Vares, S., Pulakka, S., Kouhia, I., & Holopainen, R. (2012). Methods and concepts for sustainable renovation of buildings. Finland: VTT Technical Research Centre of Finland.

Harris, J., Anderson, J., & Shafron, W. (2000). Investment in energy efficiency: a survey of Australian firms. Energy Policy, 867-876.

HQE Association. (n.d.). HQE: France’s reference certification scheme. Retrieved March 22, 2017, from http://www.behqe.com/

Ilkan, M., Erdil, E., & Egelioglu, F. (2005). Renewable energy resources as an alternative to modify the load curve in Northern Cyprus. Energy, 30(5), 555–572.

J Laustsen. (2008). Energy efficiency requirements in building codes, energy efficiency policies for new buildings. International Energy Agency (IEA), 477-488.

Jaggs, M., & Palmer, J. (2000, February). Energy performance indoor environmental quality retrofit — a European diagnosis and decision making method for building refurbishment. Energy and Buildings, 31(2), 97–101. Retrieved March 9, 2017, from http://www.sciencedirect.com/science/article/pii/S0378778899000237

James J. Hirsch & Associates. (2009). DOE2 based energy use and cost analysis software. Retrieved 2016, from eQUEST the QUick Energy Simulation Tool: http://www.doe2.com/equest/

Johnson, B. M., & Wilson, A. H. (1982). Terminology of the Conservation Industry. Canada: Building Research Note.

Johnson, R., Sullivan, R., Selkowitz, S., Nozaki, S., Conner, C., & Arasteh, D. (1984). Glazing energy performance and design optimization with daylighting. Energy

Build., 6(4), 305–317. Retrieved from http://www.sciencedirect.com/science/article/pii/0378778884900148

Juodis, V. M. (2011). Simulation based complex energy assessment of office building fenestration. Journal of Civil Engineering and Management, 16(3), 345-351. Retrieved from http://www.tandfonline.com/doi/abs/10.3846/jcem.2010.39

Kaynakli, O. (2012). A review of the economical and optimum thermal insulation thickness for building applications. Renewable and Sustainable Energy Reviews, 415-425.

Kolokotsa, D., Rovas, D., Kosmatopoulos, E., & Kalaitzakis, K. (2011). A roadmap towards intelligent net zero- and positive-energy buildings. Sol. Energy, 85(12), 3067–3084.

Kottek, M., & Rubel , F. (2017). World Maps of Köppen-Geiger climate classification. (Institute of Veterinary Public Health of Vetmeduni Vienna) Retrieved March 28, 2017, from World Map of the Köppen-Geiger climate classification updated: http://koeppen-geiger.vu-wien.ac.at/present.htm

Krarti, M. (2016). Energy Audit of Building Systems: An Engineering Approach, 2nd. Florida, USA: CRC Press, Taylor & Francis Group.

Kreith, F., & Goswami, D. Y. (2008). Energy management and conservation handbook. Florida, USA: CRC Press, Taylor & Francis Group.

Kromer, S., & Schiller, S. R. (2000). Measurement and verification protocols – M&V meets the competitive and environmental marketplaces. of the ACEEE Summer Study on Energy Efficiency in Buildings, 4227–4238.

Kuznik, F., & Virgone, J. (2009). Experimental assessment of a phase change material for wall building use. . Applied Energy, 2038–46.

Langdon, D. (2006). Literature review of life cycle costing (LCC) and life cycle assessment (LCA). Resource document. Davis Langdon Management Consulting.

Laura Aelenei, H. G. (2014). From Solar Building Design to Net Zero Energy Buildings: Performance Insights of an Office Building. Energy Procedia, 1236–1243.

Lee, A. H. (2000). Verification of electrical energy savings for lighting retrofits using short-and long-term monitoring. Energy conversion and management, 1999-2008.

LiderA. (2011). SISTEMA VOLUNTÁRIO PARA A SUSTENTABILIDADE DOS AMBIENTES CONSTRUÍDOS. Manuel Duarte Pinheiro, Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisboa. Retrieved March 22, 2017, from http://www.lidera.info/resources/LiderA_Apresentacao_geral_2011_v1.pdf?phpMyAdmin=77d31a787ce126bb305b5b4b9dcec31c

Light, C. E. N. (2011). ighting: lighting of work places: part 1: indoor work places. Brussels, Belgium: Standard CEN EN.

Ma, Z., Cooper, P., Daly, D., & Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. Energy and Buildings, 889–902.

Mahdavi, A., & Dervishi, S. (2011). Exploring the energy performance of simulation-powered lighting and shading systems controls in buildings. Proc. of Building Simulation.

Malin, N. (2010). Building Green. Retrieved August 9, 2017, from The Problem with Net-Zero Buildings (and the Case for Net-Zero Neighborhoods): https://www.buildinggreen.com/feature/problem-net-zero-buildings-and-case-net-zero-neighborhoods#

Malmqvist, T., Glaumann, M., Svenfelt, A., Carlson, P., Erlandsson, J., & Malmström,, T. G. (2011). A Swedish environmental rating tool for buildings. Energy, 1893-1899.

Marszal, A. J., & Heiselberg, P. (2011). Life cycle cost analysis of a multi-storey residential Net Zero Energy Building in Denmark. Energy, 5600-5609.

Marszal, A. J., Heiselberg, P., Jensen, R. L., & Nørgaard, J. (2012). On-site or off-site renewable energy supply options? Life cycle cost analysis of a Net Zero Energy Building in Denmark. Renewable Energy, 154-165.

Marszala, A. J., Heiselberg, P., Bourrelle, J. S., & Musall, E. (2011). Zero Energy Building – A review of definitions and calculation methodologies. Energy Build., 43, 971–979.

Meijer, F., Itard, L., & Sunikka-Blank, M. (2009). Comparing European residential building stocks: Performance, renovation and policy opportunities. Build. Res. Inf., 37, 533–551.

Michaityte, A., Zavadskas, E. K., & Kaklauskas, A. (2008). The concept model of sustainable buildings refurbishment. International Journal of Strategic Property Management, 12(1), 53–68.

Milne, M. (2017). ENERGY DESIGN TOOLS. Retrieved from ENERGY DESIGN TOOLS: http://www.energy-design-tools.aud.ucla.edu/

Mohamedali, A. (2017). A Methodology for Daylighting Optimization in Academic Libraries Case Study of EMU Main Library. Master Thesis, Eastern Mediterranean University, Architecture, Famagusta. Retrieved April 2017

Morelli, M., Rønby, L., Mikkelsen, S. E., Minzari, M. G., Kildemoes, T., & Tommerup, H. M. (2012). Energy retrofitting of a typical old Danish multi-family building to a "nearly-zero" energy building based on experiences from a test apartment. Energy and Buildings, 54, 395–406.

Mozzo, M. A. (1999). Measurement and verification of savings in performance contracting. Energy engineering, 33-45.

Nemry, F., Uihlein, A., Makishi, C., Wittstock, B., Brausen, A., Wetzel, C., . . . Gallon, G. (2008). Environmental Improvement Potentials of Residential Buildings (IMPRO-Building). JRC Scientific and technical reports. EUR 23493 EN – 2008. Retrieved from ftp://139.191.159.34/pub/EURdoc/JRC46667.pdf

Nielsen, M. V., Svendsen, S., & Jensen, L. B. (2011). Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. Solar Energy, 85(5), 757-768.

Nikolaidis, Y., Pilavachi, P. A., & Chletsis, A. (2009). Economic evaluation of energy saving measures in a common type of Greek building. Applied Energy, 2550-2559.

Owens, J., & Wilhite, H. (1988). Household energy behavior in Nordic countries—an unrealized energy saving potential. Energy, 853-859.

Pagliano, L., Carlucci, S., Toppi, T., & Zangheri, P. (2009). Passivhaus per il sud dell’Europa-Linee guida per la progettazione. Rockwool Italia, Milano.

Pathirana, M. R., & Muhtaroglu, A. (2013). Multifaceted Feasibility Analysis of PV Solar Application in Northern Cyprus. International Journal of Renewable Energy Research-IJRER, 3(4), 941-950. Retrieved August 24, 2017, from http://www.ijrer.com/index.php/ijrer/article/view/937

Pathirana, W., & Muhtaroğlu, A. (2013). Multifaceted Feasibility Analysis of PV Solar Application in Northern Cyprus. International Journal of Renewable Energy Research (IJRER), 941-950.

Peel, M., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and earth system sciences discussions, 4(2), 439-473.

Poirazis, H., Blomsterberg, A., & Wall, M. (2008). Energy simulations for glazed office buildings in Sweden. Energy Build., 40(7), 1161–1170. Retrieved 2016, from http://www.sciencedirect.com/science/article/pii/S0378778807002423

Remer, D. S., & Nieto, A. (1995). A compendium and comparison of 25 project evaluation techniques. Part 1: Net present value and rate of return methods. nternational Journal of Production Economics, 79-96.

Roberts, S. (2008). Altering existing buildings in the UK. Energ. Policy, 36, 4482–4486.

Robinson, P. D., & Hutchins, M. (1994). Advanced glazing technology for low energy buildings in the UK. Renewable Energy, 298-309.

Roosa, S. (2002). Measurement & verification applications: Option A case studies. Energy Engineering, 57–73.

Rosenfeld, Y., & Shohet, I. M. (1999, April). Decision support model for semi-automated selection of renovation alternatives. Automation in Construction, 8(4), 503–510. Retrieved March 9, 2017, from http://www.sciencedirect.com/science/article/pii/S0926580598000971

Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. Renewable and Sustainable Energy Reviews.

Santamouris, M., Pavlou, C., Doukas, P., Mihalakakou, G., Synnefa, A., Hatzibiros, A., & Patargias, P. (2007). Investigating and analysing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece. Energy, 1781-1788.

Santin, O. G., Itard, L., & Visscher, H. (2009). The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and buildings, 1223-1232.

Serghides, D. (2014). Sustainable and low energy buildings: a case study for the Cyprus multi storey residential buildings. 24th Scientific Conference on Energy and the Environment (pp. 22-24). Opatija: International Congress Energy and the Environment.

Serghides, D. K., Saboohi, K., Koutra, T., Katafygiotou, M. C., & Markides, M. (2015). Energy-Efficient Refurbishment of Existing Buildings: A Multiple

Case Study of Terraced Family Housing. Renewable Energy in the Service of Mankind, 551-560.

Serghides, D. K., Saboohi, N., Koutra, T., Katafygiotou, M. C., & Markides, M. (3-8 August. 2014). Energy-Efficient Refurbishment of Existing Buildings: A Multiple Case Study of Terraced Family Housing. In Proceeding of WREC 2014, University of Kingston, (pp. 551-560). London. doi:10.1007/978-3-319-17777-9_49

Serghides, D., & Georgakis, C. (2012). The building envelope of Mediterranean houses: Optimization of mass and insulation. ournal of Building Physics, 83-98.

Sesana, M. M., & Salvalai, G. (2013). Overview on life cycle methodologies and economic feasibility for nZEBs. Building and Environment, 211-216.

SFS. (2010). Swedish Building and Planning Act. Swedish Code of Statutes 2010:900 .

Shen, H., & Tzempelikos, A. (2012). Daylighting and energy analysis of private offices with automated interior roller shades. Solar Energy, 681-704.

Sidwell, T., Clark, S., Kumar, A., Carlyle, B., Holland, J., Miller, G., . . . Mian, D. (2004). Delivering a Re-Life Project: Preliminary Literature Review and Methodology. Brisbane, Australia: CRC Construction Innovation, Queensland University of Technology.

Singh, M., & Garg, S. (2009). Energy rating of different glazings for Indian climates. Energy, 34(11), 1986–92.

Srinivasan, R. S., Braham, W., Campbell, D. E., & Curcija, C. D. (2012). Re(De)fining Net Zero Energy: Renewable Emergy Balance in environmental building design. Building and Environment, 24, 300-315.

Stazi, F., Tomassoni, E., Bonfigli, C., & Di Perna, C. (2014). Energy, comfort and environmental assessment of different building envelope techniques in a Mediterranean climate with a hot dry summer. Applied Energy, 134, 176-196.

Stenberg, J., Thuvander, L., & Femenias, P. (2009). Linking social and environmental aspects: A multidimensional evaluation of refurbishment projects. Local Environment, 14(6), 539–554. Retrieved March 9, 2017, from http://www.tandfonline.com/doi/citedby/10.1080/13549830902904102?scroll=top&needAccess=true

Stenberg, J., Thuvander, L., & Femenias, P. (2009). Linking social and environmental aspects: A multidimensional evaluation of refurbishment projects. Local Environ., 14, 539–554.

SuPerBuildings. (n.d.). SuPerBuildings Homepage. Retrieved from http://cic.vtt.fi/superbuildings/

Susorova, I., Tabibzadeh, M., Rahman, A., Clack, H. L., & Elnimeiri, M. (2013). The effect of geometry factors on fenestration energy performance and energy savings in office buildings. Energy Build., 57, 6–13. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378778812005518

Sweatman, P., & Managan, K. (2010). Financing energy efficiency building retrofits: International policy and business model review and regulatory alternatives for Spain. Climate Strategy and Partners, Spain.

Tanasa, C., Sabau, C., Stoian, D., & Stoian, V. (2014). Study on the Life Cycle Cost of energy efficient residential buildings. In Proceedings of the 3rd International Conference on Agricultural Science (pp. 26-28). Romania: Biotechnology, Food and Animal Science (ABIFA 2014).

The International Energy Agency (IEA). (n.d.). Prefabricated Systems for Low Energy Renovation of Residential Buildings. Birmingham: AECOM ltd. Retrieved february 10, 2017, from http://www.ecbcs.org/docs/ECBCS_Annex_50_PSR.pdf

Thuvander, L., Femenías, P., Mjörnell, K., & Meiling, P. (2012). Unveiling the Process of Sustainable Renovation. Sustainability, 4, 1188-1213.

Tobias, L., & Vavaroutsos, G. (2012). Retrofitting Buildings to be Green and Energy-Efficient: Optimizing Building Performance, Tenant Satisfaction, and Financial Return. Urban Land Institute.

Torcellini, P., Pless, S., Deru, M., & Crawley, D. (2006). Zero Energy Buildings:A Critical Look at the Definition. National Renewable Energy Laboratory and Department of Energy U.S, (p. 4). California.

Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. Sol. Energy, 81(3), 369–382.

U.S. Green Building Council USGBC. (2009). LEED 2009 for New Construction and Major Renovations. United States: U.S. Green Building Council. Retrieved March 22, 2017, from http://www.usgbc.org/Docs/Archive/General/Docs5546.pdf

Uihlein, A., & Eder, P. (2010). Policy options towards an energy efficient residential building stock in the EU-27. Energy Build., 42(6), 791–798.

Verbeeck, G., & Hens, H. (2005). Energy savings in retrofitted dwellings: economically viable? Energy and buildings, 747-754.

Voss, K., & Musall, E. (2012). Net zero energy buildings. Detail Green Book.

Wholesale Solar. (n.d.). Wholesale Solar. Retrieved from Wholesale Solar: https://www.wholesalesolar.com/solar-information/off-grid-living

Yohanis, Y. G. (2012). Domestic energy use and householders' energy behaviour. Energy Policy, 654-665.

Zmeureanu, R. (1990). Assessment of the energy savings due to the building retrofit. Building and Environment, 25(2), 95-103.

APPENDICES

Appendix A: Design Alternatives Initial Costs

General inputs:

Electricity price from grid: 0.195 $ /kWh

Electric escalation rate: 10%

Discount rate: 10%

Life cycle: 20 years

Design alternative	Installation cost $/ meter square	Total area in meter square	Initial cost $
External insulation with (68 mm) thickness expanded polystyrene for walls	29.14	620	18,066.80
External insulation with (150 mm) thickness expanded polystyrene for walls	37.8	620	23,436.00
Thermal insulation above roof with (70 mm thickness) expanded polystyrene	17.42	1350	23,517.00
Thermal insulation above roof with (150 mm thickness) expanded polystyrene	26.08	1350	35,208.00
double low-E coating glazing aluminium frames with thermal insulator spacer (filled with Aragon)	200	211	42,200.00
Triple low-e coating glass with aluminium frames with thermal insulator spacer (filled with Aragon)	250	211	52,750.00
External aluminum shading devices	150	117	17,550.00
External aluminum skylight shading devices	150	100	15,000.00

The column of ‘**Annual saving cash flows $”** shows the net saving amount for the design alternative selected in every year based on electric escalation rate of 10%.

The Column ‘**Net present value for the cash flows $ or NPV**’ represents the discounted amount of column ‘annual saving cash flow’ based on a **discount rate (*i*)** of 10%.

The NPV’s values for the design alternatives represented in thesis is the sum of **Total NPV of the design alternative – initial cost of the design alternative.**

Appendix B: Economic Calculations for (70 Mm Roof Insulation + 68 mm Wall Insulation)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows $	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$11,230	10,209.10	0.9091	1
1.21	$12,353	10,208.43	0.8264	2
1.331	$13,588	10,208.80	0.7513	3
1.464	$14,946	10,208.10	0.683	4
1.611	$16,447	10,211.76	0.6209	5
1.772	$18,090	10,212.00	0.5645	6
1.949	$19,897	10,211.32	0.5132	7
2.144	$21,888	10,210.80	0.4665	8
2.358	$24,073	10,209.28	0.4241	9
2.594	$26,482	10,208.87	0.3855	10
2.853	$29,126	10,208.76	0.3505	11
3.138	$32,036	10,206.62	0.3186	12
3.452	$35,241	10,209.45	0.2897	13
3.797	$38,764	10,206.45	0.2633	14
4.177	$42,643	10,208.73	0.2394	15
4.595	$46,910	10,207.69	0.2176	16
5.054	$51,596	10,205.75	0.1978	17
5.56	$56,762	10,211.49	0.1799	18
6.116	$62,438	10,208.65	0.1635	19
6.728	$68,686	10,206.76	0.1486	20
	$1,104,430	**$204,179**	**Total NPV**	

Appendix C: Economic Calculations for (68 mm Wall Insulation)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$3,777	3,434	0.9091	1
1.21	$4,155	3,434	0.8264	2
1.331	$4,571	3,434	0.7513	3
1.464	$5,027	3,434	0.683	4
1.611	$5,532	3,435	0.6209	5
1.772	$6,085	3,435	0.5645	6
1.949	$6,693	3,435	0.5132	7
2.144	$7,362	3,435	0.4665	8
2.358	$8,097	3,434	0.4241	9
2.594	$8,908	3,434	0.3855	10
2.853	$9,797	3,434	0.3505	11
3.138	$10,776	3,433	0.3186	12
3.452	$11,854	3,434	0.2897	13
3.797	$13,039	3,433	0.2633	14
4.177	$14,344	3,434	0.2394	15
4.595	$15,779	3,434	0.2176	16
5.054	$17,355	3,433	0.1978	17
5.56	$19,093	3,435	0.1799	18
6.116	$21,002	3,434	0.1635	19
6.728	$23,104	3,433	0.1486	20
	$371,497	**$ 68,680**	**Total NPV**	

Appendix D: Economic Calculations for (Double Low-E Coating Glazing With Aluminum Frames Filled With Aragon)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$4,590	4,173	0.9091	1
1.21	$5,049	4,173	0.8264	2
1.331	$5,554	4,173	0.7513	3
1.464	$6,109	4,173	0.683	4
1.611	$6,723	4,174	0.6209	5
1.772	$7,395	4,174	0.5645	6
1.949	$8,133	4,174	0.5132	7
2.144	$8,947	4,174	0.4665	8
2.358	$9,840	4,173	0.4241	9
2.594	$10,825	4,173	0.3855	10
2.853	$11,906	4,173	0.3505	11
3.138	$13,095	4,172	0.3186	12
3.452	$14,405	4,173	0.2897	13
3.797	$15,845	4,172	0.2633	14
4.177	$17,431	4,173	0.2394	15
4.595	$19,175	4,172	0.2176	16
5.054	$21,090	4,172	0.1978	17
5.56	$23,202	4,174	0.1799	18
6.116	$25,522	4,173	0.1635	19
6.728	$28,076	4,172	0.1486	20
	$451,443	**$ 83,460**	**Total NPV**	

Appendix E: Economic Calculations for (Aluminum Shading Devices)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$2,089	1,899	0.9091	1
1.21	$2,298	1,899	0.8264	2
1.331	$2,528	1,899	0.7513	3
1.464	$2,781	1,899	0.683	4
1.611	$3,060	1,900	0.6209	5
1.772	$3,366	1,900	0.5645	6
1.949	$3,702	1,900	0.5132	7
2.144	$4,072	1,900	0.4665	8
2.358	$4,479	1,899	0.4241	9
2.594	$4,927	1,899	0.3855	10
2.853	$5,419	1,899	0.3505	11
3.138	$5,960	1,899	0.3186	12
3.452	$6,556	1,899	0.2897	13
3.797	$7,212	1,899	0.2633	14
4.177	$7,933	1,899	0.2394	15
4.595	$8,727	1,899	0.2176	16
5.054	$9,599	1,899	0.1978	17
5.56	$10,560	1,900	0.1799	18
6.116	$11,616	1,899	0.1635	19
6.728	$12,778	1,899	0.1486	20
	$205,470	**$ 37,986**	**Total NPV**	

Appendix F: Economic Calculations For (68 mm Wall Insulation + Double Low-E Glazing With Aluminum Frame Filled Aragon)

Compound Amount Factor Find *F* Given *P F/P*	**annual saving cash flow**	**net present value for the cash flows**	**Present Worth Factor Find P Given F P/F**	**Year in the study**
1.1	$9,142	8,311.08	0.9091	1
1.21	$10,056	8,310.53	0.8264	2
1.331	$11,062	8,310.84	0.7513	3
1.464	$12,167	8,310.27	0.683	4
1.611	$13,389	8,313.24	0.6209	5
1.772	$14,727	8,313.44	0.5645	6
1.949	$16,198	8,312.88	0.5132	7
2.144	$17,819	8,312.46	0.4665	8
2.358	$19,597	8,311.23	0.4241	9
2.594	$21,559	8,310.89	0.3855	10
2.853	$23,711	8,310.80	0.3505	11
3.138	$26,080	8,309.06	0.3186	12
3.452	$28,690	8,311.37	0.2897	13
3.797	$31,557	8,308.92	0.2633	14
4.177	$34,715	8,310.78	0.2394	15
4.595	$38,189	8,309.94	0.2176	16
5.054	$42,004	8,308.35	0.1978	17
5.56	$46,209	8,313.03	0.1799	18
6.116	$50,830	8,310.72	0.1635	19
6.728	$55,916	8,309.18	0.1486	20
	$899,101	**$166,219**	**Total NPV**	

Appendix G: Economic Calculations for (150 mm Wall Insulation)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$4,206	3,824	0.9091	1
1.21	$4,627	3,824	0.8264	2
1.331	$5,090	3,824	0.7513	3
1.464	$5,598	3,824	0.683	4
1.611	$6,160	3,825	0.6209	5
1.772	$6,776	3,825	0.5645	6
1.949	$7,453	3,825	0.5132	7
2.144	$8,199	3,825	0.4665	8
2.358	$9,017	3,824	0.4241	9
2.594	$9,919	3,824	0.3855	10
2.853	$10,910	3,824	0.3505	11
3.138	$12,000	3,823	0.3186	12
3.452	$13,200	3,824	0.2897	13
3.797	$14,520	3,823	0.2633	14
4.177	$15,973	3,824	0.2394	15
4.595	$17,571	3,824	0.2176	16
5.054	$19,326	3,823	0.1978	17
5.56	$21,261	3,825	0.1799	18
6.116	$23,388	3,824	0.1635	19
6.728	$25,728	3,823	0.1486	20
	$413,688	**$ 76,480**	**Total NPV**	

Appendix H: Economic Calculations for (150 mm Roof Insulation)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$9,174	8,340	0.9091	1
1.21	$10,092	8,340	0.8264	2
1.331	$11,101	8,340	0.7513	3
1.464	$12,210	8,339	0.683	4
1.611	$13,436	8,342	0.6209	5
1.772	$14,779	8,343	0.5645	6
1.949	$16,255	8,342	0.5132	7
2.144	$17,881	8,342	0.4665	8
2.358	$19,666	8,340	0.4241	9
2.594	$21,634	8,340	0.3855	10
2.853	$23,795	8,340	0.3505	11
3.138	$26,172	8,338	0.3186	12
3.452	$28,790	8,341	0.2897	13
3.797	$31,668	8,338	0.2633	14
4.177	$34,837	8,340	0.2394	15
4.595	$38,323	8,339	0.2176	16
5.054	$42,151	8,338	0.1978	17
5.56	$46,372	8,342	0.1799	18
6.116	$51,009	8,340	0.1635	19
6.728	$56,113	8,338	0.1486	20
	$902,259	**$166,803**	**Total NPV**	

Appendix I: Economic Calculations for (Triple Low-E Glazing With Aluminum Frame Filled With Aragon)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$5,034	4,577	0.9091	1
1.21	$5,538	4,576	0.8264	2
1.331	$6,092	4,577	0.7513	3
1.464	$6,700	4,576	0.683	4
1.611	$7,373	4,578	0.6209	5
1.772	$8,110	4,578	0.5645	6
1.949	$8,920	4,578	0.5132	7
2.144	$9,812	4,578	0.4665	8
2.358	$10,792	4,577	0.4241	9
2.594	$11,872	4,577	0.3855	10
2.853	$13,057	4,577	0.3505	11
3.138	$14,362	4,576	0.3186	12
3.452	$15,799	4,577	0.2897	13
3.797	$17,378	4,576	0.2633	14
4.177	$19,117	4,577	0.2394	15
4.595	$21,030	4,576	0.2176	16
5.054	$23,131	4,575	0.1978	17
5.56	$25,446	4,578	0.1799	18
6.116	$27,991	4,577	0.1635	19
6.728	$30,792	4,576	0.1486	20
	$495,117	**$ 91,533**	**Total NPV**	

Appendix J: Economic Calculations for (Skylight External Shading Devices)

Compound Amount Factor Find *F* Given *P F/P*	**annual saving cash flow**	**net present value for the cash flows**	**Present Worth Factor Find P Given F P/F**	**Year in the study**
1.1	$1,928	1,753	0.9091	1
1.21	$2,121	1,753	0.8264	2
1.331	$2,333	1,753	0.7513	3
1.464	$2,567	1,753	0.683	4
1.611	$2,824	1,754	0.6209	5
1.772	$3,106	1,754	0.5645	6
1.949	$3,417	1,753	0.5132	7
2.144	$3,759	1,753	0.4665	8
2.358	$4,134	1,753	0.4241	9
2.594	$4,548	1,753	0.3855	10
2.853	$5,002	1,753	0.3505	11
3.138	$5,501	1,753	0.3186	12
3.452	$6,052	1,753	0.2897	13
3.797	$6,657	1,753	0.2633	14
4.177	$7,323	1,753	0.2394	15
4.595	$8,055	1,753	0.2176	16
5.054	$8,860	1,753	0.1978	17
5.56	$9,747	1,754	0.1799	18
6.116	$10,722	1,753	0.1635	19
6.728	$11,795	1,753	0.1486	20
	$189,654	**$ 35,062**	**Total NPV**	

Appendix K: Economic Calculations for (150 mm Wall Insulation + Double Low-E Glazing With Aluminum Frame Filled With Aragon)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$9,742.59	8,856.99	0.9091	1
1.21	$10,717	8,856.50	0.8264	2
1.331	$11,789	8,856.83	0.7513	3
1.464	$12,967	8,856.22	0.683	4
1.611	$14,269	8,859.39	0.6209	5
1.772	$15,695	8,859.60	0.5645	6
1.949	$17,262	8,859.01	0.5132	7
2.144	$18,989	8,858.56	0.4665	8
2.358	$20,885	8,857.25	0.4241	9
2.594	$22,975	8,856.88	0.3855	10
2.853	$25,269	8,856.79	0.3505	11
3.138	$27,793	8,854.93	0.3186	12
3.452	$30,574	8,857.39	0.2897	13
3.797	$33,630	8,854.79	0.2633	14
4.177	$36,996	8,856.77	0.2394	15
4.595	$40,698	8,855.87	0.2176	16
5.054	$44,763	8,854.18	0.1978	17
5.56	$49,245	8,859.16	0.1799	18
6.116	$54,169	8,856.70	0.1635	19
6.728	$59,590	8,855.06	0.1486	20
	$958,168	**$ 177,139**	**Total NPV**	

Appendix L: Economic Calculations for (150 mm Wall Insulation + 150 mm Roof Insulation)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$14,069.06	12,790.18	0.9091	1
1.21	$15,476	12,789.28	0.8264	2
1.331	$17,023	12,789.75	0.7513	3
1.464	$18,725	12,788.87	0.683	4
1.611	$20,605	12,793.45	0.6209	5
1.772	$22,664	12,793.76	0.5645	6
1.949	$24,928	12,792.90	0.5132	7
2.144	$27,422	12,792.25	0.4665	8
2.358	$30,159	12,790.36	0.4241	9
2.594	$33,177	12,789.83	0.3855	10
2.853	$36,490	12,789.70	0.3505	11
3.138	$40,135	12,787.02	0.3186	12
3.452	$44,151	12,790.57	0.2897	13
3.797	$48,564	12,786.80	0.2633	14
4.177	$53,424	12,789.66	0.2394	15
4.595	$58,770	12,788.36	0.2176	16
5.054	$64,641	12,785.92	0.1978	17
5.56	$71,112	12,793.12	0.1799	18
6.116	$78,224	12,789.57	0.1635	19
6.728	$86,051	12,787.20	0.1486	20
	$1,383,648	**$ 255,799**	**Total NPV**	

Appendix M: Economic Calculations for (68 mm Wall Insulation + 70 mm Roof Insulation + Double Low-E Glazing)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$19,422.98	17,657.43	0.9091	1
1.21	$21,365	17,656.01	0.8264	2
1.331	$23,501	17,656.65	0.7513	3
1.464	$25,850	17,655.45	0.683	4
1.611	$28,445	17,661.77	0.6209	5
1.772	$31,288	17,662.19	0.5645	6
1.949	$34,413	17,661.00	0.5132	7
2.144	$37,857	17,660.11	0.4665	8
2.358	$41,635	17,657.49	0.4241	9
2.594	$45,802	17,656.77	0.3855	10
2.853	$50,375	17,656.59	0.3505	11
3.138	$55,408	17,652.88	0.3186	12
3.452	$60,952	17,657.78	0.2897	13
3.797	$67,044	17,652.59	0.2633	14
4.177	$73,753	17,656.54	0.2394	15
4.595	$81,134	17,654.74	0.2176	16
5.054	$89,238	17,651.37	0.1978	17
5.56	$98,173	17,661.31	0.1799	18
6.116	$107,990	17,656.40	0.1635	19
6.728	$118,796	17,653.13	0.1486	20
	$1,910,170	**$ 353,138**	**Total NPV**	

Appendix N: Economic Calculations for (150 mm Wall Insulation + 150 mm Roof Insulation + Double Low-E Glazing)

Compound Amount Factor Find *F* Given *P F/P*	**annual saving cash flow**	**net present value for the cash flows**	**Present Worth Factor Find P Given F P/F**	**Year in the study**
1.1	$21,492.90	19,539.20	0.9091	1
1.21	$23,642	19,537.91	0.8264	2
1.331	$26,006	19,538.62	0.7513	3
1.464	$28,605	19,537.28	0.683	4
1.611	$31,477	19,544.27	0.6209	5
1.772	$34,623	19,544.74	0.5645	6
1.949	$38,082	19,543.43	0.5132	7
2.144	$41,892	19,542.44	0.4665	8
2.358	$46,073	19,539.54	0.4241	9
2.594	$50,684	19,538.75	0.3855	10
2.853	$55,745	19,538.54	0.3505	11
3.138	$61,313	19,534.44	0.3186	12
3.452	$67,449	19,539.87	0.2897	13
3.797	$74,190	19,534.12	0.2633	14
4.177	$81,614	19,538.49	0.2394	15
4.595	$89,782	19,536.50	0.2176	16
5.054	$98,750	19,532.77	0.1978	17
5.56	$108,637	19,543.77	0.1799	18
6.116	$119,501	19,538.34	0.1635	19
6.728	$131,458	19,534.72	0.1486	20
	$2,113,768	**$ 390,778**	**Total NPV**	

Appendix O: Economic Calculations for (70 mm Roof Insulation)

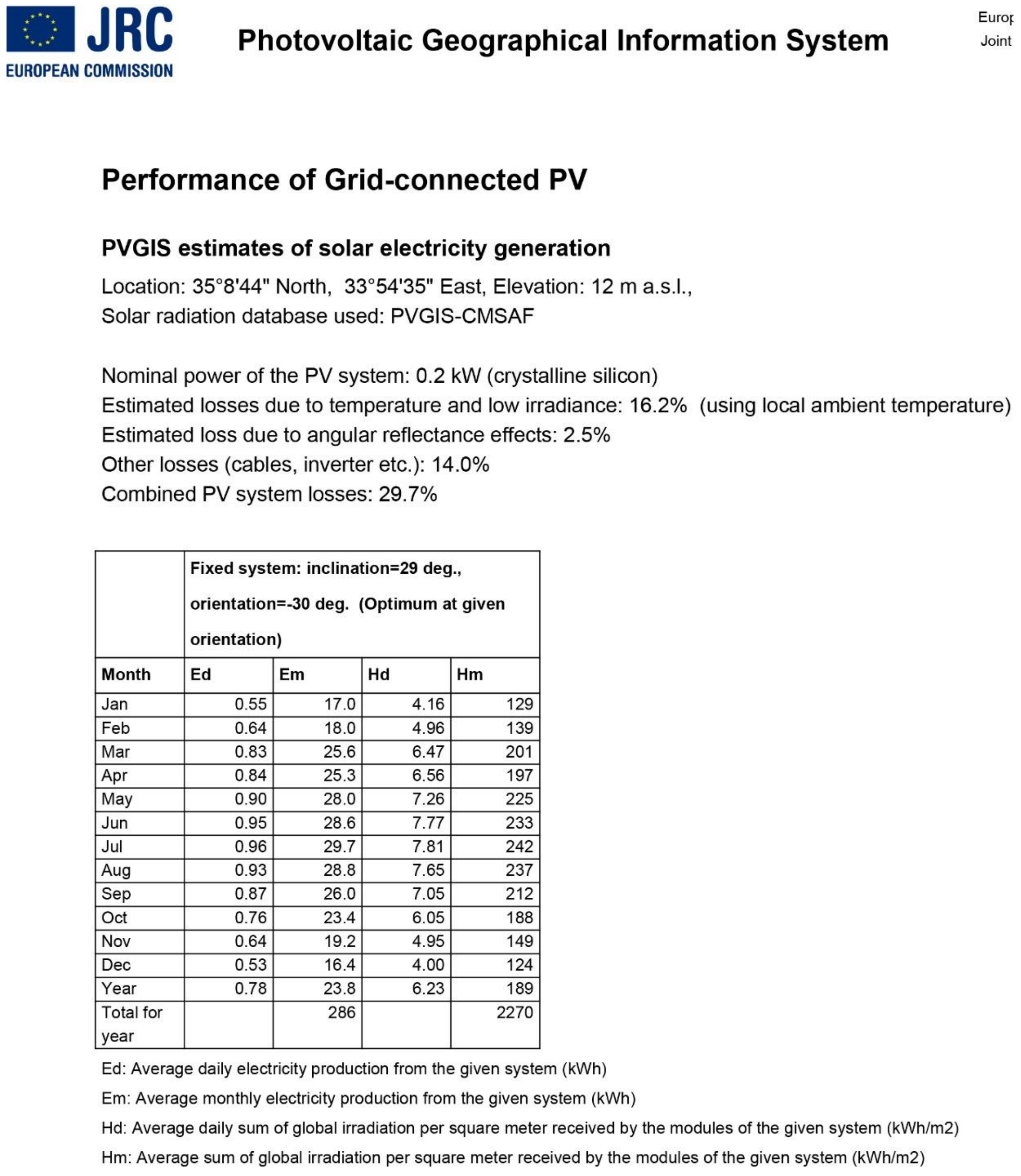
Compound Amount Factor Find *F* Given *P F/P*	**annual saving cash flow**	**net present value for the cash flows**	**Present Worth Factor Find P Given F P/F**	**Year in the study**
1.1	$8,136	7,396	0.9091	1
1.21	$8,949	7,396	0.8264	2
1.331	$9,844	7,396	0.7513	3
1.464	$10,828	7,395	0.683	4
1.611	$11,915	7,398	0.6209	5
1.772	$13,106	7,398	0.5645	6
1.949	$14,415	7,398	0.5132	7
2.144	$15,857	7,397	0.4665	8
2.358	$17,440	7,396	0.4241	9
2.594	$19,185	7,396	0.3855	10
2.853	$21,101	7,396	0.3505	11
3.138	$23,209	7,394	0.3186	12
3.452	$25,531	7,396	0.2897	13
3.797	$28,083	7,394	0.2633	14
4.177	$30,893	7,396	0.2394	15
4.595	$33,985	7,395	0.2176	16
5.054	$37,379	7,394	0.1978	17
5.56	$41,122	7,398	0.1799	18
6.116	$45,234	7,396	0.1635	19
6.728	$49,760	7,394	0.1486	20
	$800,114	**$ 147,919**	**Total NPV**	

Appendix O: Economic Calculations for (Photovoltaic Panels)

Compound Amount Factor Find *F* Given *P F/P*	annual saving cash flow	net present value for the cash flows	Present Worth Factor Find P Given F P/F	Year in the study
1.1	$14,597.00	13,270.13	0.9091	1
1.21	$16,057	13,269.26	0.8264	2
1.331	$17,662	13,269.74	0.7513	3
1.464	$19,427	13,268.83	0.683	4
1.611	$21,378	13,273.58	0.6209	5
1.772	$23,514	13,273.90	0.5645	6
1.949	$25,863	13,273.01	0.5132	7
2.144	$28,451	13,272.34	0.4665	8
2.358	$31,291	13,270.37	0.4241	9
2.594	$34,422	13,269.83	0.3855	10
2.853	$37,859	13,269.69	0.3505	11
3.138	$41,641	13,266.91	0.3186	12
3.452	$45,808	13,270.59	0.2897	13
3.797	$50,386	13,266.68	0.2633	14
4.177	$55,429	13,269.65	0.2394	15
4.595	$60,976	13,268.30	0.2176	16
5.054	$67,067	13,265.77	0.1978	17
5.56	$73,781	13,273.24	0.1799	18
6.116	$81,159	13,269.55	0.1635	19
6.728	$89,281	13,267.09	0.1486	20
7.4	$98,198	13,266.55	0.1351	21
8.14	$108,018	13,264.59	0.1228	22
8.954	$118,820	13,272.15	0.1117	23
9.85	$130,710	13,267.01	0.1015	24
10.835	$143,780	13,270.94	0.0923	25
	$1,435,575	**$331,740**	**Total NPV**	

Appendix P: Economic Calculations for (1.2*1.0 M Photovoltaic Panel Generation When Placed On Roof)

Retrieved online from (European Commission, Joint Research Centre, 2017)



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Photovoltaic Geographical Information System

Europ
Joint

Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

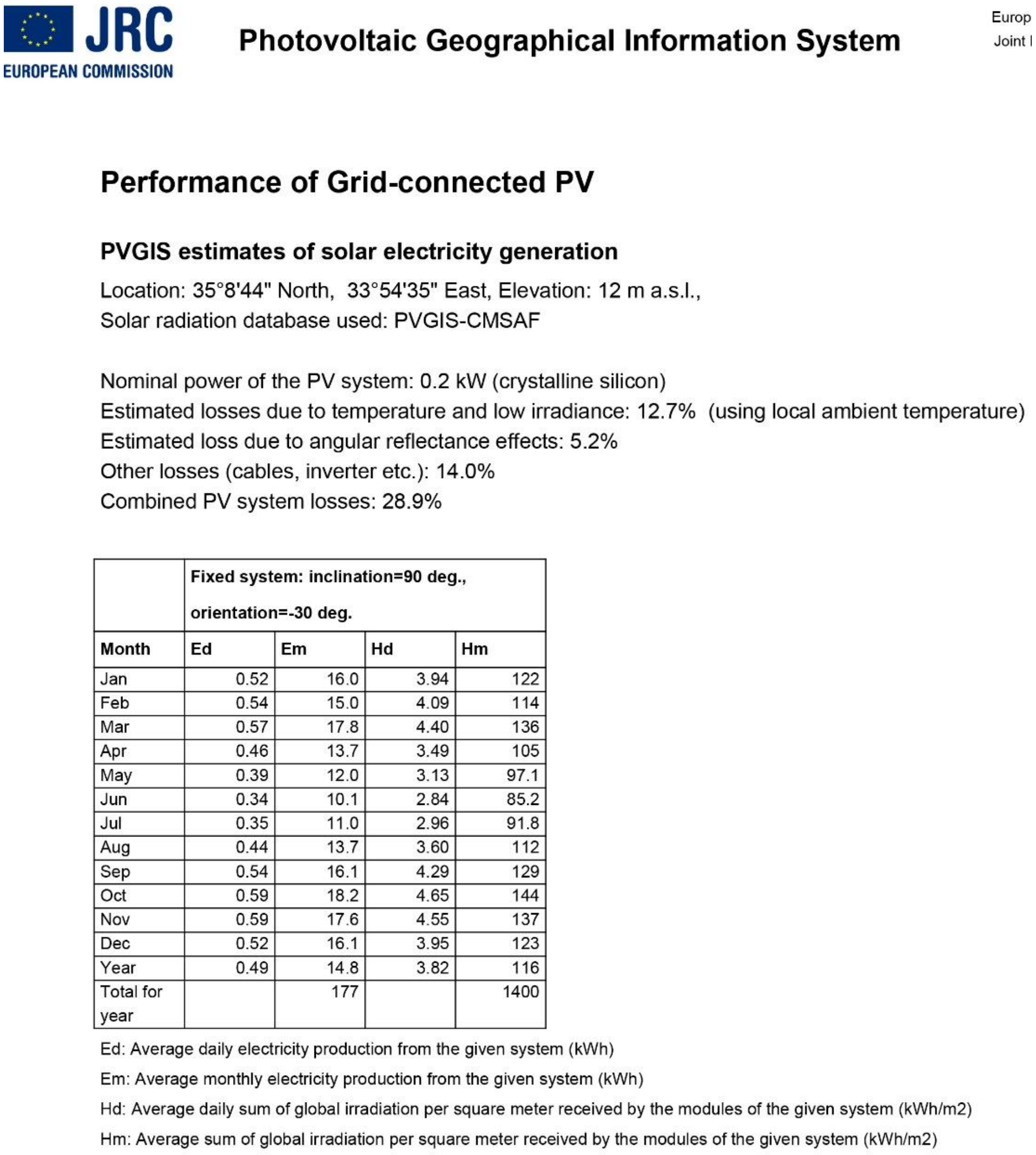
Location: 35°8'44" North, 33°54'35" East, Elevation: 12 m a.s.l.,
Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 0.2 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 16.2% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 2.5%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 29.7%

	Fixed system: inclination=29 deg., orientation=-30 deg. (Optimum at given orientation)			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	0.55	17.0	4.16	129
Feb	0.64	18.0	4.96	139
Mar	0.83	25.6	6.47	201
Apr	0.84	25.3	6.56	197
May	0.90	28.0	7.26	225
Jun	0.95	28.6	7.77	233
Jul	0.96	29.7	7.81	242
Aug	0.93	28.8	7.65	237
Sep	0.87	26.0	7.05	212
Oct	0.76	23.4	6.05	188
Nov	0.64	19.2	4.95	149
Dec	0.53	16.4	4.00	124
Year	0.78	23.8	6.23	189
Total for year		286		2270

Ed: Average daily electricity production from the given system (kWh)
Em: Average monthly electricity production from the given system (kWh)
Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)
Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

Appendix Q: Economic Calculations for (1.2*1.0 M. Photovoltaic Panel Generation When Placed On South-East Facade)



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Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

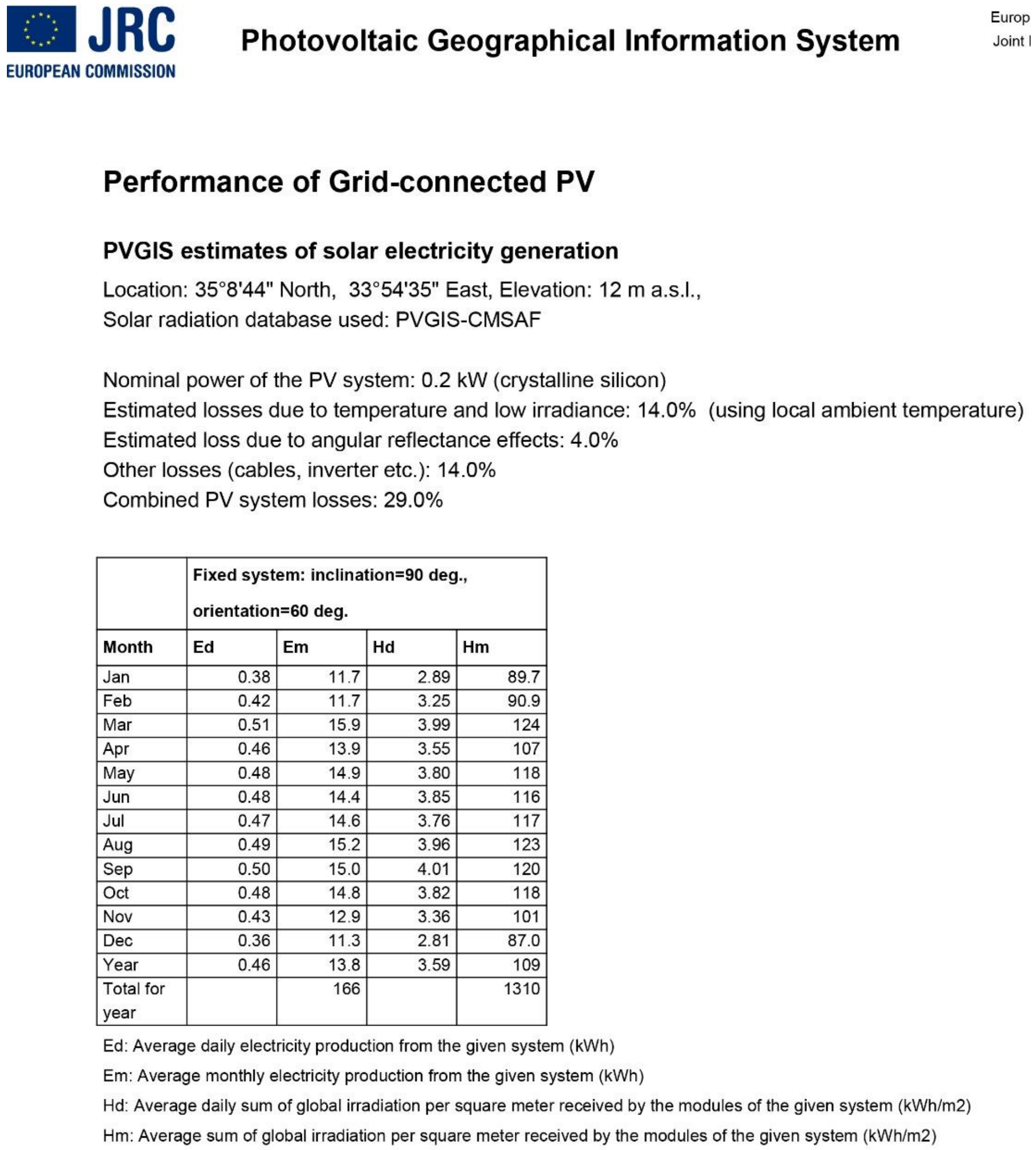
Location: 35°8'44" North, 33°54'35" East, Elevation: 12 m a.s.l.,
Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 0.2 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 12.7% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 5.2%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 28.9%

	Fixed system: inclination=90 deg., orientation=-30 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	0.52	16.0	3.94	122
Feb	0.54	15.0	4.09	114
Mar	0.57	17.8	4.40	136
Apr	0.46	13.7	3.49	105
May	0.39	12.0	3.13	97.1
Jun	0.34	10.1	2.84	85.2
Jul	0.35	11.0	2.96	91.8
Aug	0.44	13.7	3.60	112
Sep	0.54	16.1	4.29	129
Oct	0.59	18.2	4.65	144
Nov	0.59	17.6	4.55	137
Dec	0.52	16.1	3.95	123
Year	0.49	14.8	3.82	116
Total for year		177		1400

Ed: Average daily electricity production from the given system (kWh)
Em: Average monthly electricity production from the given system (kWh)
Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)
Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

Appendix R: Economic Calculations for (1.2*1.0 M. Photovoltaic Panel Generation When Placed On South-West Facade)



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Performance of Grid-connected PV

PVGIS estimates of solar electricity generation

Location: 35°8'44" North, 33°54'35" East, Elevation: 12 m a.s.l.,
Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 0.2 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 14.0% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 4.0%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 29.0%

	Fixed system: inclination=90 deg., orientation=60 deg.			
Month	**Ed**	**Em**	**Hd**	**Hm**
Jan	0.38	11.7	2.89	89.7
Feb	0.42	11.7	3.25	90.9
Mar	0.51	15.9	3.99	124
Apr	0.46	13.9	3.55	107
May	0.48	14.9	3.80	118
Jun	0.48	14.4	3.85	116
Jul	0.47	14.6	3.76	117
Aug	0.49	15.2	3.96	123
Sep	0.50	15.0	4.01	120
Oct	0.48	14.8	3.82	118
Nov	0.43	12.9	3.36	101
Dec	0.36	11.3	2.81	87.0
Year	0.46	13.8	3.59	109
Total for year		166		1310

Ed: Average daily electricity production from the given system (kWh)

Em: Average monthly electricity production from the given system (kWh)

Hd: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m2)

Hm: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m2)