Assessment of Optimal Investment Alternatives for Energy Retrofitting Measures of an Institutional Building

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ABSTRACT

Built environment in general is accountable for more than 40% of total global energy consumption. Although the amount of building's contribution in energy demand supposedly should increase with growing number of population, yet in recent decade, adopting energy conservation measures all around the globe not only prevented the escalation of energy consumption but also reduced it to a certain level. In North Cyprus however, the share of building stock which statistically appeared to be a major participant in energy consumption, due to absence of energy efficiency legislation in both new construction as well as existing buildings is substantially high. This thesis demonstrated a quantitative approach using combination of thermal modeling, deterministic financial model, sensitivity and Monte Carlo analysis to evaluate technical and financial energy efficiency potential among variety of retrofitting measures by considering a spectrum of associated uncertainties, changes and risks among independent input variables within the entire predetermined investment horizon on public non-residential building. The main objective of this study through complete demonstration of energy efficiency investigation is to assist investors in decision making process as well as encouraging government authorities in promoting application of energy efficiency measures with supplementation of impellent legislation and incentives. The building department of civil engineering in Eastern Mediterranean University has been technically and financially evaluated to examine the financial attractiveness of proposed four alternatives retrofitting scenarios. Retrofitting scenarios were included roof insulation, replacement of single glazed typical windows in the building with double glazed low-e windows, installation of lux and lighting control devices and the last scenario considered as combination of all aforementioned scenarios. An advanced stimulation software tool namely, *design builder* is employed to quantify energy consumption of the case study as well as the impact of each retrofitting scenario on building energy demand reduction. The result from technical assessment of the building demonstrated scenario 4 as the optimal scenario in terms of energy conservation. Henceforth, the result from thermal modeling is fed into designed deterministic financial model using Excel software to project the financial merit of each retrofitting alternative. From deterministic financial appraisal of four existing scenarios it is concluded that scenario 2 generates highest net present value (NPV) and internal rate of return (IRR) and it is minimized the payback period of initial retrofitting investment. Finally, through the sensitivity analysis, critical variables have been identified and by conducting a Monte Carlo analysis using *Cristal Ball* for each critical variable within the specified time horizon the probability distribution of intended output criterion is demonstrated. At the end based on stochastic behavior of key input variable on financial model's outcome the optimum alternative is selected. In conclusion after performing sensitivity and risk analysis on the financial model it has been justified that scenario 2 should be considered as optimal scenario among others.

Keywords: Energy efficiency, Thermal modeling, Cost benefit analysis, Risk analysis

ÖZ

Genel olarak inşa edilmiş çevre, toplam küresel enerji tüketiminin% 40'ından fazlasından sorumludur. İnşa edilen binaların operasyonel fazlarının enerji talebi nüfus artışıyla doğrudan orantılıdır. Son on yılda, tüm Dünya'da ciddi önem arz eden enerji koruma önlemlerinin alınması, inşa edilen binaların enerji talebindeki tırmanmayı engellemekle kalmadı, aynı zamanda sözkonusu yapıların enerji talebini sınırlı bir düzeye indirdi. Kuzey Kıbrıs'da devletin enerji verimliliği mevzuatının bulunmamasından dolayı ve istatistikel bulgular doğrultusunda konut dışı bina stoklarının enerji ihtiyaç ve tüketimindeki payının oldukça yüksek olduğu gözlemlenmiştir. Bu çalışmada, kamuda enerji verimliliği uygulama potansiyelini bütünsel değerlendirme sürecini gerçekleştirmek için uyarlanmış bir metodoloji vardır. Bu çalışma, konut dışı bina kategorisinde olan Doğu Akdeniz Üniversitesi'nde İnşaat Mühendisliği Bölümü'nün önerilen alternatif enerji verimliliği bakımından güçlendirme senaryolarının enerji tüketim talebini azaltma hususundaki muhtemel olumlu etkilerini değerlendirmek için teknik ve finansal analizlerin gerçekleştirilip sonuçlarının irdelenmesini içerir. Geliştirilen her bir uyarlama senaryosunun bina enerji talebinin azaltılması üzerindeki etkisi DesignBuilder programı aracılığıyla simule edilerek değerlendirilmiştir. Bundan sonra, her bir güçlendirme alternatifi ekonomik değerini değerlendirmek için Excel elektronik tablosu kullanılarak sağlanan ekonomik bir modele benimsenen termal modelleme sonucu ve nihayetinde stokastik davranışı temel alarak belirlenen zaman ufku içinde en iyi güçlendirme alternatifi, finansal modelin sonucu üzerinde Monte Carlo risk analizi metodu uygulanarak Finansal modelin sonucundaki anahtar girdi değişkeni seçilmiştir.

Anahtar Kelimeler: Enerji verimliliği, Termal modelleme, Maliyet fayda analizi, Risk analiz

To my Wife and Mother for their support and love

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% COC	Percentage of Change in Real Price of Related Energy Source
% E_H	Percentage of Electricity Contribution in Heating
% LPG_H	Percentage of LPG Contribution in Heating
AC	Air Conditioner
A_C	Appliances Cost
A_E	Energy Consumption in Appliances
AHU	Air Handling Unit
AICFV	Association of Engineers in Climate, Ventilation and Cooling
ASHRAE	American Society Heating, Refrigerating Air Conditioning Eng
AVG E_f	Average Fan Coil Energy Consumption
AVG E_p	Average Pump Energy Consumption
BACS	Building Automation and Control System
BCR	Benefit Cost Ratio
B_j	Cash Inflow
BPIE	Building Performance Institute Europe
BREEAM	Building Research Establish Environment Assessment Method
C_0	Initial Investment
CBA	Cost Benefit Analysis
C_C	Cooling Cost
C_E	Energy Consumption in Cooling
CFC	Chlorofluorocarbon
CFL	Compact Fluorescent Lamp

CH4	Methane
CIC	Construction Industry Council
C_j	Cash Outflow
CO2	Carbon Dioxide
DBT	Dry Bulb Temperature
DOE	Department of Energy
DPP	Discounted Payback Period
DSF	Double Skin Facade Strategy
DSM	Demand Side Management
EAT	Energy Audit Team
EC	Electro Chromic
E_f	Fan Coil Energy Consumption
EISA	Energy Independence and Security Act
EMU	Eastern Mediterranean University
E_p	Pump Energy Consumption
EPBD	Energy Performance of Buildings Directive
EPC	Performance Certificate
ERFD	European Regional Development Fund
ERM	Energy Retrofitting Measure
ERM	Environmental Resource Management
ESCO	Energy Service Company
E_U	Unit Price of Electricity
EUI	Energy Use Intensity
FW	Future Worth

FCU	Fancoil Unit
F_t	Net Cash Flow at Year t
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHP	Geothermal Heat Pump
gpe	Inflation Rate
GWP	Global Warming Potential
H2O	Water Vapor
H_C	Heating Cost
H_E	Energy Consumption in Heating
HVAC	Heating, Ventilation and Air Conditioning
IECC	International Energy Conservation Code
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
KWH	Kilo Watt Hours
L_C	Lighting Cost
LCC	Life Cycle Cost
L_E	Energy Consumption in Lighting
LEED	Leadership in Energy and Environmental Design
LPG	Liquid Petroleum Gas
LPG_U	Unit Price of LPG
MIRR	Modified Internal Rate of Return
n	Number of Years
N2O	Nitrus Oxide

NOI	Net Operating Income
NPV	Net Present Value
NZEB	Net Zero Energy Building
O3	Ozone
OC(n)	Operational Cost of Year n
OH_f	Fan Coil Operating Hours
OH_p	Pump Operating Hours
OPs	Operational Programs
ORR	Overall Rate of Return
P	Present Worth
r	Nominal Discount Rate
R	Real Discount Rate
R VALUE	Thermal Resistance Coefficient
SIP	Structural Insulated Panel
SMB	Small and Medium Building
SPP	Simple Payback Period
STA	Stabilization Strategy
SUB	Substitution Strategy
t	Study Life of Project
TVM	Time Value of Money
U VALUE	Thermal Transmittance Coefficient
UN	United Nation
XPS	Extruded Polystyrene Foam Board
λ VALUE	Thermal Conductivity

Chapter 1

INTRODUCTION

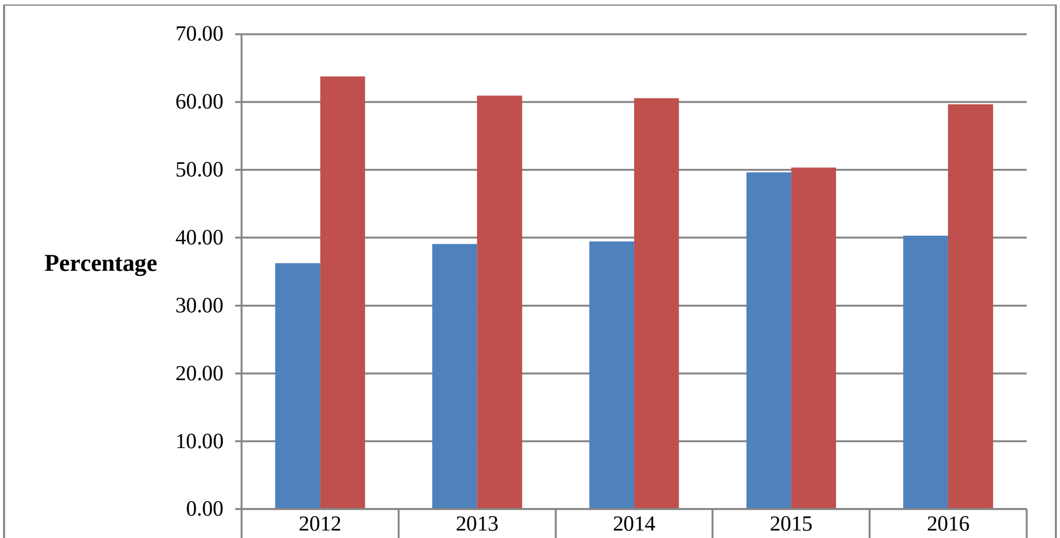
1.1 Background

Every activity of human beings today somehow attached to the either form of energy. Beside other possible drivers for energy consumption, population growth has the crucial role in energy consumption's forecast. Since an accurate estimation of future energy consumption have always been one of the human beings concerns, adjusting sufficient number of infrastructure as well as application of precautionary measures in parallel with population growth in order to balance the energy supply with demand seem to be necessary (Zabel, 2009). It has been estimated that by 2050 up to 10 billion people on the earth will have housing, energy, clean water, food, transportation, infrastructure and social services demand (UN, 2015), and that will make buildings as a part of built environment, a major energy consumer around the world. (Abergel, Dean, & Dulac, 2017; UN, 2015) revealed that building construction growth particularly in Asia and Africa expected to be boost up to 2060. International energy agency in its annual report also mentioned that the amount of floor area covered within next 40 years estimated to be tripled in Africa and almost double for most of Asian region along with population growth, which will cause growth in energy demand. It also reported that although Fossil fuel use in buildings remained stable at roughly 45 Exajules (EJ), but Carbon dioxide (CO_2) emission from buildings reduced slowly from 9.5 Giga tones (Gt) CO_2 in 2013 to 9.0 Gt CO_2 in 2016 (Munksgaard, Pedersen, & Wien, 2000). This reduction mostly was as a result of progressing in decreasing carbon intensity in power generation according to (IEA, 2017b), also based on the report form international energy agency the share of residential and nonresidential buildings from total energy consumption in the world is around 30% (International Energy Agency -IEA, 2017) where 80% to 90 % of the energy consumption in building's life cycle contributes in operating phase, and the rest 10% to 20% consumed as embodied energy in buildings life cycle demand (Ramesh, Prakash, & Shukla, 2010) . It is evaluated that there are over 25 billion m^2 of existing floor space just in the EU27 (Economidou, Laustsen, Ruyssevelt, & Staniaszek, 2011). Therefore, it seems indispensable to consider existing building stock for energy efficient interventions as a key to considerably reduce the inauspicious impacts of buildings on the environment and economy (Menassa, 2011). Building energy retrofits as a primary and low cost strategy depends on its extension appeared to play crucial role reducing energy use and greenhouse gas emissions from existing buildings. It creates an opportunity for owners to extend their building's life as well as achieving monetary benefits as a result of reduction in energy demand along with number of other monetary and non-monetary benefit such as creating job opportunities, enhancing human health, and improving thermal comfort (Jafari, 2018). However, one of the main challenges among all probable obstacles in implementing building's energy renovation is decision making process by investors which itself is subordinate of great number of uncertainties. By considering the entire variable at play from technical, strategic and political perspective, financial return as a prime driver among investors has major contribution in pursuing energy retrofit measures in an existing building. Therefore, an investment evaluation method which could vanquish over possible financial handicaps and effectively quantifies the economic value of any sustainable retrofitting investment by proposing optimal investment alternative is seems to be incumbent. In conclusion this study expected to implement a systematic, practical and reliable financial appraisal of investment on energy retrofitting alternatives for nonresidential buildings in North Cyprus to identify possible variables at play and demonstrate the applicable procedure to select optimal alternative among other energy retrofitting alternatives.

1.2 Statement of the Problem

Developing economy in 1980s in Turkish republic of northern Cyprus (TRNC) initiated the urbanization process and despite all existing economic embargoes and political isolation, the current construction boom in North Cyprus which yielded from immediate dominant factors such as united nation (UN) peace plan, also known as Annan plan along with other financial determinants like inflationary expectation, devaluation in Turkish Lira, offshore banking altogether generated rapid stimulated construction investment in North Cyprus (Yorucu & Keles, 2007). As a result of this exponential growth and due to lack of political agenda for controlling urban planning, infrastructure physical quality and buildings adaptability to local environmental climate as well as absence of regulatory bodies to superintend the process of construction and domination of number of privately owned company over entire construction industry in North Cyprus, poorly built buildings without initiative in the reduction of energy consumption from became as one of the critical features of the construction sector in North Cyprus (Ozarisoy & Altan, 2017). In addition to aforementioned issues the problem with progressive and inexorable rise in energy cost and energy import dependency of the country became due to the cause. Altogether along with exclusion from European directives due to international isolation of North Cyprus led to ignoring the implementation of energy efficiency directives by government bodies, in construction industry in North Cyprus.

(Katafygiotou & Serghides, 2014) has revealed that energy consumption by public and commercial buildings in European countries is estimated to be nearly 40 % of total energy consumption therefore, achieving energy consumption improvement without taking nonresidential building’s effect into account sounds unattainable. Figure1.1 illustrated the share of nonresidential building in compare with residential building from the total number of issued construction permit for the buildings in North Cyprus within the years 2012 to 2016 (State Planning Organization, 2019)



	2012	2013	2014	2015	2016
Nonresidential (%)	36.25	39.08	39.45	49.64	40.32
Residential (%)	63.75	60.92	60.55	50.36	59.68

Figure 1.1: Residential and Nonresidential building’s permit in North Cyprus (State Planning Organization, 2019)

From the Figure 1.1 although nonresidential building’s contribution share in new construction is less than residential but with approximately 40% from total construction is undeniable. On the other hand according to the data recovered from KIBRIS TÜRK ELEKTRİK KURUMU (KIBTEK), electricity consumption for nonresidential buildings including (commercial, state, tourism and other type of nonresidential buildings) is allocated up to 33% of total electricity consumption in North Cyprus (Kibtek, 2019). Relying on the fact that monetary benefit is considered as highest concerns among investors, thus, in the absence of government subsidies and incentives and also lack of research in this area specifically in North Cyprus, there is a need for financial investigation to unveil the financial attractiveness of implementing energy retrofit measures in nonresidential buildings in North Cyprus. This study is conducted to investigate the possible monetary benefits from implementing retrofitting measures on an institutional building (Department building of Civil Engineering in Eastern Mediterranean University) to promote performing of building energy refurbishment in existing nonresidential buildings and assist the public and government authorities in informing investors about the financial prudency of such measures.

1.3 Research Questions

In respect with stated problem following questions for the case study is addressed:

- **Question 1**: From energy conservation point of view does EMU's Civil Engineering Building have potential to adopt retrofitting measures?
- **Question 2**: What are the efficient retrofitting alternatives which could be utilized for the case study by considering associated circumstances and limitation for institutional building's type to reduce energy consumption?
- **Question 3**: by taking into account associated risk and uncertainties, shall investors invest in building retrofitting? If yes to what extent the investment is justifiable?

1.4 Aim and Objectives

Considering all grounding information and the significance of issue, the aim of this study is to developing a systematic and practical analysis model to evaluate both the technical and particularly financial feasibility for implementing variety of energy retrofitting measures on existing buildings. It is expected that financial analysis in making process for both public and private investors.

To achieve aforementioned aim of the thesis following research objectives are considered:

1. To perform a holistic building's inspection.
2. To evaluate energy consumption of existing building through thermal modeling.
3. To select the most compatible retrofitting measure and perform post retrofitting energy consumption analysis on the building.
4. To evaluate the financial profitability from implementing each retrofitting alternative based on deterministic value.
5. To observe the impact of each independent input variable in financial model on forecasted results using sensitivity analysis.
6. To assess the influence of identified critical variables on the financial model's outcome using Monte Carlo risk analysis in order to accommodate the existing uncertainties within the critical variables.

1.5 Scope and Limitation

The scope of the research area in this study narrowed down to technical feasibility assessment of selected retrofitting measures on the building from energy conservation point of view. Also as far as financial appraisal of these alternatives concern the type of investment in this study assumed to be self-funding by investors, without any loan, subsidies or grants from government.

Since meticulous calculation of pre and post-retrofitting alteration in energy consumption of the building is concatenated to building's prototype model in thermal modeling, it is considered to be in direct relation with the input information from the building. Therefore, any misleading information on actual material, building's orientation, building's plan, and other related data for modeling the building could have produce deluding results in the form of far more optimistic or pessimistic outcomes in compare with expected actual energy saving potential. This study due to, several limitations such as lack of expertise in building energy inspection, unavailability of appropriate and updated data, absence of accurate measurement device and deficit in information on building's materials, history and technical component specification which had to be provided by university technical affairs, will be handicapped in terms of thermal modeling and energy demand calculation. On the other hand, the validation of thermal modeling output could not be accurately examined because, obtained energy bill for both the energy sources such as electricity and liquid petroleum gas (LPG) could not reflect actual monthly breakdown of energy consumption of the building. Hence distinguishing the exact building energy consumption for the building is out of the question and subsequently deviation from actual result is inevitable. From the financial evaluation point of view also, lack of historical data for change in initial cost of investment as well as the change in building's energy requirement within the specified investment horizon and instead application of assumption and expert's opinion in risk analysis might create deviation from actual result.

1.6 Methodology

By holistic review on utilized methodology in this study, it is classified into two major steps including firstly evaluation of building's energy consumption prior and after application of proposed retrofitting scenario. And secondly assessment of financial profitability of implementing each retrofitting alternative. As it illustrated in figure 1.2 technical feasibility of retrofitting alternatives could be assessed through five steps which are building's inspection, thermal modeling preparation using Design Builder software, existing building energy demand calculation and validation of the result from thermal modeling and post retrofitting energy demand calculation of existing building. Financial feasibility evaluation of retrofitting measure however, could be generalized into three steps including profitability assessment of each retrofitting alternative based on deterministic values, determination of critical input variable in financial model using sensitivity analysis and finally accommodating existing risk and uncertainties by performing Monte Carlo analysis (risk analysis) using Crystal Ball software. Figure 1.2 presented an overview of utilized steps within the proposed methodology.

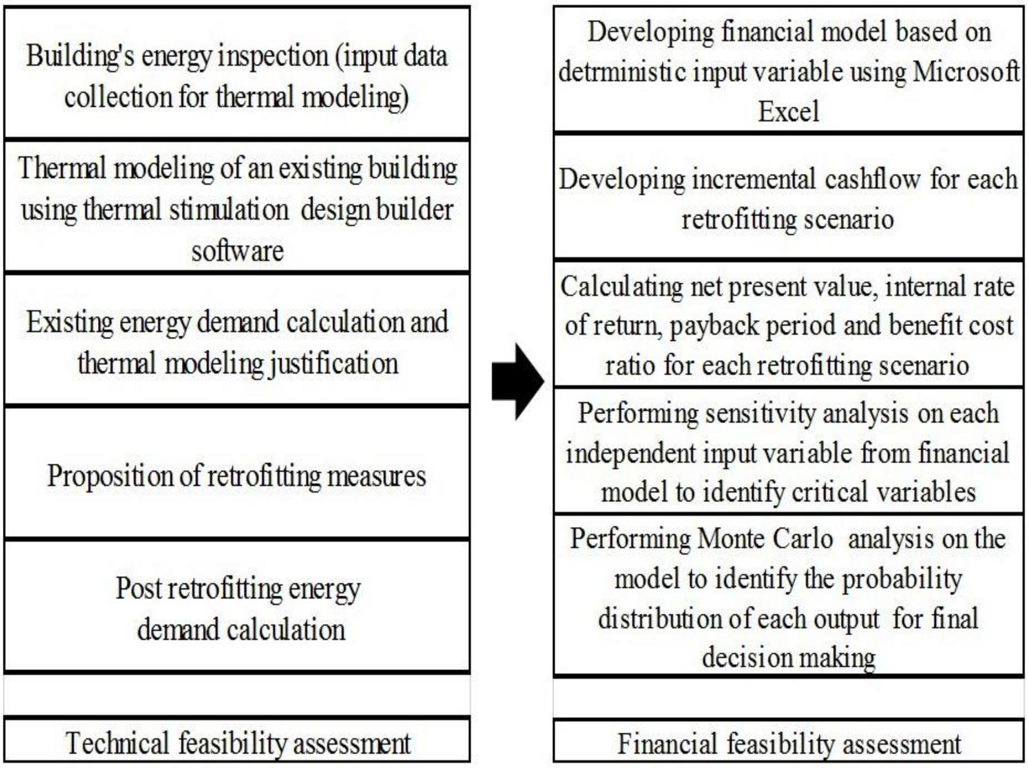


Figure 1.2: Methodology path

1.7 Research Contribution and Novelty

The contribution to the knowledge of this research could be classified into two general contexts of theoretical and practical. Where within the theoretical context that has the main contribution to the current body of knowledge, the general methodology for implementing consecutive technical and financial assessment of the building is provided in detail. On the other hand, within the practical context of this study all related technical and financial calculation on the actual case study using software such as Design builder, Microsoft Excel and Crystal Ball step by step demonstrated. Adopted analysis procedure in this study could be generally implemented on any type of residential and nonresidential buildings with particular modification in terms of building thermal modeling (which varies based on building's structure) and availability and usability of material for retrofitting alternative proposition (could be defined based on building's application) from technical feasibility assessment and also alteration in input variable such as investment horizon (based on remaining building's useful length of life) and initial cost of investment (based on selected type of retrofitting measures) from financial feasibility assessment. At the end as per discussion with energy service companies (ESCOs) and private investors, due to significance of the subject (implementing energy retrofitting measure on existing buildings) the proposed financial model in this study could be utilized by both private and public sectors in construction industry to enable them to perform prefeasibility study on any number of considered energy retrofitting alternative before undertaking the project.

Novelty of the thesis is majorly belonged to financial evaluation of retrofitting scenario where by considering all existing input variable at play a reliable deterministic financial model based on discounted cash flow is developed and to eliminate the effect of inflation all the input variables are considered in real (inflation adjusted) term. Financial feasibility assessment at the end completed by performing both sensitivity and Monte Carlo risk analysis to accommodate existing uncertainty and risk which ignored within the deterministic financial appraisal.

1.8 Organization of Thesis

In the next chapter a literature review on significance of energy efficiency, building's contribution in global energy consumption and the most recent and effective approaches in energy conservation and finally energy retrofitting in the buildings and its components (technical and financial analysis) are reviewed. Chapter 3 and 4 of this study allocated to introducing the case study and implementing technical feasibility assessment of different retrofitting measure on it. In addition, the financial feasibility assessment on all proposed retrofitting alternative will be performed and eventually sensitivity and risk analysis will identify the key variables in financial analysis and their impact on final results. Chapter 5 will sum up the results and will discuss the entire procedure to justify the selection of best alternative. Finally, in the last chapter 6 the conclusion and future recommendation for this study will be provided. Figure 1.3 provided a flowchart as research's map for this study:

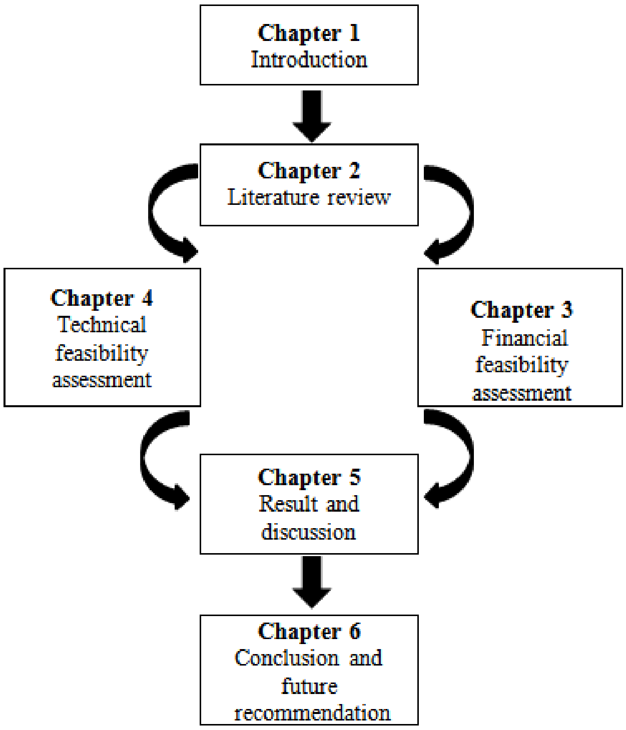


Figure 1.3: Study's map

Chapter 2

LITERATURE REVIEW

“We simply must balance our demand for energy with our rapidly shrinking resources. By acting now we can control our future instead of letting the future control us” (Jimmy Carter)

2.1 Introduction

This chapter provided a review of existing literature on mutual interaction between human population growth and energy demand, the role of built environment and specifically building in energy consumption with a holistic overview on existing statistics, type of energy efficiency measures and its benefits and costs, energy retrofitting measures as a part of energy efficiency and its barriers, incentives, cost and benefits and at the end a detailed literature review of each step in implementing energy retrofitting from building’s inspection to financial modeling and risk analysis.

2.2 Human Beings and its Footprint on Energy Consumption

Nowadays every aspect of human’s life is somehow associated with energy resources. Simply put adjusting the balance between the demand and supply of energy has become human’s major challenge and will determine our future and eventually our next generation’s futurity. Given the current trend of population growth rate will lead us to 50% more energy demand by 2050 just to sustain humanity without mentioning their welfare.

Regardless of destructive issues caused by depletion of energy sources, the most remarkable issues arise from energy overconsumption are:

Increased Carbon Footprint: the process of manufacturing of any type of product act like double edge sword for human being it can benefit them by providing goods and services and along with responsibilities toward greenhouse gas (GHG) emissions. Carbon footprint is defined as mass of cumulated of all emissions of CO_2, produced through your activities in a given period of time (Hertwich & Peters, 2009). (enerdata, 2019) Revealed, the amount of CO_2 generated from total fuel combustion in average per annum within last 10 years increased by 1.56%.

Increased Risk of Climate Change: Whilst certain levels of greenhouse gases are essential for maintaining air temperatures necessary for life on Earth, many of the Earth's ecosystems are highly susceptible to even minor temperature variations. The most common greenhouse gases in the Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and chlorofluorocarbons (CFCs). Other than water vapor, which is not significantly affected by human activity, concentrations of carbon dioxide in the atmosphere contribute the greatest to global warming. While the global warming potential (GWP), or ability of a gas to contribute to global warming, of carbon dioxide is much less than for other GHGs such: as methane (with a GWP 25 times that of CO_2) and nitrous oxide (with a GWP 298 times that of CO_2), its abundance means that, it is the most significant human-influenced contributor to global warming (Crawford, 2011). The most remarkable environmental issues that world is engaged with is increasing in the global temperature due to Climate change. Based on annual report from the Intergovernmental Panel on Climate Change (IPCC) statement the dominant cause of global warming in the mid-20th century was human activities. In its 2013 fifth assessment report, the IPCC stated that "extremely likely that more than half of the observed increase in global average surface temperature" from 1951 to 2010 was caused by human activity. By "extremely likely", it meant that there was between a 95% and 100% probability that more than half of modern global warming was due to humans activities (Cook et al., 2016). The potential of dramatic effects of global temperature rise such as increasing sea level as a result of melting snow and icebergs as well as catastrophic damage caused by the impact of natural storm, increase in air pollution level and hundreds of others negative direct influences which is counted as consequence of global warming and GHG concluded that in contemporary era number one enemy of human being could be the consequences of their own actions which namely resulted as the main driver behind this devastating issue. And if it cannot be controlled through precautionary activities the image of what we know as today's world will be vanishing for our next generation.

Reduction in supply due to resource depletion and consequently higher Energy costs by increasing demand and decreasing supply: Fossil energy considered as fundamental driver of the Industrial Revolution and continues to play a dominant role in global energy systems. The evident rule of the market indicates the relation between the prices and the demand and production. Resource energy depletion leads to reduction in energy supply and growing in the amount of world's population causes increase in energy demand. Eventually the compensation of the remaining demand will kick the price higher and make more often used energy sources more valuable than past. Finally, population growth and its subordinates seem to be creating an endless loop toward energy over consumption and production and its harmful outcomes. Hence by considering the complexity of stimulus factors which influence the schema of energy consumption and production singly and together, apparently some of the techniques to break through this loop as a major preventive factors are to controlling the consumption pattern from within through sustainability and energy efficiency measures which goes on in this study with identification of capable areas in energy consumption as well as CO_2 production.

2.3 Built Environment and its Role on Energy Consumption

Understanding the allocation pattern of energy distribution among sectors will provide better projection of global energy consumption in future (U.S. Energy Information Administration, 2016). Before starting with contribution of different industries in energy consumption, there are terms which required to be explained. The built environment according to construction industry council (CIC) applies to all type of buildings and civil engineering infrastructure above and below the ground as well as the landscapes, between or around them. The built environment was accountable for almost 40% of global energy consumption. It has been also expressed as a diverse spectrum of human-made infrastructure systems, comprises buildings, transport networks (roads, bridges, railways etc.) and utilities (water, power, telecommunications etc.) which considered necessary for human survival (Crawford, 2011). The full assessment of built environment impact on energy consumption comprises building and transportation sector as well as the embodied energy associated with materials (Anderson, Wulfhorst, & Lang, 2015), which in total accounted for 62% of global energy consumption (Khatib, 2012). However according to (IEA, 2016) since 2016 the share of built environment decreased to 58% while the industries increased to 38% in the meantime the rest of energy is consumed in agriculture sector, as well as non-feedstock related non-energy use. The Figure 2.2 could illustrate a clear vision of energy distribution among different sectors:

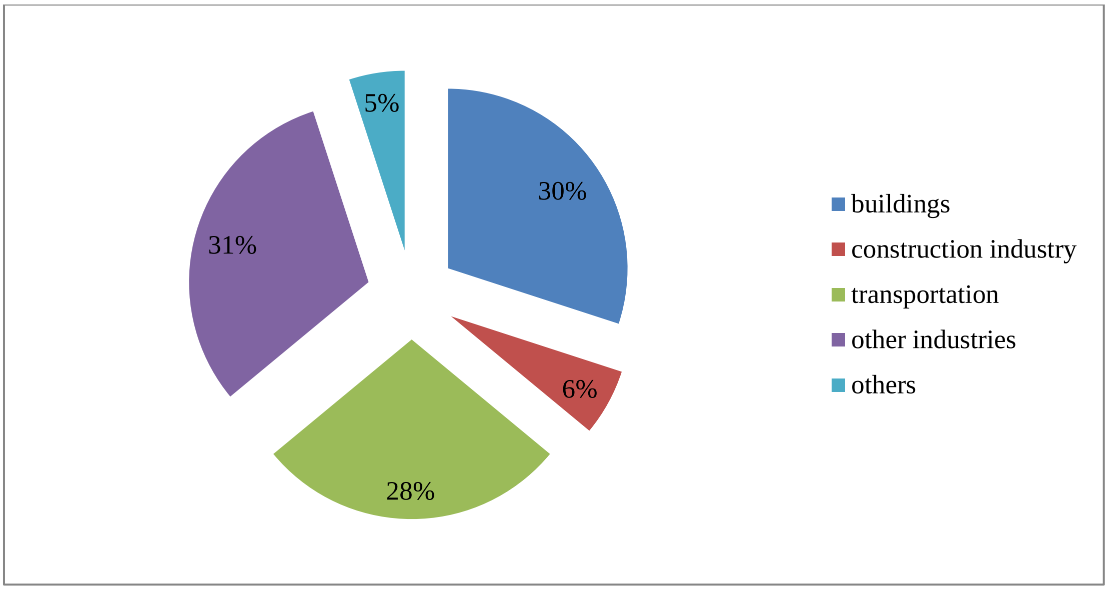


Figure 2.1: Global energy consumption distribution based on sectors (percentage) (International Energy Agency -IEA, 2019)

2.4 Buildings as a Part of Built Environment

As the primary objective of buildings to provide the comfort area for its residence with broad gamut of serving types such as residential, industrials, offices and institutional and so on, they are by far the most complex element within the built environment form the energy consumption point of view. With these requirements for natural resources comes greenhouse gas emission and consequently a range of environmental impacts, which occur across the life of a building (Crawford, 2011). Undeniably the human made construction of any structure required several form of energy resources from the planet earth. Buildings also as a complicated part of built environment is not an exception and in order to provide basic and essential human necessities they need energy resources to supply required factors for human comfort such as heating, cooling, lighting, water provision etc. (Crawford, 2011). Complexity of the construction sector and specially buildings arise from numerous components which taking part in its life cycle.

2.4.1 Life Cycle Energy of the Buildings

According to (Ramesh et al., 2010) Life cycle of buildings composed of three major phases where energy flow being consumed in each phase differently. As it demonstrated in following Figure 2.2 the life cycle of the buildings are include construction or manufacturing phase, use phase and demolition phase.

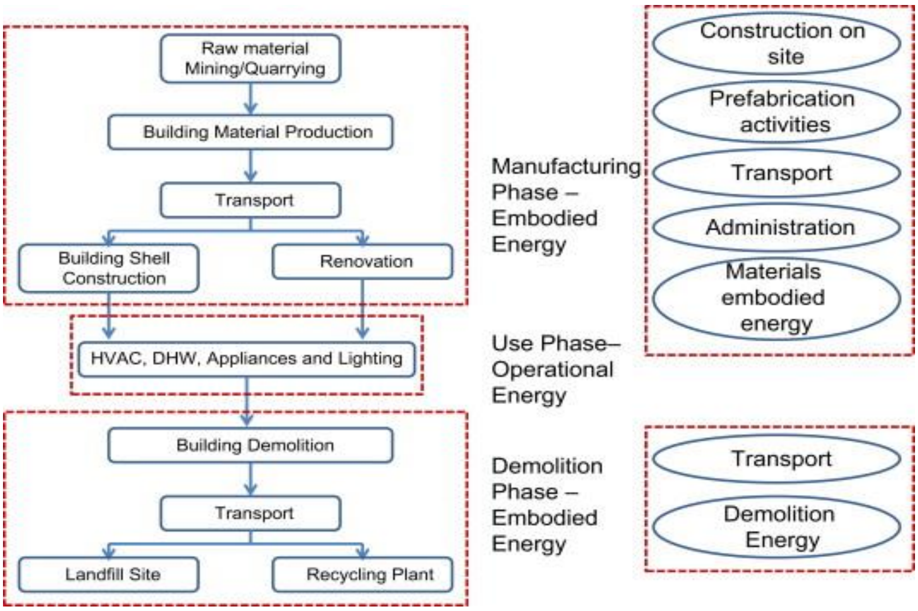


Figure 2.2: Building's life cycle (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014)

Buildings energy consumption could be investigated from different point of views. From one perspective energy demand in buildings classified as direct and indirect energy consumption. Direct energy consumption implies the required energy for construction, operation, rehabilitation and eventually demolition; indirect energy demand is through the production of the materials and their technical installations (Sartori & Hestnes, 2007) From other perspective, constitution of energy consumption in life cycle of the buildings falls into two major categories:

1. Embodied energy which refers to utilization of energy during manufacturing and demolition phase of the building. It is the sum of energy consumed building material production (the amount of energy used to excavate the raw

material, manufacture and transport to the building site), installation and energy consumption at the time of erection/construction and renovation of the building.

2. Operational energy consumption indicated the requirement of energy for maintaining comfort condition purposes along with the operation of variety of buildings system such as (heating, ventilation and air conditioning (HVAC), domestic hot water, lighting, and for running facilities. The level of operational energy consumption varies to a great extent on level of comfort required, climatic conditions and operating schedules (Ramesh et al., 2010).

(Langston & Langston, 2008) proposed that, while measuring operating energy consumption is easier and less complex and time consuming than, determining embodied energy, in addition to calculate embodied energy there is no accurate and pervasive method which is adopted widely. Therefore mismatching result for embodied energy consumption in buildings seems to be inevitable in regard with distinct variable involvement (Dixit, Fernández-Solís, Lavy, & Culp, 2010). Despite all contrasts Results confirm that 80 to 90 percent of the energy consumption in building life cycle contributes in operating phase and the rest 10 to 20 percent used as embodied energy in buildings life cycle demand (Ramesh et al., 2010).

2.4.2 Buildings Type Energy Demand and CO2 Emission

Buildings performance institute Europe (BPIE) distinguished the buildings into residential and nonresidential type and revealed out of 25 billion square meter of useful floor space in EU 27 (referring to 27 countries of European Union members during 2007 to 2016 except for UK due to Brexit negotiation) 75% of total floor space accounted for residential building and the rest 25% belongs to nonresidential (NR) buildings (Economidou et al., 2011).

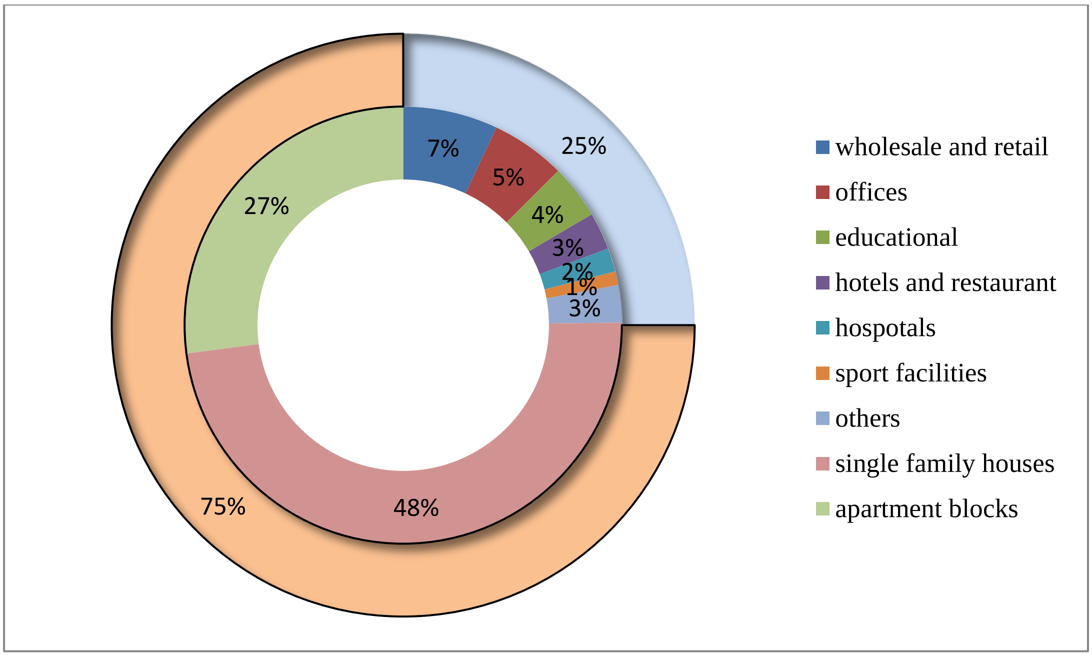


Figure 2.3: Residential and NR buildings floor area breakdown in Europe (Economidou et al., 2011)

From buildings application point of view in 2015 the share of residential buildings from total energy consumption in the world is around 22% which is 73% of total buildings energy consumption and 61% of summation of building and building construction sector in global energy consumption while nonresidential buildings consumes 8% of total world energy demand 27% of buildings sector energy consumption and finally 23% of summation of building and building construction sector in global energy consumption (International Energy Agency -IEA, 2017).

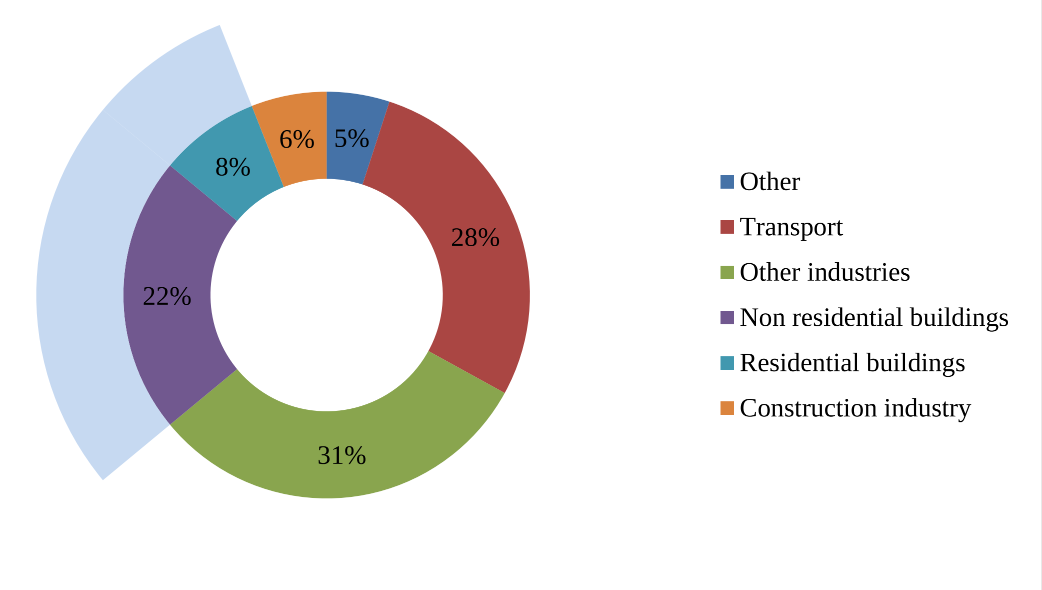


Figure 2.4: Energy consumption based on building's type (IEA, 2017a)

The portion of residential buildings is 60 % from 28% of buildings share of CO_2 emission in total which is 21% from direct CO_2 emission and 39 % from indirect CO_2 emission in case of nonresidential buildings is 40% which is almost 11% from direct CO_2 emission and 29% from indirect CO_2 emission. From another perspective also residential buildings contribution in total CO_2 emission from different sectors is around 17% as for nonresidential buildings to total 11% (Abergel et al., 2017).

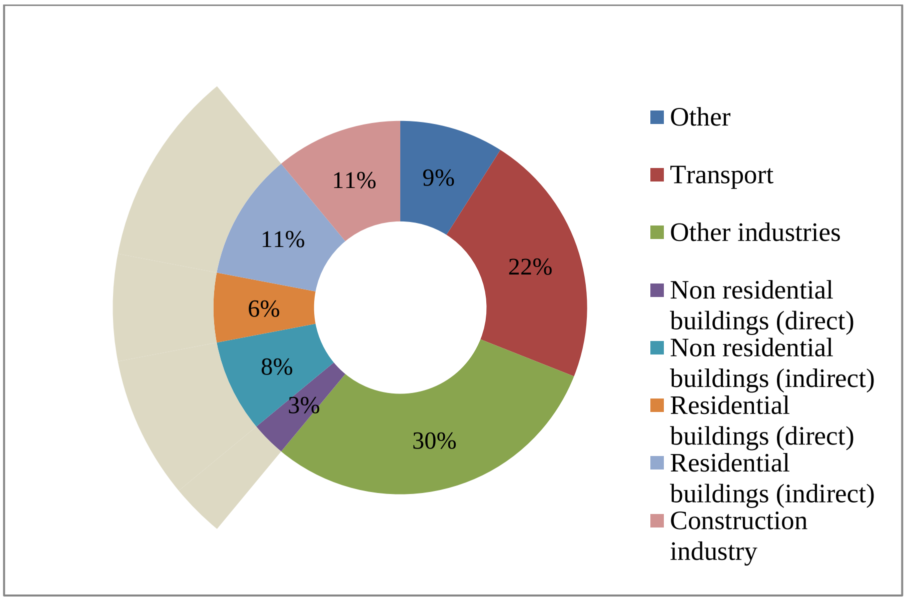


Figure 2.5: CO_2 emission based on building's type (IEA, 2017a)

At a glance Buildings and construction are responsible for more than 35% of global final energy use and almost 40% of energy-related CO_2 emissions.

2.5 Factors Affecting Energy Consumption in the Buildings

(Silva & Sandanayake, 2012), by analyzing 20 key research papers identified five major categories and 36 sub categories within them which affect buildings energy consumption as it demonstrated in Table 2.2 and explained as follow:

Climate: by portioning the indoor built environment from external environment buildings act as a qualifier.(Lam, Tsang, Yang, & Li, 2005), identified five climatology (climate types), namely severe cold, cold, hot summer and cold winter, mild, and hot summer and warm winter and five major weather parameter as temperature, solar radiation, wind speed and direction, moisture content of air. In support of the effect of weather condition on buildings energy consumption, (Kalamees et al., 2012) Specifically stated that, temperature as a major weather parameter has the strongest impact on the heating and cooling energy demand, and during winter and summer. According to (Y. Liu & Harris, 2008; Yu, Fung, Haghighat, Yoshino, & Morofsky, 2011) even a small rise or reduction in ambient temperature consequently affects occupant behavior and cause significant change in building energy consumption. And that is the reason why climatic data play vital role in providing comfortable and protective indoor conditions to its occupants against outdoor environment in building industry (Oxizidis, Dudek, & Papadopoulos, 2008).

Buildings related characteristics: Although according to (Papadopoulos, Theodosiou, & Karatzas, 2002; Yu et al., 2011) Floor area, size, age, envelope, fabric ,shell, form, shape, materials and construction as building-related parameters have direct effect on energy consumption in buildings but (Y. Liu & Harris, 2008) Argued there are other buildings related characteristics such as orientation and the nature of the surroundings, also have an influence, but are often ignored.

Occupant related characteristics: Buildings do not use energy, but people do (Janda, 2011) The levels of occupancy and occupant behavior have direct relation to energy consumption in buildings. (Y. S. Kim & Srebric, 2017) believes approximately 10% to 40% of the energy can be saved, if the occupants' presence/absence is factored into the building operation based on a dozen different case studies conducted in commercial buildings. So basically Introducing energy efficiency measures without taking into account effective parameters which have influence on building performance such as user satisfaction can often be counter-productive and the reason is users are more incline toward adapting their environment to obtain comforting conditions (Jafari, 2018). On the other side due to relation of occupant behavior with social and humanities science and human decision-making process which are complex and multifactorial, the broad spectrum of variable involved the complexity increases when examining human related activity associated with energy demand. Therefore Numerous studies have examined the influence of occupant's behavior from different angles on the energy consumption in buildings in order to qualitatively and quantitatively interpret occupant behavior, foster energy efficiency, and decrease the breach between the predicted and real energy consumption. According to (Paone & Bacher, 2018), by study conducted on the state of the art related to the impact of building user behavior on energy efficiency, categorized in terms of methodology, type of buildings and energy investigated, geographical area, and impact of occupant behavior it is concluded that based on the complex nature of the matter the most comprehensive review on energy behavior frameworks among 35 different studies between 2013 to 2016 presented by (Wilson & Dowlatabadi, 2007) and explored the most relevant social theories that determine individual decision-making. It also concluded further analysis on the interactions between technological improvement and behavioral change is needed to influence the energy effect of occupant behavior, to better grasp of occupant behavior driven by feedback and predict actual building performance.

Building service system related characteristics: (Oldewurtel et al., 2012) stated According to International Energy Agency report buildings service system related characteristics and energy efficient management of building systems plays a crucial role in cost and energy consumption reduction. Hence choosing the appropriate option of building related services such as HVAC, installation, operation and maintenance of these services are vital in implementing energy conservation and efficiency measures.

Socio economic and legal related characteristics: Socio economic factors along with government legislation and policies toward applying energy efficiency measures and in line with it the incentives to accelerate energy efficiency adoption have also huge impact on buildings energy performance. Educational and cultural awareness in energy consumption pattern in addition to controlling over energy use regulation and market price may lead the society to reform the pattern of energy consumption. Income is another important factor which somehow interrelated with education and awareness of environmental issues although the relation is complex but the influence of income factor on increasing the level of awareness and education among society members proved it as infrangible element of energy performance (Silva & Sandanayake, 2012) Another study carried out by (Mora, Carpino, & De Simone,

2015) in the University of Calabria (Italy) using overall 111 surveys to compare relative roles of socioeconomic and behavioral variables of occupants as compared with the climate and physical building characteristics in Mediterranean climate. The study generalized the influential factors into physical characteristics involved buildings characteristic, weather type of energy fuel and energy utilities in the buildings and occupant's factors include household specifications and occupants behaviors. The statistical analysis of the reports from the survey revealed that floor area and climate are the most remarkable physical parameters for electricity demand in the buildings and age, number of household and income can be mentioned concerning the occupants. Also investigating on BOMA BESt (one of the largest data base on existing buildings energy and performance data base in Canada) by considering commonly accepted factors which have effect on buildings such as age and size of the buildings, efficiency features on the building and occupants engagement in addition to management, operation, monitoring and ongoing commission revealed that although energy efficiency measures, buildings characteristics and occupant related behavior do make difference in the level of energy consumption in the buildings yet they are not the absolute determinative factors and the parameters which address management, operational and ongoing commissioning could indeed have crucial influence on energy performance in the buildings (Skopek, 2013). Table 2.2 demonstrated the amalgamation of all aforementioned influential factors on change in building's energy consumption for general (all type of buildings), nonresidential (commercial, tourism and etc.) and residential buildings.

Table 2.1: Factors affecting energy consumption in the buildings

Factors	general	nonresidential	residential
climate			
climatology / climatic location /zone		✓	✓
weather parameters	✓	✓	✓
buildings related characteristics			
type	✓		✓
age	✓	✓	✓
size/ gross floor area/ number of floors	✓	✓	✓
class	✓	✓	
usage hours		✓	
geographical location		✓	
design / structural parameters		✓	✓
orientation		✓	
envelope / fabric		✓	✓
construction quality		✓	
workers density		✓	✓
share of areas served by a/c , illumination and lift	✓	✓	✓
IEQ / indoor thermal quality	✓	✓	✓
nature of surrounding	✓		
rent			✓
availability of infrastructure			✓
occupant related characteristics			
occupancy rate	✓	✓	✓
occupancy behavior and activities	✓		✓
preference relevant to indoor comfort		✓	✓
awareness of energy consumption		✓	
building service system related characteristics			
buildings service system specification		✓	✓
buildings service system load		✓	✓
orientation and maintenance scheme		✓	
efficiency / condition of building service system		✓	✓
age of buildings service system		✓	✓
sub facilities service offered			
appliance ownership			
socio economic and legal related characteristics			
education	✓		
culture		✓	
income /social class			✓
age of the head / householders			✓
availability of energy resources locally		✓	
energy market prices	✓	✓	
energy use regulation	✓	✓	

2.6 Energy Efficiency

2.6.1 What is Energy Efficiency in Buildings and Why it is Important

Rapid inclination in world's energy demand as a result of parameters such as exhaustion of energy resources and population growth and its subordinates grew the concerns over controlling energy consumption using energy efficiency measures and renewable energy utilization as two pillars of sustainable energy. Both of these precautionary actions could be considered as effective mean to establishing energy supply and demand balance with promoting cleaner methods of producing energy, and the promotion of efficient energy use. Energy efficiency concept as a whole is a bottom up prospective associated with an individual activity while in contrast with this concept, energy intensity is a top down or accumulation look at energy consumption of an economy unit. Energy efficiency yield through two fundamental concepts of efficient energy utilization and reducing the amount of energy used which have mutual interaction on each other. In other word energy efficiency as ratio of output to input of energy referring to preserving same level of service with less energy consumption which can be achieved by technological and organizational alteration inclusive in all sectors (Kiss, 2013). Built environment as the major contributor with 64% of total energy consumption (U.S. Energy Information Administration, 2016) as well as 52% of total GHG globally, (Anderson et al., 2015) Identified as an indisputable source of energy consumption and pressurizer factor on the natural environment among other sectors. On the other hand buildings and generally buildings construction sector plays a vital role as huge part of built environment sector with variety of demands form in terms of energy. The contribution of building and building industry in total energy consumption as of today estimated to be 36% which is 30% allocated to buildings and the rest to construction. In the meantime buildings and its construction are responsible for 39% of total CO_2 emission that from this amount 28% is from buildings construction itself and the rest of 11% is from other sectors in construction industry (International Energy Agency -IEA, 2017).

Despite all the efforts has been made so far Energy Agency suggests that buildings-related emissions are on track to double by 2050 (Pomponi & Moncaster, 2016). Considering energy efficiency in the buildings defined as the extent to which the energy consumption per square meter of floor area of the building measures up to established energy consumption benchmarks for that particular type of building under defined Climatic conditions (United Nations Industrial Development Organization, 2008), diverse set of end use activities such as Space heating, cooling and lighting all together accounted for a majority of building energy consumption in different countries. On the other hand buildings design and material type also have undeniable effect on embodied energy consumption as well as remarkable influence on energy consumed for a select set of end uses.

2.6.2 Benefits of Energy Efficiency in the Buildings

The evaluation of benefits of implementing energy efficiency measures in buildings should be assessed by considering the overall benefits within buildings lifecycle (Pacheco, Ordóñez, & Martínez, 2012). The advantages of the energy efficiency measures implementation could be investigated based on single or multiple objectives and they are undoubtedly numerous from all the economical and the environmental and social point of view. There has been so many research conducted toward illuminating of energy efficiency benefits namely:

From the social approach: improved comfort and increase in indoor air quality due to improved energy efficiency in buildings, Creation of employment as a result of increased activity in energy improvements in buildings and it may also affect the productivity of buildings services.

From environmental perspective: reduction in primary and secondary energy use which directly or indirectly affects CO2 emission and Decrease in natural resource use.

And finally from financial and economical point of view: Lowering the overall energy consumption has a direct positive impact upon life-cycle costs such as reduced electricity use for lighting, office machinery and domestic type appliances as well as decreasing energy use for space heating and/or cooling and water heating and Lower maintenance requirements which consequently Increasing the reliability of the buildings (UNEP, 2014; United Nations Industrial Development Organization, 2008).

2.6.3 Methods of Encouraging Energy Efficiency

Based on the evidences the potential energy cost saving alone is insufficient encouragement to promote investing into energy efficiency measures, unless the costs of using energy soar up. While People’s attitude altered toward increasing concerns about the environment and sustainable development but the results still remain negligible. Incentives and regulations as an effective means for investors to compel more strive are categorized into two major groups:

Regulatory instruments: Regulatory instruments are the methods that governments use to interfere in the market by imposing forces such as restrictions, bans, taxes and mandatory codes to acquire positive alteration in terms of the social, economic or environmental gains in societies. Mandatory codes, carbon energy tax policies and tradable permits falls into regulatory instrument group.

Voluntary instruments: this instruments acts as an incentive by offering codes and eco-labeling schemes to investors to make commitment toward more environmentally friendly process or products. This type of voluntarily action is supported by rebates with governments and since rebates effectively lower the cost of implementing enhancement measures it could motivate them to perform these preventive measures. Unilateral and negotiated agreements, voluntarily programs and other programs such as demand side management (DSM) programs are as part of voluntarily instruments (Lee & Yik, 2004). To improving energy efficiency of building in systematic manner the classification is different.

Building energy codes: include legally binding regulatory instructions like energy consumption standards for construction sectors in china which liable the investor to establish a target for 65% reduction in energy consumption of new buildings in compare with existing buildings or the energy performance of buildings directive (EPBD) in Europe which widely used for regulating various environmental themes. EBPD directives and its origination will be discussed in detail within this part.

Incentive based scheme: these incentive encourage investor to employ energy efficiency measures by providing subsidies or permits to offset the cost of improving the buildings include economic incentives which provides more financial attractive offers for investors such as certifications and market based programs. For example Europe promotional initiative within the context of GREENLIGHT PROGRAMME which signed by partner and the commission in which partner will commit the profitability of upgraded equipment which installed in the buildings.

Eco labeling scheme: applicability of these schemes could be varies from adoption a single threshold performance rating or labeling the progressive standard in buildings such as leadership in energy and environmental design (LEED) for US or building research establishment environmental assessment methods (BREEAM) for UK and legally nonbinding buildings energy codes like international energy conservation code (IECC) or the American society of heating, refrigerating and air-conditioning engineers (ASHRAE) and voluntarily building environmental performance assessment scheme like HK-BEAM.

There are also other incentives such as technology transfer programs covering the flows of knowhow, experience and equipment and is the result of many day-to-day decisions of different investors involved like Transfer of Wood frame Construction Technology Characterized by High Energy Efficient to Slovakia or information and education campaigns like green and Sustainable building websites that have been set up by various investors, which is providing a wide range of information varying from simple product information to step-by-step guides on how to design and build a sustainable building (W. L. Lee & Yik, 2004; UNEP, 2014).

2.7 Categorization of the Buildings Based on Adopted Energy Efficiency Measures

In perusing energy efficiency of buildings variety of technological approaches could be implemented. In this study energy efficiency models categorized into three major groups:

1. **Low energy buildings:** Today low-energy buildings are identified as a building with less energy required in comparison with standard building

constructed in accordance with current building regulations. Existing sub categorization of low energy buildings are known as:

- 50% energy buildings: as it clear by the name this type of low energy buildings consumes only half of the energy needed by a standard building.
- Zero energy building: A zero-energy building, also known as a zero net energy (ZNE) building, net-zero energy building (NZEB), net zero building or zero-carbon building is the buildings which consume very low amount of energy which could be nearly zero. The energy requirement in these buildings should be supplied to a very serious extent by renewable energy sources onsite or nearby. In the other word 'Zero energy' means that the energy provided by on-site renewable energy sources is equal to the energy used by the building (Szalay & Zöld, 2014; UNEP, 2014). This type of low energy buildings recently is very much considered by authorities to the point where implementation of ZEBs are discussed and proposed at the international level for example in US, Energy Independence and Security Act of 2007 (EISA 2007) authorizes the Net-Zero Energy Commercial Building Initiative to support the goal of net zero energy for all new commercial buildings by 2030. It further specifies a zero-energy target for 50% of U.S. commercial buildings by 2040 and net zero for all U.S. commercial buildings by 2050 also in EU according to article 9 of EPBD recast 2010 from 2018 all public owned or occupied by public authorities buildings must converted to NZEB and from 2020 onward the legislation is applicable for all the buildings (Marszal et al., 2011).
- Active and passive houses: analysis of buildings nowadays concentrated on constructing healthier and more comfortable lives for building's in this regard

active House concept complements the definition with the adding features such as smart cooling, heating and lighting system to the house to aim reduction of negative impact on the climate as well as elevating the occupants comfort. It is an accentuated environment concerns concept that, putting some emphasis on preserving the nature and reducing the human habitat pressure on it (“Total Building Performance and Active House Concept,” 2014). While passive houses are construction concept of a rigorous, voluntary standards for improving energy efficiency in buildings by providing comfortable interior climate using energy sources inside the building such as the body heat from the residents or solar heat entering the building and without implementing active system. Passive houses consume less than a quarter of the energy used by a standard building and their precedence to other type of low energy buildings are due to their prevention from building's ecological footprint from one side and o the other hand it is believed that There is absolutely no cutting back on occupants comfort in these buildings (Passipedia, 2019).

- Energy plus buildings: this form of buildings based on their capacity on generating extra redundant energy could be classified either as low energy buildings or as separate categorization. The concept of energy plus buildings or according to European Commission ‘plus energy building’ built on the combination of buildings with energy efficiency level of a passive building and additional integrated active energy supply systems that exploit solar or wind energy like photovoltaic panels or micro-wind generators. So in general the energy performances of such buildings are so outstanding that the energy balance in building is always positive. Energy plus buildings during the summer sell excess amounts of electricity generated by its active system to the national grid and buys it back during the winter. Since the spaces for embedding the photovoltaic panels or the wind generators are often limited these technologies cause extra investment costs of at least 10 % compared to a standard building .The prerequisite for such a building is the existence of a national sales tariff, which is not yet the case in most countries. The current tariffs are heavily subsidized to promote the development of new technology in developed countries. Plus Energy Buildings are currently rare but are likely to become a new building trend in the near future (Comission, 2019; PAROC, 2018).

2. **Eco Cities:** energy efficiency measures expanded its objectives from particle (building) to bigger vision (city) the concept of Eco city is derived from human settlement modeled based on the self-sustaining resilient structure and function of natural ecosystems. It aimed to supply its inhabitants with healthy abundance without demanding more renewable resources than it replaces , more waste than it can assimilate or recycle for new uses or than nature can dilute and absorb harmlessly, and finally without being toxic to itself or neighboring ecosystems. Its inhabitants' ecological impacts reflect global supportive lifestyles; its social order indicates fundamental principles of fairness, justice, reasonable equity and consensus at ample levels of happiness (Standards, 2018). According to ("Total Building Performance and Active House Concept," 2014) The energy chain for buildings in Eco Cities include the following items:

   Low-energy houses;

   Low-temperature heating systems;

   Low-temperature heat distribution system;

Use of renewable energy sources whenever possible;

Heat production as near as possible;

Electricity production can be centralized.

2.8 Energy Retrofitting (Energy Efficient Refurbishment)

Regardless of existing models diversification in pursuing energy efficiency objectives in buildings for new construction, due to allocation of majority of building’s number to already existing buildings, energy retrofitting or energy refurbishment have significant role among other energy efficiency models improve level of energy consumption in the buildings. (Kolokotsa, Diakaki, Grigoroudis, Stavrakakis, & Kalaitzakis, 2009) defines retrofitting as a general concept of any undertaken action during the operational stage of the building.in addition it implies to necessary action implemented which will optimize building’s energy and / or environmental performance while building renovation refer to necessary modification to bring the building back to its original stage. Various energy retrofit measures can affect energy efficiency in buildings in different ways which could be classified into five main groups as:

Controlling measures: it could be done by supplying suitable control over various devices for the Mechanical systems, lighting, ventilation, and the efficient use of multifunctional Equipment, among others.

Load reduction measures: By rehabilitating the mechanical systems; replace fixtures, Appliances, and lighting with energy efficient models, among others.

Enveloping measures: insulate and air-seal the roof or ceiling, walls, and floor; Replace the windows and doors with energy-efficient models.

Renewable energy technologies: provide renewable-energy sources such as Solar thermal systems, solar photovoltaic/thermal systems, geothermal power Systems, among others.

Human behavior: by Altering energy consumption patterns of occupants and different methods such as education, individual metering, among others (Jafari, 2018).

Also there are other energy efficiency models which fall within the concept of energy efficient refurbishment such as improvement of life cycle performance of the buildings which also called commissioning.

2.8.1 Significance of Energy Retrofitting

Energy retrofitting may refer to overall optimization of building performance. It is considered as major approach toward sustainable built environment with considerably low cost and high return. At the same times it proposes a remarkable reduction in global energy demand as well as greenhouse gas emission (Ma, Cooper, Daly, & Ledo, 2012). It has been estimated replacement rate (the rate at which new buildings either replace or expand old stocks) of existing buildings by the new construction is only around 1% to 3% annually (IPEEC, 2017). For instance just in European Union as of year 2011 more than 40% of the buildings built before 1960 and from the rest of 60% almost 90% of them built before 1990 which indicated about 1% replacement rate. Nonetheless almost up to 2% of the buildings undergo renovation each year, yet it is estimated that the majority of these renovation do not provide buildings with appropriate efficient measure and therefore full potential energy saving could not be achieved (Ma et al., 2012). The graph in Figure 2.6 presents the rough evaluation of existing building stock's age profile in both residential and nonresidential sectors. According to the data extracted from (Artola, Rademaekers, Williams, & Yearwood, 2016), 35% of the EU's buildings are revealed to be over 50 years old and by considering the slow replacement rate up to 110 million buildings out of estimated 210 million existing buildings could be in need of renovation which indicates the huge potential of building's energy retrofitting in just EU.

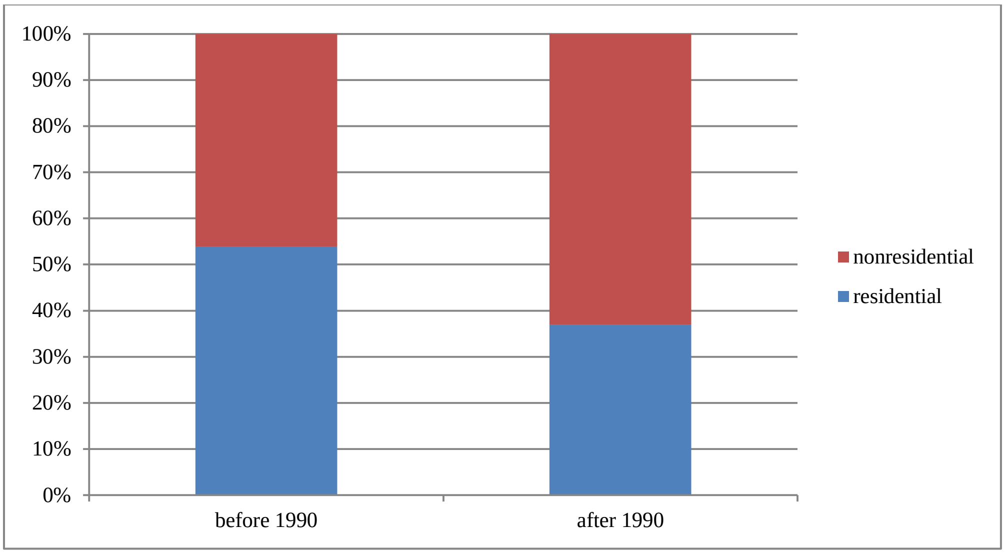


Figure 2.6: Age profile of the buildings in EU as of 2011(percentage) (Artola et al., 2016)

2.8.2 Barriers, Incentives, Cost and Benefit of Energy Retrofit

✓ **Barriers:** the (ENTRANZE, 2019) predicted the annual building retrofit rate on floor area and the percentage based by considering three scenario (BAU - Low: Moderate policy ambition with moderate level of subsidies and available budget, New policies - moderate - Medium: Some effort in more innovative and consistent policy packages, however with a moderate ambition (medium), New policies -

ambitious - High: Strong effort in more innovative and consistent policy packages, with a high policy ambition (high) in three type of building retrofitting (deep ,medium and light) among EU28. They came to conclusion that the share of buildings stock renovation from all type and by all scenarios from almost 10% in 2020 will increase up to 30% by 2030. Although this elevation obviously demonstrated relatively successful implementation of incentive and policies within the European Union countries, yet at a glance on scheme and future plan of EU in terms of achieving certain level of sustainability and considering the huge potential of EU in terms of renovation that stated before, they seem to be far behind the schedule and manifestly failed to implement the appropriate combination of motives, directives and most importantly clear financial benefit for involved investors, which itself indicated to existing barriers of energy retrofit adoption by investors from different perspectives. The barriers of effectuation of energy retrofitting has been evaluated by various studies, (Hong et al., 2015) assessed the key barriers toward adopting energy retrofitting in buildings from financial point of view such as installation costs, difficulty securing financing, payback periods etc. (Artola et al., 2016) categorized the major obstacles into five groups:

Financial barriers: Renovation costs, Access to finance Low energy prices.

Technical barriers: Lack of technical solutions, Cost of technical solutions, Lack of knowledge of construction professionals.

Regulatory barriers: Fragmentation of the supply chain, Burdening of home owners.

Process barriers: Varying ambition of performance requirements, multiple definitions for renovation.

Awareness barriers: Lack of awareness.

✓ **Incentives:** on the contrary the Policy options to boost renovation include all voluntary and regulatory initiatives or schemes that are designed to stimulate the energy efficient renovation of buildings in the EU Are mostly classified as:

Regulatory: Mandatory building codes, Minimum Energy Performance Standards (MEPS), Refurbishment obligations, Energy Efficiency Obligation Schemes (EEOS).

Financial and fiscal: Subsidies and financial instruments, Grants for research, innovation and demonstration, programs (e.g. for NZEBs & smart meter roll-out), Tax incentives, Energy Service Companies (ESCOs).

Information campaigns & labeling: Awareness raising and information campaigns, EU Energy Performance Certificates (EPCs), (Voluntary) energy labeling schemes, EU Eco design and energy labeling.

Others: Voluntary and negotiated agreements, Energy audits, Skills development and capacity building programs. The amalgamation of all the incentives and regulation alongside with barriers and considering the growth rate of building energy retrofitting testifies that there are still missing parts to complete this puzzle. In order to digest the drivers for investors all the benefits and costs of implementing energy retrofit in buildings need to be considered.

✓ **Benefits:** Benefits of promoting energy retrofit in buildings could be grouped in relation with investor's requirements. Following Tables 2.3, 2.4 and 2.5 provided a general insight of classification of energy retrofit advantages based on different perspectives.

Table 2.2: Benefits of promoting energy retrofit (Staniaszek, 2013)

Benefit category	Benefit subcategory
Economic	Energy cost saving
	Economic stimulus
	R&D, industrial competitiveness & export growth
	Property values
	Impact on public finances
	Energy import bill
	Impact on gross domestic product (GDP).
Social	Reduced fuel poverty
	Health
	Increased comfort and productivity
Environmental	Carbon saving.
	Reduced air pollution
Energy system	Energy security.
	Avoided new generation capacity
	Reduced peak loads.

Table 2.3: Benefits of promoting energy retrofit (Artola et al., 2016)

Benefit category	Benefit subcategory
Environmental	Energy savings & GHG emissions reduction
	Reduced usage of materials
Economic	Employment
	GDP and public budgets
	Innovation
	Sectorial modernization
	Energy security
	Productivity benefits
Social	Health benefits
	Reduction energy poverty
	Wellbeing / comfort
	Energy bill savings
	Increase in property value & tenant satisfaction

Table 2.4: Benefits of promoting energy retrofit (Jafari, 2018)

Benefit category	**Benefit subcategory**
Economic	Energy consumption cost
	Maintenance and replacement cost
	Resale benefits
	Property tax
Environmental	Life-cycle environmental impacts
	Fossil fuel conservation
	Reduction in CO2 emissions
Social	Occupants' health and comfort impact
	Society enhancement
	Cultural and community education
	Project investor enhancement
	Building quality and technology enhancement
	Socio-economic growth

Considering Tables 2.2, 2.3, 2.4 as a small picture of whole studies on benefits of energy retrofit in buildings it is comprehensible that three major category of economic, environmental and social benefit are usually investigated in researches in order to perusing investors to adopt energy retrofit in existing buildings.

✓**Costs:** Cost of implementing energy renovation could be also classified based on different perspective. Depends on the features of the research this classification could varies from analyzing the barriers of implementing energy retrofitting measures (ERM) to financial analysis of certain project. Tables 2.5, 2.6 illustrated how the component of the cost related to ERM could be different from different approaches.

Table 2.5: Costs of promoting energy retrofit (Artola et al., 2016)

Cost category	Cost subcategory
Property owners and land lords	Assessment costs
	Installation costs
	Financing costs
	Hidden costs
	Costs of understanding regulations
Authorities	Set up costs
	Implementing administrating, monitoring costs
	Other costs e.g. Advising cost on regulation
Tenants	Potential rent increases
	Hidden costs

Table 2.6: Costs of promoting energy retrofit (Yuming Liu, Liu, Ye, & Liu, 2018)

Cost category	Cost subcategory
Costs before implementing ERM	Cost of investigating and testing of ERM
	Cost of audit for ERM
	Cost of decision making for ERM
	Cost of design for ERM
Cost during the ERM	Cost of building envelope retrofit
	Cost of indoor heating system retrofit
	Cost of OHPN retrofit
	Cost of heat source system retrofit
Cost during operating stage	Cost of service and management
	Cost of equipment ,maintenance and update
Cost during demolition stage	Cost of demolition

2.8.3 Decision Making in Adopting ERM

Decision making process as a general concept is highly depends on number of variable and uncertainty involved in the task. Therefore, greater the number of uncertainty lead to more complicated decision making process. In every step of designing retrofitting procedure there are many complications included like Change in climate services, human behavior and governmental policy are from those uncertainties which may cause a challenge for investors whether to implement ERM or not on specific case or how effective will become those energy retrofitting measure. All of those uncertainties could directly or indirectly affect the selection process of retrofit technologies and consequently the success of retrofit project and due to highly interactive nature of these subsystems on buildings they could make a selection process of retrofit technologies a very complicated task (Ma et al., 2012) In the construction industry, normally funding decisions are made based on the initial cost instead of life-cycle cost which itself could be the reason for low patronage of energy retrofits due to its high upfront costs and a general lack of trust on information about the benefits of retrofits (Jafari, 2018) Other challenges may include financial limitations and barriers, perceived long payback periods, and interruptions to operations The willingness of building owners to pay for retrofits as a result of insufficient Financial support from the government, particularly due to split incentives issues which considered to be key factor for owners in adopting ERM because the cost of implementing energy retrofit falls on owner's shoulder whereas the primarily benefit of it goes to tenants pocket (Ma et al., 2012). In conclusion refurbishment concept's boundaries could not be easily specified. As a matter of fact, due to its vast spectrum it could vary from a simple repair like painting façades to a more complicated procedure including structural reinforcement. At the same time it highly depended on investors aim and objective which could target for increasing single family indoor comfort up to major investor looking for a total refurbishment in order to maximize profits and ease of sales (Ferreira, Pinheiro, & Brito, 2013) Dealing with these uncertainties and system interactions is presumed as considerable technical challenge in any sustainable building retrofit project and as retrofitting strategy defined as a tradeoff between the necessary investment to perform retrofitting strategy and the benefit obtained from energy retrofitting it required great effort to balance all the aspect of cost and benefit include economic, environmental and social aspects to design an accurate and convincible energy retrofitting scenario for investors. To address the complexity issue of adopting energy retrofitting (Nielsen, Jensen, Larsen, & Nissen, 2016) identified six key area (goal setting, criteria weighting, building diagnosis, design alternatives generation, performance estimation and design alternatives evaluation) where formal decision making methods could be instrumental in retrofitting projects. Based on these six areas (Jafari, 2018) summarized the literature reviews on decision making in energy efficiency which indicated among a variety of proposed measures, the decision-makers as primary actors (building's owner, investors and advisors) have to accommodate environmental, energy-related, financial, legal or Regulatory and social factors to achieve the best possible compromise to satisfy needs and requirements.

2.9 Steps in Implementing Energy Retrofitting Measure

(Kamari, Corrao, & Kirkegaard, 2017) Emphasizing on designing retrofitting process in sustainable way, in which sustainability is described as contestable development of society and economy on a long-term basis within the framework of the carrying inclusion of the earth's ecosystems by (UN, 2013). (Ma et al., 2012) Is proposing overall process of sustainable building retrofit program within five major steps as it illustrated in Table 2.7.

Table 2.7: Sustainable building retrofit phases (Ma et al., 2012)

Phase I	Project setup and pre retrofit survey	definition of scope of retrofit
		set the objective of retrofit
		determine available resources
		pre retrofit survey
Phase II	Energy auditing and performance assessment	energy auditing
		select key performance indicator
		building performance assessment and diagnostic
Phase III	Identification of retrofit options	energy saving estimation
		economic analysis
		risk assessment
		prioritize retrofit options
Phase IV	Site implementation and commissioning	site implementation
		test and commissioning (T&C)
Phase V	Validation and verification	post measurement and verification (M&V)
		post occupancy survey

(Kolokotsa et al., 2009) Classified the entire process of implementing ERM into two general phases of design and operation and explicated each item's objectives and process as follow:

The aim of design phase is to achieve the best equilibrium between the necessary design factors versus a combination of criteria that are subject to specific issues. By involving parameter such as building shape, orientation, building mass, type of glazing and glazing ratio and shading. The design phase will influence the occupants' comfort, the heating and cooling energy demand as well as the lighting demand.in this stage predefined design aspects and solutions, subject to the building owner's subjective preferences like cost of the building, energy efficiency, aesthetics, etc. will be proposed by designers with the help of simulation building modeling. In the operational stage of a building but, decisions making of necessary energy efficiency measures will be undertaken with the support of energy audit and survey procedures via four major steps:

Step 1: Buildings analysis to evaluate the features of the energy systems and the patterns of energy use for the building from the architectural, mechanical, electrical drawings and interviewing with building operators as well as Analysis of the historical variation of the utility bills which allows obtaining the pattern of energy consumption.

Step 2: Walk-through survey by determining customer concerns and needs, assessing the current operating and maintenance procedures, recognizing existing operating conditions of major energy use equipment (lighting, heating ventilation and air-conditioning systems) and evaluating the occupancy, equipment and lighting (energy use density and Hours of operation) which all together could be an assistant to identify Potential energy saving measures.

Step 3: Creation of the reference building as base-case model, using energy analysis and simulation tools to estimate the energy savings incurred from appropriately selected energy conservation measures.

Step 4: Evaluation of energy saving measures is performed by developing predefined list of energy conservation measures and comparison with baseline energy use simulation model to calculate initial costs required implementing the energy conservation measures and finally the cost-effectiveness of each energy conservation measure using an economic analysis method (simple payback or life cycle cost analysis) will be evaluated.

Each and every aforethought step in operational phase of ERM has been investigated separately in different studies and number of retrofitting guidelines has been developed in many countries around the world to address effective building energy retrofitting process.

In this part by referring to variety of studies and guidelines we will investigate the most popular steps in implementing energy retrofitting for commercial buildings:

2.9.1 Benchmarking

Based on (Energy & Guide, 2015) definition of benchmarking procedure is including two major steps which are current building performance evaluation and comparison. Benchmarking considered to be stating point in understanding building's energy performance. Comparison in benchmarking could be classified as best in class comparison when it compare the building with best performance building with similar characteristic, average comparison which will compare the building with average performance in the same class, baseline comparison in which the evaluation made by comparing the building with its historical performance or at the end standard performance comparison which compares energy performance of the buildings with standard energy codes. Energy benchmarking also could allow buildings receive certificate based on their performance such as energy star label (Energy & Guide, 2015; Xuchao, Priyadarsini, & Siew Eang, 2010).

2.9.2 Energy audits

Energy auditing utilizes investors with a comprehensive understanding of building's energy performance to explore best energy saving opportunities through an investigation of the current equipment, operation and building energy use patterns. Energy audit normally broken down into three steps:

✓ Pre site visit analysis which involves collecting data related to current operation and energy performance of the building

✓ Site visit by filling template audit forms, taking photos interviewing operating staff and service contractor crates opportunity to collect necessary data closer observation of building's operation

✓ Post site analysis and reporting will finally enables auditors to complete engineering and financial analysis and provide detail report to benchmarking result in order to suggest retrofit and operational improvement and rank them based on their cost effectiveness (Energy & Guide, 2015).There are various levels of energy auditing which suggested in different studies and guideline based on the requires severity of auditing as well as the funding plan (AX Consulting, 2001) suggested following levels of auditing in Table 2.8.

Table 2.8: Description of auditing type (AX Consulting, 2001)

LEVEL I	Level 1 is the basic level which provides basic information on the opportunities for energy and water savings on a very draft (basic) level. This may be called a walkthrough audit
LEVEL II	with The proposals for energy and water saving proposals based on some measurements , it more detailed than LEVEL I
LEVEL III	Energy and water consumption is carefully studied and the proposals for energy and water saving measures and investments are so well-prepared that they are ready for implementation

(Krarti, 2011) demonstrated energy audit type in Table 2.9 which could be ranged from short walk through to very detailed analysis. The book is assumed four general type of energy auditing as follow:

Table 2.9: Description of auditing type (Krarti, 2011)

DESCRIPTION OF AUDITING TYPE	
walk through audit	walk through audit is consists of a short on-site visit of the facility to identify areas where simple and inexpensive actions can provide immediate energy use or operating-cost savings.it is also known as operating and maintenance (O&M) measure.
utility cost analysis	this audit will facilitate careful analyze of the operating costs of the facility where Typically, the utility data over several years is evaluated to identify the patterns of energy use, peak demand, weather effects, and potential for energy savings and it is recommended to perform walk through audit prior to utility cost analysis to get acquainted with the facility and its energy systems.
standard energy audit	Standard audit is a comprehensive energy analysis for the energy facility system which is consists of the development of a baseline for the energy use of the facility and the assessment of the energy savings and the cost-effectiveness of selected energy conservation measures.
detailed energy audit	This audit is the most exhaustive but also time-consuming energy audit type. Specifically, in terms of instruments that are applied to calculate energy consumption for each energy system. Moreover sophisticated computer simulation programs are typically considered for detailed energy audits to evaluate and recommend energy retrofits for the facility.

But USA guideline and (TERI, 2019) introduced (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ASHRAE as a most common and standard approach among many approaches which could be chosen by investors to implement an energy audit.it explicated that all ASHRAE audits have share common foundation in energy consumption analysis that range from simplest form of reviewing historical building energy use and cost by taking into account the utility bills for at least previous two years to calculate building’s energy use intensity (EUI) to most sophisticated approach which represents complex and significant capital investment decision with the high level of confidence. The priority of auditing type in this guideline is presented in following Table 2.10 based on their complexity, level of effort and cost:

Table 2.10: Description of auditing type (Energy & Guide, 2015)

ASHRAE LEVEL I	It is considered as brief walk through of the building and a survey of the building's energy consuming equipment also implementing no cost or low cost measure of energy systems to evaluate a rough estimation of energy consumption. This method is not accurate enough financial decision making on capital intensive projects.
EBCx	This is a low cost strategy for optimizing existing building operations. EBCx process normally pursued separately before equipment retrofit. It is considering as a retrofit type but since it is related to energy audits also known as audit type.
ASHRAE LEVEL II	This method provides more accurate look at the building's energy consumption by calculating breakdown of energy consumption by end-use include heating, cooling and interior lighting. In this method all the practical measures will be analyzed in the report which will result in providing predicted energy saving and project cost. The accuracy of this method is higher than previous one but still not accurate enough to be used in highly capital intensive projects.
ASHRAE LEVEL III	due to its high level of confidence in predicting the result this method also known as investment grade audit.it provide the most exhaustive analysis on building energy system and therefore will reduce the risk and uncertainty of the result. In this method along with investigating all the energy system the interaction between systems are also will be taken into account which act as an sensitivity analysis.

The difference between a benchmarking and energy audits is that an energy benchmarking calculates a building's energy performance as compared to other similar buildings, while energy audits notify the investors where and how their building are losing energy and provides investors with cost-effective retrofitting solutions to those issues.

2.9.3 Retrofitting Scenario

Once two previous stages have revealed the issues and opportunities for improvement of building performance by considering the entire variable at play such as age and condition of equipment or timing and coordination of upgrades a long time holistic approach is required to offer best upgrading option which maximizes the return on investment. The extent of retrofitting measure of each approach will vary according to the amount of investment, required time to perform the scenario and consequently the amount of energy saving will also change based of selection of approaches. USA retrofitting guideline categorized these approaches into three major groups as it demonstrated in Table 2.11. (ARUP, 2009) As UK energy retrofitting guideline recommend four steps of retrofitting and one last step of demolition option based on existing condition of building as it demonstrated in Table 2.12.

Table 2.11: Type of retrofitting in existing buildings (Energy & Guide, 2015)

Retrofitting type	Description	Energy saving potential
Existing building commissioning	EBCx approach sometimes may lead to significant results with minimal risk and capital outlay through improving buildings and restructuring maintenance procedure. It is included of four phases: planning, investigation, and implementation and hands-off which has been discussed in detail in EPA s retro commissioning guide for building owners.	Average 23%
Standard retrofit	Standard retrofit considered as a useful approach for building owners who are restricted in incremental capital upgrade for their buildings. It facilitates cost effective and low risk efficiency upgrade options include equipment, system and assembly retrofits.	In combination with EBCx energy saving will increase to 40%
Deep retrofit	unlike other types deep retrofit required larger upfront investment which may have longer payback period as well.it will have impact on multiple building system and assemblies along with the interaction between energy systems	Average of 50%

Table 2.12: Type of retrofitting in existing buildings (ARUP, 2009)

Retrofitting type	Description
level 1 (tune up and minor refurbishment)	Carry out the health check on BMS and control; revise the lay out in improving daylight and flexibility, low energy ICT option on replacement, re commissioning on building services.
level 2 (intermediate refurbishment)	LEVEL 1 + renew lighting and control system, remove false to expose thermal mass.
level 3 (major refurbishment)	Replacement of major plant, services, floor finishes, raised floor and internal walls, installation of external solar control.
level 4 (complete refurbishment)	Only substructure, superstructure and floor structure retained structural and façade alteration. Possible relocation of cores and rises
level 5 (demolition)	Consider demolition and rebuild

And consequently (ARUP, 2009) determined the selection of retrofitting type in according with existing building performance as it demonstrated in Table 2.13.

Table 2.13: Retrofitting option selection (ARUP, 2009)

	Excellent	**Good**	**Poor**	**Very poor**
Excellent	maintain	level 1	level 2	level 3
Good	level1	level2	level3	level 3
Poor	level 2	level 3	level 3	level 4
Very poor	level 3	level 3	level 4	level 5

Once type of building retrofit is determined the selection of optimal initiatives whether it is in managerial area, energy system area or other areas is the next prime objective of retrofitting process. Numerous recommendation has been proposed by variety of studies, researches and guidelines in practical retrofitting measures and approaches by taking to account, climate, geographical situation, environmental, occupants comfort and etc. of the building as influential elements in determining retrofitting measures. although Most of the guidelines are classified retrofitting measure according to depth of retrofit as well as predefined climate categorization which has been explained in advance in their content for example USA guideline (Energy & Guide, 2015) grouped the climate as hot-humid, hot-dry, cold, very cold and marine and explicate each item in detail, others like UK guideline (ARUP, 2009), categorized it according to cost, environment, occupants comfort and the value of initiative to the owners. (Kolokotsa et al., 2009) mentioned as a general comment, all efforts toward improvement of building performance are concentrated on selecting specific actions or action without the adoption of a global and holistic approach such as provided in guidelines mostly due to the problem's complexity and this is the vital part of each retrofitting studies which distinguishing them from each other. In its research the different actions for improving buildings' energy efficiency are grouped into: building service (HVAC, mechanical equipment, office equipment, electrical equipment), energy management tools including the tools for monitoring and controlling of the building during its operation and improvement in building envelope and design aspects (roof, walls, glazing, passive solar heating, daylight and reduction of cooling load). (E., Kalagasidis, & Johnsson, 2010) considered 23 types of measuring upgrades include technical (reduction of power for lighting and appliances and Upgrade of ventilation systems with heat recovery), building envelope below and above the ground improvement (change of U-value of knee walls, slope roofs or replacement of windows) and retrofitting of attics and roofs (attic joists, knee walls, slope roof, flat roof) based on their cost. (Rabani, Madessa, & Nord, 2017) summarizes the retrofit measures for building envelope and insinuated that almost most of studies dealing with envelope retrofitting emphasizes that insulation and renewable technologies like PCM integration have the most impact among other practices for retrofit of building envelope and create an opportunity to achieve a zero or plus energy level. It presented its renovation strategy based on improvement of building envelope and building system and service by considering the element such as: Internal/external insulation, PCM integrated wall; Immersion; Attachment, Insulation (above, beneath, or within the existing structure); Skylights, Triple-glazing; low-E coating; gas filling; Insulation; electro-chromic (EC) windows from envelope and Geothermal heat pump (GHP), Passive solar cooling and heating system and Other renewable technologies from systems and services.

2.9.4 Building a Business Case for Selected Energy Retrofit Measure

Regardless of probable energy reduction by implementing proposed energy scenarios, without manifest and justified sound economic merit, energy retrofit initiative will not achieve mass penetration and adoption by investors (Menicou, Exizidou, Vassiliou, & Christou, 2015). By applying sensitivity analysis the study in china revealed that in retrofitting the existing building lack of attractiveness to investors from an economic perspective is usually due to energy price as the most sensitive factor following by initial costs and energy conservation rate and also selection of retrofit materials will greatly influence the economic outcome and consequently the scenario attractiveness for investors (Yuming Liu et al., 2018). Also direct and tangible benefit from the investment which normally acquired through reduced utility costs will directly deliver a significant cut in total operating costs and for income-producing properties lead to potential increase in net operating income (NOI). In conclusion an economic analysis for each energy retrofitting scenario must be presented to investors to assist them in decision making in adoption of energy retrofitting measures.

Financial appraisal of retrofitting measure: European commission (European Commission, 2014) in its framework proposed Cost Benefit Analysis (CBA) as explicitly required procedure, among other elements, as a basis for decision making on the co-financing of major projects comprises of operational programs (OPs) of the European Regional Development Fund (ERDF) and the Cohesion Fund. Also (Jenkins & Harberger, 2011) in their book introduced cost benefit analysis as a method for investment decision which targeted public officials and private analyst to develop and evaluate investment projects to promote economic and social well-being of the country. Then again, some of other methods such as life cycle cost (LCC) or other advanced analysis methods can be used to evaluate the cost effectiveness of multiple retrofit alternatives (Ma et al., 2012). Since in building retrofitting analysis, approaches must aim at costs during total life of building instead of considering single period, therefore life cycle cost as an evaluation measure is frequently suggested and used by several researchers using three approaches:

Conventional LCC: where all the costs are included in project life time.

Environmental LCC (LCA): where a complementary environmental assessment based on evaluation of externalities is added to conventional LCC.

Social LCC : which by considering environmental and social effect of the project on net economic welfare provide the investors with more sophisticated and developed method to assess internal and external costs (Bonazzi & Iotti, 2016).

Several researches applied LCC method in their building energy retrofit valuation such as (Kme?kov? & Kraj??k, 2015) in 2015 by applying LCC on residential building showed a potential of energy consumption reduction of more than 50 % by implementing the energy saving measures or (D'Alpaos & Bragolusi, 2018) by providing a systematic literature review based on 127 articles on valuation approaches to buildings energy efficiency and retrofit strategies concluded most frequently used is economic valuation is LCC. But regardless of participation of LCC method in researches and economic evaluation of projects, this method particularly is useful to quantify financial outflows for the analysis which have high initial investment and is characterized by a long life cycle with relevant cash outflows during time (e.g., for maintenance and energy consumption) (Bonazzi & Iotti, 2016) .

Cost benefit analysis which also known as discounted cash flow but, by jointly evaluating cash inflow and outflow generated by an investment focuses more on investments with high risks contest. Also due to value generation of energy retrofitting adoption to the owners, the amount of initial investment hoped to be covered by future energy saving as a result of retrofitting, hence, cost and benefit analysis could be suitable alternative among other methods to evaluate both of investment parameter as a cash outflow and the benefit for both monetary and non-monetary aspect as an cash inflow. This method is widely known as a standard approach in financial evaluation. CBA approach as well employed in several studies, such as in techno-economic evaluation to Optimize and encourage the retrofitting of buildings by maximizing NPV and through splitting incentives between building owners and users as one of the major issues in adopting retrofitting measures (Kumbaroglu & Madlener, 2012a) or by using cost benefit analysis (Zhao et al., 2015) proved that the payback period for applying efficiency measure in commercial building in china ranges from 2.9 to 4.1 years, in green building renovation also the research implies that although commercial offices required additional building cost however the IRR expected from implementing retrofitting measure could reach up to

12% (Ross, López-Alcalá, & Small, 2010). In 2010 (Zavadskas, Kaklauskas, Raslanas, & Kazimieras, 2004) by adopting cost benefit analysis for economic evaluation of dwellings in Lithuania concluded that the sum of initial dwelling market price and renovation expenses is 20 to 30% lower than the market value of the most of newly built apartment in the region, in 2014 (Gabay, Meir, Schwartz, & Werzberger, 2014) in the study on Israeli office buildings by taking into account , the cost of compliance for different level of retrofitting and benefit for both the entrepreneurs and public for 20 years period under both standard and economical alternatives deduced that, implementing the optimum level of retrofitting type which eventually lead to maximum saving in resource usage under standard circumstances will be involved of extra cost ranging from 4% to 12% whereas based on economical alternatives the additional cost estimated between 0.12% to 1.3%.At the end recently In 2015 (Christersson, Vimpari, & Junnila, 2015) assessed the financial potential of real estate energy efficiency investments with discounted cash flow approach and concluded that in addition to tempting returns on energy efficiency improvement actions Especially for large property owners' portfolio -wide energy efficiency improvement actions could generate significant outcomes in terms of value increase, thus taking advantage of economies of scale. Considering cost benefit analysis (CBA) as distinguishing tool which assists decision makers to accept profitable project and reject detrimental cases, general principle for investment appraisal in any projects are consist of following steps (European Commission, 2014) :

- ✓ Description of the context
- ✓ Definition of objectives
- ✓ Identification of the project
- ✓ Technical feasibility & Environmental sustainability

✓ Financial analysis

✓ Risk analysis

The list of fundamental concepts of an analytical framework in CBA is as follows:

Opportunity cost: Opportunity costs indicates the benefits of investors that could be missed when choosing one alternative over another and due to its hidden nature it could be easily overlooked (Kenton, 2015). The justification of CBA lies in scrutiny that investment decisions taken on the basis of profit motivations and price mechanisms lead which could be questioned by eliminating the parameter such as opportunity cost. According to (Jenkins & Harberger, 2011) to measure the opportunity cost of capital, a monetary value must be allocated to it in a way that, it should be equal to what has been sacrificed by using it in the project rather than in its next best use.

Investment horizon: time horizon is explained as the period of time in which the effects of the investment being valued. It considers elements of obsolescence in the investment, along with legal or contractual complication and even the personal judgments of the owner (Bonazzi & Iotti, 2016) it is considered as the outmost importance for evaluating long term investment. While (Adan & Fuerst, 2015) mentioned in their study that significant cost savings from energy efficiency measures over 25 and 40 years' time horizons, particularly when energy prices are high, (European Commission, 2014) Depend on the sector of intervention; a long period outlook ranging from 10 to 30 years which could be adopted.

Time value of the money (TVM): any cash flow as a result of economic analysis of projects must be comprises of impact of the diminishing value of money over time which called time value of money (Menicou et al., 2015). The concept of time value of money represents the impact of time on the value of any currency which leads to devaluating of the currency in future. Simply put it means the available amount in present time worth more than same amount in future due to its earning potential. TVM is also sometimes known as present discounted value (Chen, n.d.) .

Discounting: this is an extension of simple cash flow analysis to determine the present value of a payments or stream of payments to be received in future (Herbohn & Harrison, 2002). Discounting process could be implemented by taking into account the time value of money using an interest rate (discount rate) hence it will reduce the risks of investing in a project. Present worth of certain amount using discounting process is calculated by following formula:

$$\mathbf{p} = \frac{\mathbf{F}}{(\mathbf{1+r})^{\mathbf{n}}} \qquad \textbf{(2.1)}$$

Interest rate (discount rate): discount rate in simple terms refers to the opportunity cost of funds that are invested in the project is a key and highly sensitive variable in applying investment criteria for scenario selection. The significant impact of even small variation in discount rate in analysis result sometimes may lead to catastrophe in terms of final choice of project (Jenkins & Harberger, 2011). Incremental approach: an important element in the investment appraisal is to examine the incremental impact of the project that is retrofitting scenario in this case, which means how net economic benefits of the project in presence of retrofitting scenario could be expected to differ from those that would overcome in its absence. This process of with/without case must be implemented distinctively, clearly and accurately, so any benefits or costs that would exist in “without case” Is not considered in “with case” scenario. It is noticeable that, the “without project” situation does not imply that if the retrofitting scenario is not undertaken nothing is done to the current Situation, but In principle it indicates a sort of moving picture of how the Relevant items and markets would naturally evolve if the project were left aside, but with “good” decisions being taken on all other (non-project) matters at each step (European Commission, 2014; Jenkins & Harberger, 2011).

Economic performance indicators: there are variety of criterion could be adopted by analysts to encourage investors to apply energy retrofitting measures in their existing building. These economic analysis criterions such as net present value (NPV), internal rate of return (IRR), overall rate of return (ORR), benefit-cost ratio (BCR), discounted payback period (DPP), and simple payback period (SPP), are being adopted by analysts to evaluate the economic feasibility of building retrofit measures.

✓ Net present value (NPV): NPV criterion is most widely adopted criteria among investors due to major drawbacks and limitation that other alternatives involve which make them not only less reliable but potentially misleading. As a result of their point of conclusion they may create unnecessary confusion and mistakes. The NPV is calculated as the sum of the discounted benefits and costs (Kumbaroglu & Madlener, 2012b), it basically measures the change in wealth created by the project (Jenkins & Harberger, 2011), the formula which is employed for this aggregation is as follow:

$$\mathbf{NPV} = -\mathbf{C_0} + \sum_{\mathbf{t=1}}^{\mathbf{n}} \frac{\mathbf{F_t}}{(\mathbf{1+r})^{\mathbf{t}}} \qquad \mathbf{(2.2)}$$

(Jenkins & Harberger, 2011; Nikolaidis, Pilavachi, & Chletsis, 2009) set up three rules while using NPV as criterion for project evaluation and selection.

Rule 1: under normal circumstances while a single case is been assessed using NPV if NPV>0 accept the project if NPV<0 reject the project and if NPV=0 it is indifference.

Rule 2: Within the budget constraint, choose the alternative that maximizes the NPV.

Rule 3: When there is no limitation in terms of budget constraint but a project must be chosen from mutually exclusive alternatives the best choice is the alternative that generates the largest NPV. But regardless of its reliability NPV approach has several limitations, its major limitation according to (Menassa, 2011) are:

1. Determination of discounting rate which itself could be major source of risk in calculating NPV.
2. The extended time horizon in NPV calculation always will lead to significant uncertainties included physical , business and institutional uncertainties (Gluch & Baumann, 2004) where adjustment of those uncertainties include modifying the discount rate or other variables may yield complications.
3. Being, out of the question, the predictability of accurate energy consumption due to several elements such as difference in occupancy, hours of building system operations, building and system maintenance condition and predicted against actual weather data creates limitation since in required some assumption toward developing future cash flow for a given investment.

✓ Internal rate of return (IRR) or Modified internal rate of return (MIRR): IRR (internal rate of return) criterion is considered for both public and private sector as a way to define attractiveness of the project. IRR defined for each project as a discount rate that makes NPV calculated from entire cash flow of the project zero. It will be obtained from the same formula as NPV:

$$\mathbf{IRR} = \mathbf{NPV} = \sum_{\mathbf{j=0}}^{\mathbf{n}} \left[\frac{(\mathbf{B_j} - \mathbf{C_j})}{(\mathbf{1+IRR})^{\mathbf{j}}}\right] = \mathbf{0} \qquad \mathbf{(2.3)}$$

However, IRR has its own disadvantages and it is not reliable enough to predict profitability of an investment due to several problems associated with it. (Jenkins & Harberger, 2011) Described these problems as:

1. Since IRR calculated as root of mathematical equation, in the projects such as road project some major items of equipment must be replaced from time to time so the cash flow undergoes through major geometric or arithmetic gradient costs it may not be possible to determine a unique internal rate of return for those projects.
2. In comparing between two or more mutually exclusive project the IRR ignores the difference between scales of and length of life of the projects. Also in choosing among various alternatives with different starting times regardless of similarity in their length of life IRR could be considered misleading criterion.
3. In some cases irregularity of the cash flow between alternatives which is common situation in project finance arrangements could also cause issues once IRR considered as prime criterion in comparing different alternatives together.

Modified internal rate of return (MIRR) however solved some of the problems associated with IRR since it defined as the actual IRR, wherein the reinvestment rate does not correspond to the IRR. MIRR is used to rank various investments in equal size; and it is calculated using following formula:

$$\mathbf{MIRR==\sqrt[n]{\frac{F(POSITIVE\ CASH\ FLOW\times COST\ OF\ CAPITAL)}{P(INITIAL\ OUTLAY\ \times FINANCING\ COST)}}-1} \qquad \mathbf{(2.4)}$$

Numerator refers to future value of positive cash flow at the cost of capital and denominator refers to present value of negative cash flows at the financing cost.

✓ Benefit cost ratio (BCR): it is also known as profitability index which calculated from dividing Present value of cash inflow (benefits) to present value of cash out flow (costs) by taking into account an opportunity cost of fund as the discount rate. It will indicate the profitability of the project once the BCR value is greater than 1. also among variety of mutually exclusive projects the one with highest BCR is more acceptable. Although it can be used solely as an indicator for accepting the project or choosing among different projects yet this criterion has its own limitation for instance, it could be misleading while dealing with project with different size or perhaps as its most distinguishing drawbacks, it is highly sensitive to the way in which Costs are defined in setting out the cash flows (Jenkins & Harberger, 2011).

✓ Payback period: in general, it indicates the number of required years for the net cash flow to repay the capital investment. The shortest the Payback period the sooner project will reach to breakeven point and initiate profit making process. Although due to not taking entire future cash flow into account there has been some criticizes on adopting payback period as an criterion to evaluate an investment but it is still known as one of the most commonly used methods among organizations since it is being widely applied and easily understood (Awomewe & Ogundele, 2008), yet, as a matter of fact relying on this criterion only, could make so many complication when it come to the point that investors required to assess the case of investment with long life. However, it has been used by private sector as an investment criterion to evaluate the risk level in instable countries from political or economic point of view. Payback period in its simplest for calculating how many years it is required for the undiscounted cash flow to repay the investment (simple payback period) and in its more sophisticated form it considers discounted cash flow (discounted payback period) to compute the required years to repay an investment. Since in retrofitting investment, investors are more enthusiastic to receive their capital investment as soon as possible, therefore payback period is one of the permanent investment indicators in evaluating the investment among investors for instance an study on public school in Rome the authors calculated environmental benefits achieved as a result of planned activities based on payback period (De Santoli, Fraticelli, Fornari, & Calice, 2014) or in the research conducted by European project Republic-ZEB, this criterion offered as a package to promote not only energy-efficient, but also cost-effective technical solutions (Corrado, Murano, Paduos, & Riva, 2016). There also has been other examples of the research on the same area of interest using payback period in investment evaluation by (Kim, 2017) and (Matic, Calzada, Eric, & Babin, 2015) which has been provided by (Gorshkov, Vatin, Rymkevich, & Kydrevich, 2018).

So far all the basic characteristics of diverse commonly used financial analysis methods have been described in detail, however according to (Energy & Guide,

2015) there are additional consideration must be taken into account when choosing among these methods :

- In some of these methods energy saving and financial impacts are interrelated thus it could cause skewing in the analysis if double counting saving is not considered accurately.
- Since furcated cash flows are dependent with dynamic variables such as energy price, inflation rate and so on. A sensitivity analysis that accompanied by risk analysis may reveal the most critical variables and their impact on project final value.
- The section of the existing approaches to evaluate the project should be based on how a decision maker is comfortable with that particular method.
- LCC method due to its realistic portrayal of project economics and its rigorous steps in accounting both cash inflows and outflows over the analysis time known as one of most appropriate approaches among others while the cases are among mutually exclusive alternatives. However in non-mutually exclusive alternatives NPV and MIRR approaches ensures the highest and best use of limited capital.

Chapter 3

TECHNICAL ASSESSMENT

3.1 Introduction

In this chapter energy consumption of the building for both base case scenario (existing building) and post retrofitted scenario for each retrofitting alternative is calculated. Through this chapter thermal stimulation software (Design Builder) is utilized to create a thermal modeling prototype from existing building by considering the collected information on building's situation through building's inspection. Henceforth the result from thermal stimulation software is validated by making comparison with actual energy bill consumption for existing building. Once the model is validated in the next step performed is to select a set of alternatives as energy retrofitting measures. Aforementioned alternatives have been chosen based on governing constraint of an institutional building and to improve existing impaired and sensitive component of the buildings which have the most contribution in terms of heat transfer in the building. At the end energy consumption of each retrofitting alternative is calculated using the thermal model and the result is fed into financial analysis as energy requirement of the building to eventually obtain the operational cost of the building.

3.2 Technical and Financial Assessment

Energy efficiency potential in the buildings could be evaluated through technical and economic assessment. As it defined by (Belzer, 2009), technical potential of the buildings refers to the amount energy conservation occurred from application of technically feasible measures from an engineering point of view while Economic potential of the buildings comprises assessment of economic and financial feasibility of those measures which already proven to be technically feasible.

3.2.1 Prerequisites of Building's Technical Assessment

Disclosing the technical retrofitting capacity of the case study will fully dealt in this chapter in detail but as foreword for each retrofitting measure feasibility analysis, three prerequisites of holistic site description, geographical and climate's circumstances of the area and the thermal regulation governing the country must be taken into consideration which the following will be explained.

Site description: With respect to previous statement the technical and economic evaluation of institutional building has been performed through the use of department of civil engineering in Eastern Mediterranean University (EMU) as a case study. The Department of Civil Engineering is located in Famagusta (eastern region of North Cyprus) within the main campus of the university with total of 8660 meters square area which approximately 6000 meter square area of the building is considered as covered area. The building is built in three consecutive years from 1996 to 1998 in three different periods. In the first period in 1996, 3600 meter square of the building was built and in second and third period from year 1997 to 1998 respectively 2682 and 2378 square meter constructed. It is comprised of three floors which accommodate nearly 800 students and staffs as of today rate of occupancy and facilitated with offices, classrooms, laboratories, computer centers and other facilities associated with the program. The perspective view of case study building is illustrated using actual picture taken from the site and modified AutoCAD plan which was provided by technical authorities of the building. Following building's schematic are pictured by bird's view facility in Revit architecture software as it shown in Figures 3.1, 3.2, 3.3, 3.4.

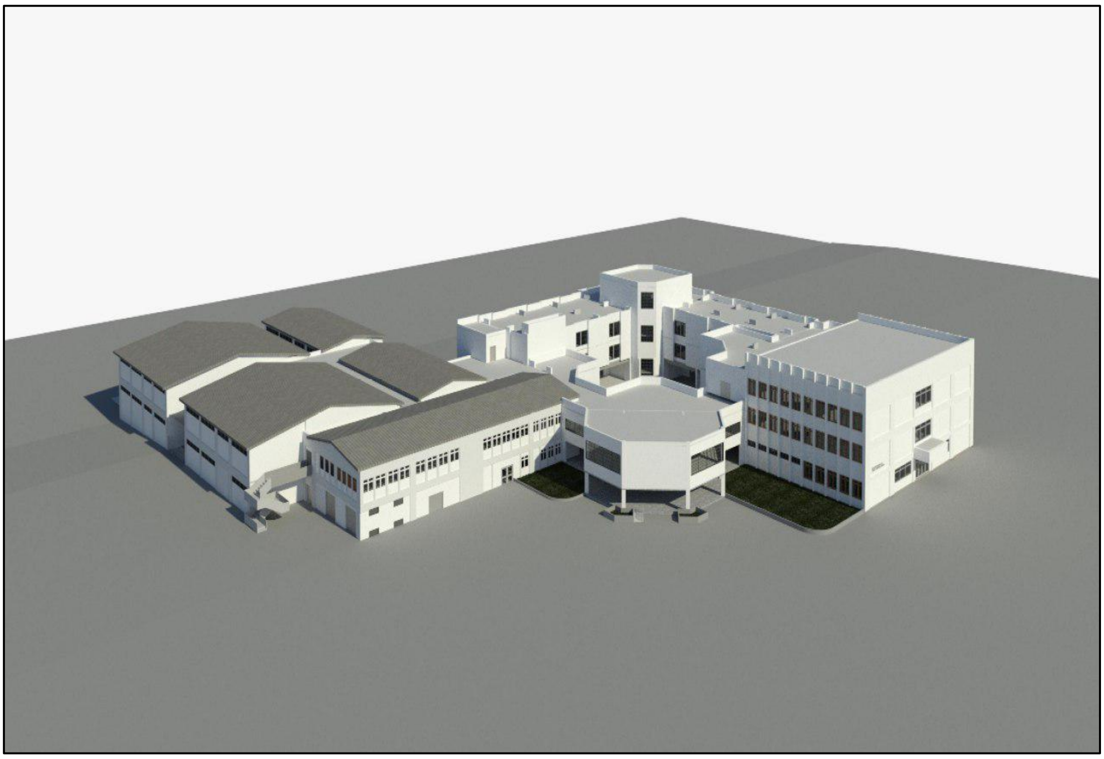


Figure 3.1: South view of civil engineering building

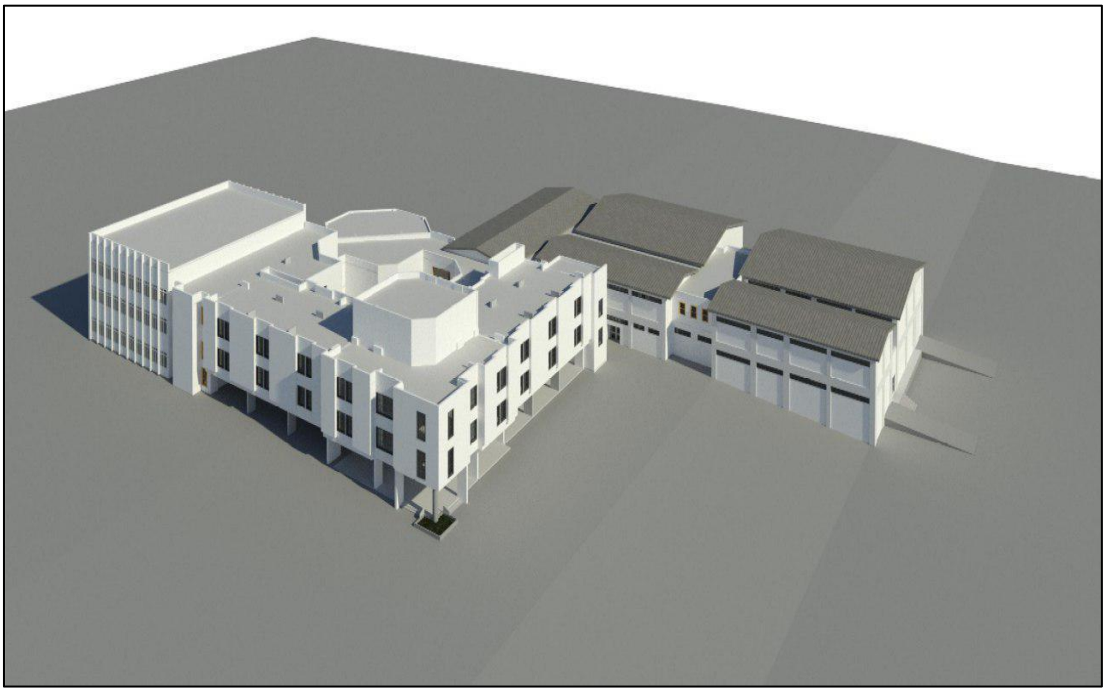


Figure 3.2: North view of civil engineering building

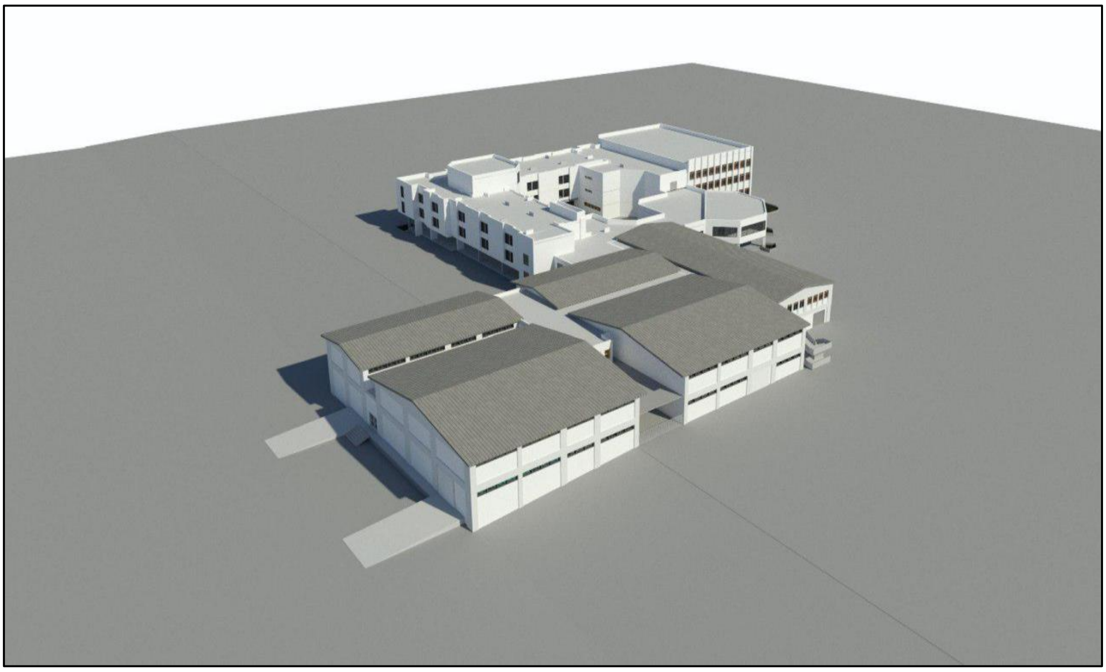


Figure 3.3: West view of civil engineering building

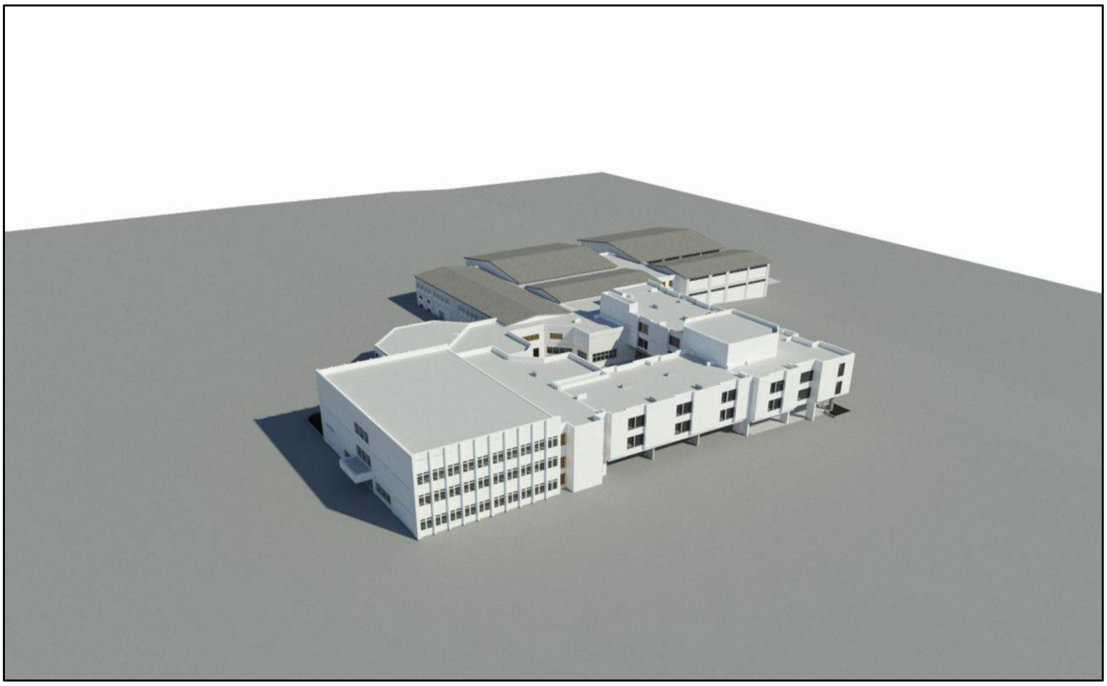


Figure 3.4: East view of civil engineering building

In this study the financial feasibility of proposed retrofitting scenario on the case study will be examined. Since genuine calculation of energy consumption of the case study using software as a first step toward developing retrofitting scenario is highly depends on accurate building's specification and orientation, location coordination and climatic data input of that particular region therefore, following information is provided in detail throughout this chapter.

Climate and geographical coordination: The study is undertaken in Famagusta which is located in east of Turkish republic of northern Cyprus (North Cyprus). Cyprus as a whole included both northern and southern part located in the eastern Mediterranean and considered as third largest island after Sicily and Sardinia. The closest neighbors to Cyprus from the north is Turkey and from south to southwest, Lebanon, Syria, Israel, Egypt and Greece respectively. The coordinates of Cyprus sits on latitude 35 degree north and longitude 33 degree east. Based on Cyprus meteorological service data, the main geomorphological characteristics of the island is classified into four major zone as coastal climatic zone, inland climatic zone, semi –mountainous climatic zone and mountainous climatic zone which the case study placed in coastal climatic zone ("Department of Meteorology - Climate of Cyprus," 2019). The climate of Cyprus according to Koppen-Geiger falls into subtropical (Csa) type and the north eastern region of the island is considered partly Semi-Arid (Bsh) which means Famagusta shows mild characteristics of Mediterranean climate. Maximum dry bulb temperature (DBT) in Cyprus elevating up to 42 Celsius in august and the minimum DBT may drop to -6 Celsius in January .the prevailing wind mostly comes from north-east direction while the most consistent wind direction in Cyprus is from south- west and west, amalgamation of all these characteristic indicates that hot and dry summer and on the contrary wet and moderate winters are known as cohesive climate characteristic of Cyprus which directly affect the energy demand of annual heating and cooling (Ozarisoy & Elsharkawy, 2008) .The first step in building thermal modeling is to define the location and climate condition of the site in the stimulator software. As it already stated, the general information on Cyprus climate is already provided but in order to perform the thermal modeling all the climate information must be converted to an appropriate file extensions to be able to import them into the Design Builder. Therefore the process will be started by extracting the considered site location's climate information from one the accessible software such as energy plus, Metronome or other online website which included that particular location in their data base. In this case climate.onebuilding.org has been used to extract EPW extension for further conversion. In the next step the EPW file extension must be converted to four other extensions include EPW, STAT, AUDIT and DDY to be able to comply with design builder software. This conversion process could be performed using the software called Element. There is also other complementary software which could import climate file with EPW extension from a specific location and provide more detail information on the climate condition and possible energy efficiency measures for that particular location. Climate consultant is one of that software which in this case utilized to provide following information on the case study location and climate.

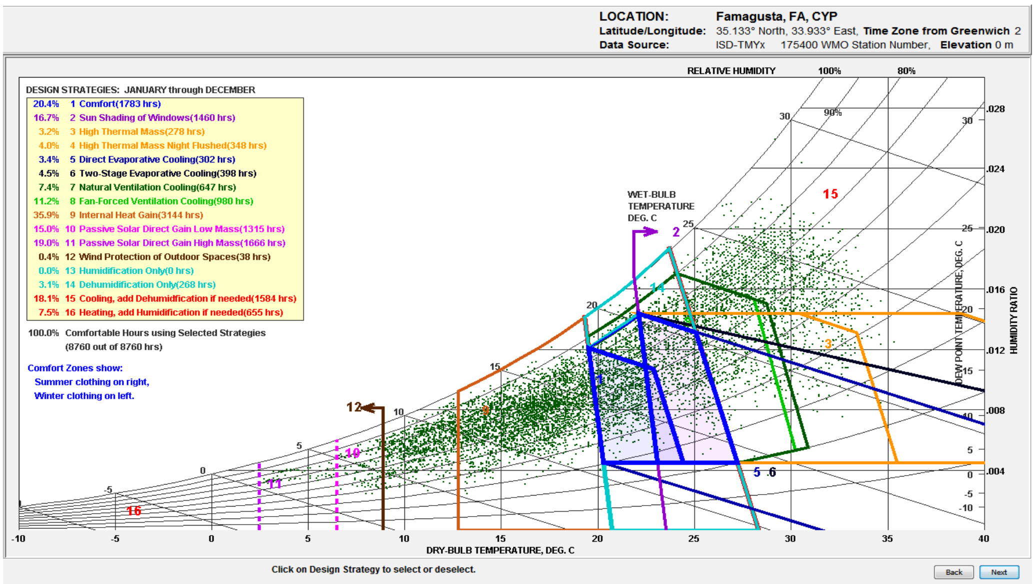
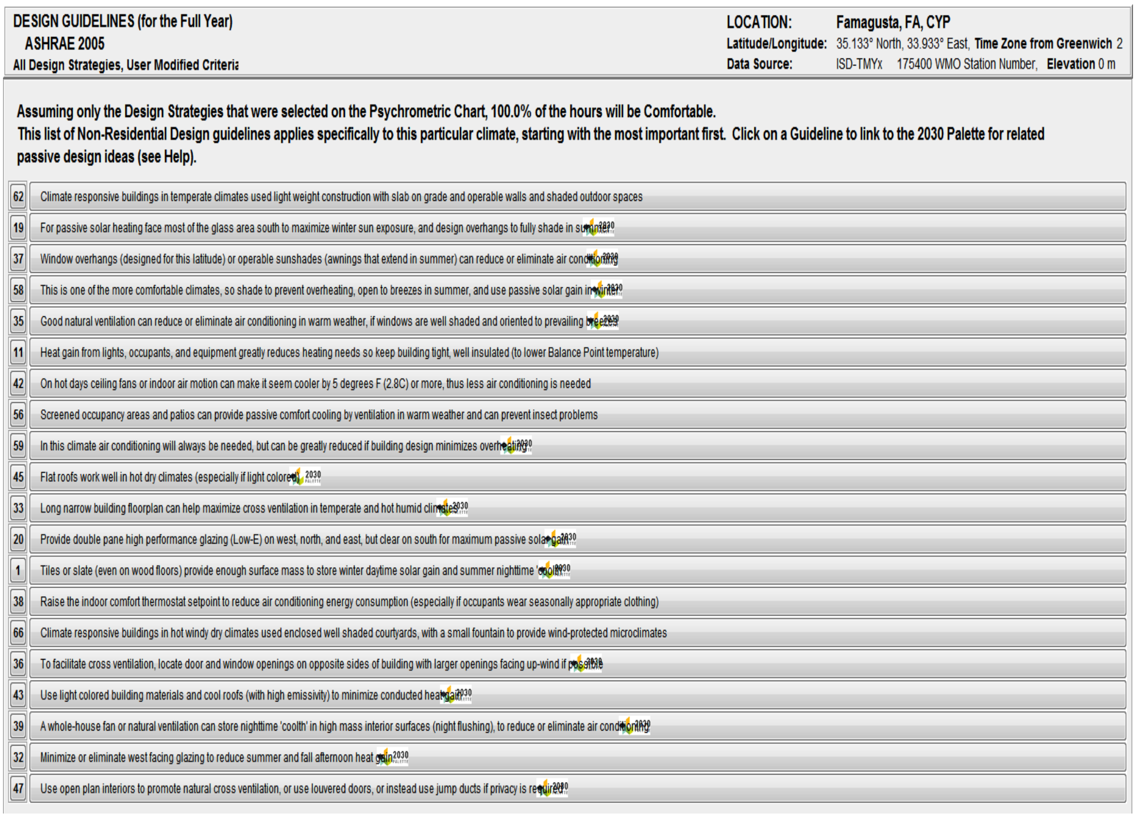


Figure 3.5: Psychrometric chart for Famagusta climate condition

The Psychrometric chart extracted form climate consultant software in Figure 3.5 representing a graphical Psychrometric process of air by considering physical and thermodynamic properties such as dry and wet bulb temperature, humidity and enthalpy. It also provides a list of possible recommended action on energy retrofitting measure with their possible effect on energy conservation using combination of predefined comfort zone in the previous steps which in this case is based on ASHRAE handbook of fundamental comfort model up through 2005 and climatic condition of the site. Also the graph will be followed by a Table of recommended retrofitting measure based on required action which illustrated in Figure 3.6.


DESIGN GUIDELINES (for the Full Year)
ASHRAE 2005
All Design Strategies, User Modified Criteria

LOCATION: Famagusta, FA, CYP
Latitude/Longitude: 35.133° North, 33.933° East, Time Zone from Greenwich 2
Data Source: ISD-TMYx 175400 WMO Station Number, Elevation 0 m

Assuming only the Design Strategies that were selected on the Psychrometric Chart, 100.0% of the hours will be Comfortable.
This list of Non-Residential Design guidelines applies specifically to this particular climate, starting with the most important first. Click on a Guideline to link to the 2030 Palette for related passive design ideas (see Help).

62	Climate responsive buildings in temperate climates used light weight construction with slab on grade and operable walls and shaded outdoor spaces
19	For passive solar heating face most of the glass area south to maximize winter sun exposure, and design overhangs to fully shade in summer
37	Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning
58	This is one of the more comfortable climates, so shade to prevent overheating, open to breezes in summer, and use passive solar gain in winter
35	Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes
11	Heat gain from lights, occupants, and equipment greatly reduces heating needs so keep building tight, well insulated (to lower Balance Point temperature)
42	On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed
56	Screened occupancy areas and patios can provide passive comfort cooling by ventilation in warm weather and can prevent insect problems
59	In this climate air conditioning will always be needed, but can be greatly reduced if building design minimizes overheating
45	Flat roofs work well in hot dry climates (especially if light colored)
33	Long narrow building floorplan can help maximize cross ventilation in temperate and hot humid climates
20	Provide double pane high performance glazing (Low-E) on west, north, and east, but clear on south for maximum passive solar gain
1	Tiles or slate (even on wood floors) provide enough surface mass to store winter daytime solar gain and summer nighttime 'coolth'
38	Raise the indoor comfort thermostat setpoint to reduce air conditioning energy consumption (especially if occupants wear seasonally appropriate clothing)
66	Climate responsive buildings in hot windy dry climates used enclosed well shaded courtyards, with a small fountain to provide wind-protected microclimates
36	To facilitate cross ventilation, locate door and window openings on opposite sides of building with larger openings facing up-wind if possible
43	Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain
39	A whole-house fan or natural ventilation can store nighttime 'coolth' in high mass interior surfaces (night flushing), to reduce or eliminate air conditioning
32	Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain
47	Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required

Figure 3.6: Climate consultant retrofitting measure suggestion

Light weight construction, facing glass area toward south side to exploit solar heating, windows over hangs and operable sunshades and good natural ventilation and all other type of approaches which sorted in ascending form, from the most to least importance are considered as an approach to reduce energy consumption in this climate type and by taking to account the ASHRAE handbook comfort level standards. The other useful features that climate consultant could offer from EPW climate file are temperature range, monthly diurnal averages, radiation range, illumination range, sky cover range, wind velocity range, wind chart and so many other useful features which could be employed in case of necessity. At the end adducing to (Menicou et al., 2015), and the climate characteristic of Cyprus will justifying that, the energy requirements allocation for cooling is considerably higher than heating energy demand where the research indicated more than 50% of total energy consumption is devoted to cooling process and in return 25% of energy consumption used for heating process.

Building energy codes and regulation in North Cyprus: In North Cyprus due to lack of public energy regulation, incentives and guides, whether the aim of retrofitting is simple retrofit (low cost or no cost recommendation) or long term investment (comprehensive energy efficiency capital investment plan), and compatible, flexible and comprehensive guide could not be adopted to clarify retrofit implementation path. Therefore, ASHRAE which is the most well-known organization with more than 5000 members around the world from building services engineers, architects, mechanical contractors, building owners, equipment manufacturer's employees, and devoted to developing and publishing technical standards to improve building services engineering, energy efficiency, indoor air quality, and development, is considered as a major reference in this study unless it is stated.

3.3 Technical Feasibility Assessment

Based on (Clement & Clément, 2012) technical retrofit potential of the building is acquired through four major steps:

Inventory of fixtures: refers to the detailed list of existing appliances, materials and in general current condition of the buildings which could be achieved by following steps: Document collection, Technical visit, Interviews with occupants.

Energy consumption analysis: refers to calculating energy consumption in the buildings which could be performed through either of the dynamic stimulation or spreadsheet calculation which will be explained further in detail.

Recommendation and evaluation on retrofit scenarios: this step alludes to final step of retrofitting alternative proposition with respect to identified deficiencies, via prior steps.

Evaluation of energy demand alteration by applying the retrofitting scenarios on the base case model: proposed alternatives impact on energy consumption will be investigated through either of spreadsheet or building energy software tools.

3.3.1 Inventory of Fixtures (Buildings Inspection Implementation)

Building's orientation, components specification, resident's behavior, managerial approaches and in general all the coherent parameters to the building itself could significantly affect the amount of energy consumption as other involved parameter in calculation of building's energy demand .as a result knowing enough of buildings details for accurate energy demand calculation seems to be inevitable. And as it mentioned earlier in literature review data collection process would be performed through building's inspection as one of the steps of energy audit. It also has to be considered that the depth of detail in information acquired from building's inspection is highly in direct relation with type of contemplated energy auditing process. According to (ASHRAE, 2005) buildings with up to 100000 square feet (up to 9290 square meter) gross area falls to small and medium commercial buildings, nonetheless based on (Jim Kelsey, 2011) the audit level required for buildings with more than 50000 square feet gross area (more than 4645 square meter) is level two, yet, due to aforementioned issues in terms of time, budget and equipment availability and for the ease of calculation, since the prime objective of this study is financial evaluation of proposed retrofit scenario, the building inspection in this study is limited which subsequently will reduce the level of accuracy in both building and appliances monitoring and eventually the energy calculation. Basically inventory of fixtures or building's inspection as it explained before is categorized into three steps:

Document collection: It also called pre-site visit analysis and include collecting and reviewing of building related data including:

- Onsite contacts: it should be including property, facility and technical manager of the building along with maintenance technician.
- Building plans: include any type of paper based sketch up; software based 2D and 3D plan and cross section with all detailed structural, architectural and mechanical specification.
- Construction documents: include construction date and other past renovation related data and reports.
- Envelope information: include information on envelope thickness, layer type and insulation specification of walls, roof and ceilings of the building as well as all doors and windows before actual site visit from the concerned authorities.

- Equipment information: it could be including all equipment specification, age, brand name which existed in the building before actual site visit from the concerned authorities.
- Historical energy use data: comprised of at least one-year energy bills (electricity, gas, oil and etc.) for benchmarking and output validation.

It is notable that according to practical experiences and as per simple rule of thumbs, the older the building is the tougher collecting in depth and accurate documents about it. Since energy efficiency was not a key issue in the past, all related document was not present. Therefore extracting the precise information on some hidden area of the building (such as building envelope) is out of the question or it is required destructive and exhaustive examination. hence part of the calculation which is associated with these key data had to be performed based on assumptions which was handicapped the entire study and eventually jeopardized the result:

1. The technical affair department is in charge of all the technical, property and maintenance management of the university. Technical and maintenance management's contacts of the case study have been collected.
2. AutoCAD design of the case study in 2D collected. There have been so many required modifications in plan and cross section design since the AutoCAD design was sketched from building condition in 1997 and the building was under major construction back then. But through building inspection most of changes applied to the new plan and cross section design with intermediate accuracy. There were no available documented information on Structural and mechanical specification of the building and all the information obtained from interviews conducted with technical authorities. The ground floor's plan as

well as detailed information on the area of each zone as an example is provided in Table 3.1 and Figure 3.7.

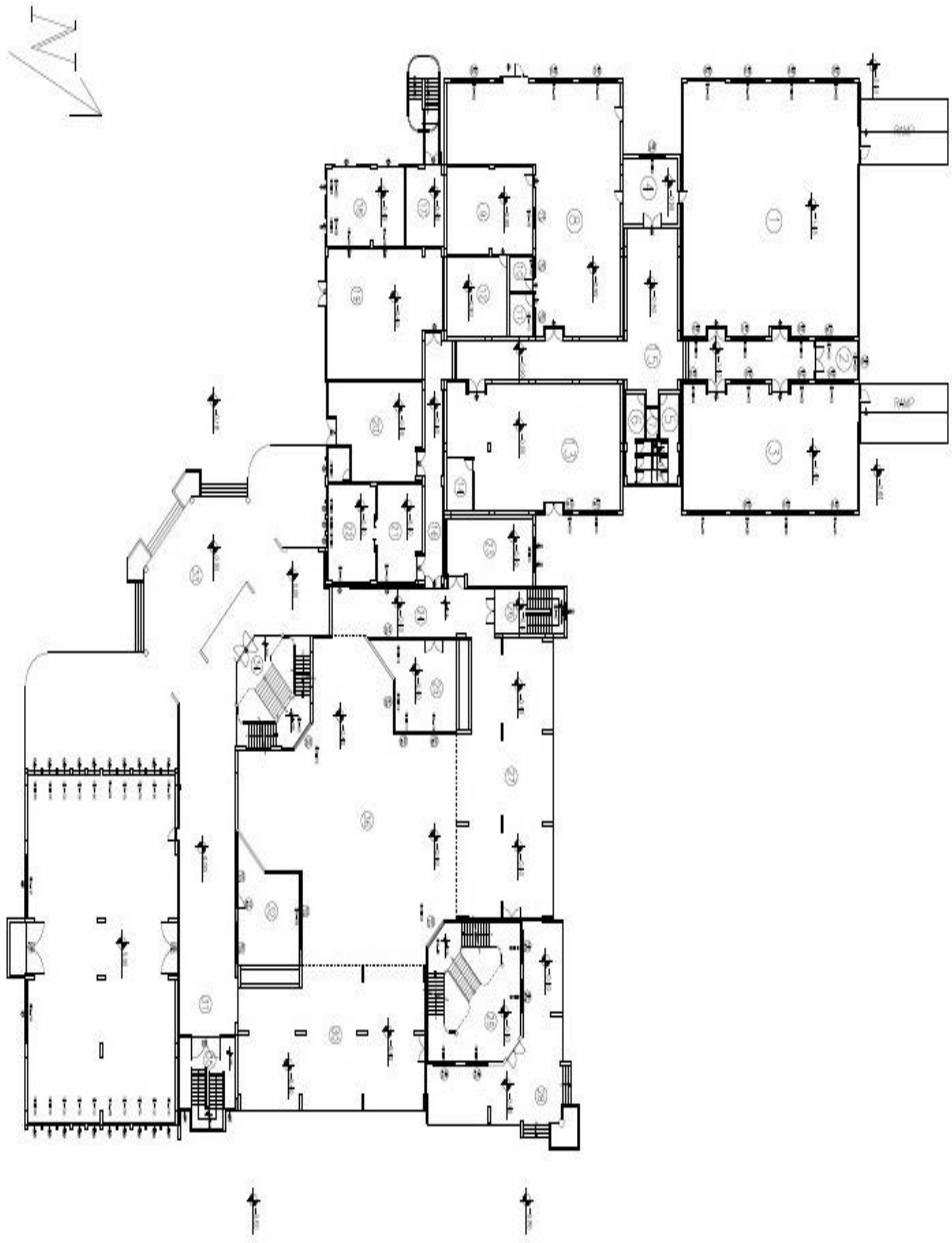


Figure 3.7: Ground floor AutoCAD plan

Table 3.1: Ground floor inspection (Area m2)

Zone number	1	2	3	4	5	6	7	8	9	10
Zone application	**Structural lab**	**Storage**	**Material lab**	**Office**	**Wc**	**Wc**	**Kitchen**	**Soil lab**	**Soil lab**	**Office**
Area	**371**	**14**	**184**	**30**	**16**	**16**	**4**	**378**	**62**	**7**
Zone number	11	12	13	14	15	16	17	18	19	20
Zone application	**Office**	**Soil lab**	**Transport lab**	**Empty room**	**Corridor**	**Corridor**	**Storage**	**Electrical room**	**Mechanical room**	**Surveying lab**
Area	**8.5**	**41**	**184**	**11**	**178**	**36**	**24**	**51**	**69**	**78**
Zone number	21	22	23	24	25	26	27	28	29	30
Zone application	**Classroom**	**Research office**	**Classroom**	**Corridor**	**Computer room**	**Staircase**	**Parking**	**Parking**	**Staircase**	**Parking**
Area	**36**	**39**	**47**	**70**	**55**	**27**	**217**	**122**	**110**	**218**
Zone number	31	32	33	34	35	36				
Zone application	**Corridor**	**Printer room**	**Front door corridor**	**Staircase**	**Staircase**	**Open space**	Total	**3651.5**		
Area	**155**	**56**	**215**	**65**	**38**	**419**				

3. The exact construction year as it already mentioned which is between years 1996 to 1998 so the building is estimated to be 22 years old. According to technical affairs authorities there was no major refurbishment process conducted on the building within these years.
4. According to the contractor of building from technical affairs, three categories of wall have been recognized which comprises of external walls that surrounded entire building and made of clay blocks with 15 cm thickness, first coating of cement plaster of 3 to 5 cm, finishing coating of cement plaster up to 2 cm and finally very thin layer of normal paint. Internal walls that covers the inside area of the building except office areas and built from clay blocks, cement plaster of 3 cm and gypsum plaster of 2 cm maximum. And as a last type of wall, partitioning walls are including for separating office area from each other which made of aerated concrete blocks with 10 cm thickness and gypsum plaster or gypsum board up to 2 cm which directly applied on concrete block surface. Floors components are entirely identical for whole floor areas in the building and built from concrete slab with 15 cm thickness as a floor base that covered with up to 5 cm of sand for piping protection and leveling the floor area. Above this layer there is maximum 2 cm of mortar which will be covered by 4 cm thick mosaic. Ceilings are entirely covered by gypsum plaster with 2 cm thickness which directly applied on concrete slab in most of the area. But apart from the ceiling in floors, corridors in office and lab areas are cover with PVC suspended ceiling in all three floors. All the roof tops in open areas covered with a leveling concrete which applied on concrete slab and a single or double layer of water insulation membrane with less than 1 cm thickness. Apart from the staircase and office areas which covered with typical UPVC

double glazed windows the rest is UPVC single glazed. The doors are normally from either of typical wooden doors or aluminum glass door partitions. There was no particular information obtained from technical authorities on building's equipment and HVAC related data.

5. Electricity bills collected for entire year 2018 which was provided as an excel sheet with kilowatt hours (KWH) of electricity consumption for each month. Since electricity bills delivered as one excels sheet for five different departments and a health center for one year, distinguishing the amount of electricity consumption for the case study as an exact amount seems to be impossible. The same issues applied to LPG bills which provided by technical affair in Liter purchased of LPG along with the unit price which is fixed price, this time but the gas consumption bill covers four engineering department and health center and that is because mechanical department heating system's energy source is just electricity and not the combination of gas and electricity like other engineering department's building so it is excluded from the bill. Therefore in order to validating acquired building energy consumption through software as base case scenario, some assumptions must be taken into account which will be explained in detail further. Tables 3.2 and 3.3 demonstrated the actual electricity and LPG bills.

Table 3.2: Electricity bill for year 2018 (Kwh)

Electricity consumption (KWH)	
January	88000
February	66000
March	14000
April	114000
May	122000
June	114000
July	146000
August	140000
September	116000
October	142000
November	82000
December	78000
Total	**1222000**

Table 3.3: LPG invoices for year 2018 (TL)

LPG purchased price (TL)	
January	8565
February	6555
March	29305
April	86132
May	0
June	0
July	3581
August	0
September	0
October	0
November	0
December	66056
total	**200194**

It is notable that for LPG bills, the only information which is provided is the amount of purchased and the provided information does indicate neither the amount of consumption nor the duration of consumption.

6. The entire building constructed for educational purposes, so from the site occupation distribution it is 100% occupied by students, faculties and administrators. The area reparation of the building is as follow: the total covered area of the building is 7100 square meter in which corridors, laboratories and classrooms with 2308, 1436 and 1138 square meter allocated with maximum area from the total area and respectively staircases, lavatories

and kitchens with 448, 232 and 34 square meter have the least allocated area among others. An appropriate solution for energy auditing when it come to the point of calculating building energy demand is to considered all existing zone in the building with an equal amount of occupation and activity distribution. In the following doughnut chart in Figure 3.8 the distribution of each area of the case study is illustrated by means of both square meter (inner circle) and percentage from the total area (outer circle).

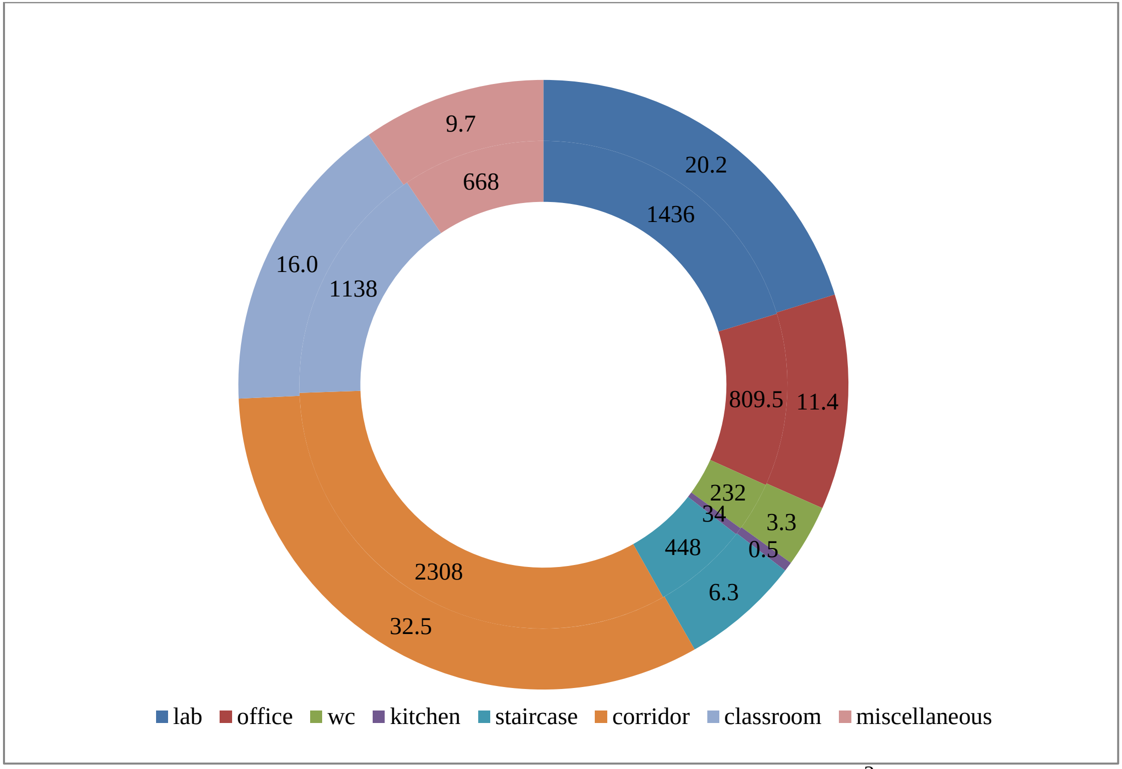


Figure 3.8: Area distribution in civil engineering building by m^2 and percentage

Technical visit: also called site visit, it is an opportunity for an auditor to observe the building closely and collect required data on-site. During the technical visit auditor will complete building inspection whether it is walkthrough inspection using basic building performance tracking by filling out the templates audit form , evaluating energy appliances and equipment in the building , taking photo or more exhaustive type of building inspection beyond the basic to take greater control over building's energy performance and find out energy system interrelations with the help of more sophisticated tools and equipment (Friedman, Crowe, Sibley, & Effinger, 2011), (Energy & Guide, 2015) and (Clement & Clément, 2012) indicated that there are 7 major building's characteristics such as wall, roof, floor, doors and windows structure as well as lighting and HVAC system specification, which have to be investigated during the technical visit of the building.in this inspection but along with detailed characteristics of these 7 major elements constituent content , there are other parameters that must be taken into consideration to facilitate energy auditor in order to evaluate building actual energy consumption. Due to direct connection of building's envelope and outside environment, heat transfer constantly occurs between both the surfaces. Therefore taking control over heat transmission in building will play crucial role in increasing the level of comfort and subsequently decreasing the energy demand and cost. In office buildings the impact of consumed material in building's envelopes is even more vital due to additional environment requirement such as more illuminating spaces, occupancy level and etc. which distinguishes these types of building into more sensitive building to the outdoor climatic conditions compared to buildings with different functions. As a matter of the fact thermal properties of buildings materials such as material type, insulation type and envelope component thickness ranked as one of the most significant value in terms of calculating thermal conductivity of the building (Masoudeh Nooraei & Farshad Nasrollahi, 2013). It is concluded by (Panayiotou et al., 2010) that, 80% of total building envelopes in Cyprus do not apply thermal insulation at all that simultaneously could affect the level of heat transmission in the building and hence the energy demand.

In order to perform thermal modeling of the building and eventually calculates energy demand there are certain parameters as an input are required. One of the most significant information while performing an inspection on envelope structure is to identify the U value of particular envelops component. U value refers to heat transmission measure of that particular envelope element (W/m^2K). The lower U value is the better insulation properties of specified component. The amount of U value could be calculated using other parameter which called R value as follow.

$$\textbf{U value} = \frac{\mathbf{1}}{(\textbf{sum of all R values for each component})} \qquad \textbf{(3.1)}$$

R value as a resistant index refers to measure of resistance to the flow of heat through given material(m^2K/W) and unlike U value, increasing in R value represents better insulating property and controlled heat and cool transmission as a result. The R value itself could be calculated from thermal conductivity of each material that sometimes refers as λ value.

$$\textbf{R value} = \frac{\textbf{thickness of each layer}}{\textbf{thermal conductivity of that layer}} \qquad \textbf{(3.2)}$$

The λ value indicated the measure of the rate at which temperature differences transmits through the material (W/mK). So the less thermal conductivity of building's material the less energy demands to maintain comfort condition. In order to calculate the U value of each envelops segment, necessarily the λ value of constituent components of that particular segment must be taken into account. It is remarkable that building energy consumption in this study as it previously mentioned is calculated using energy stimulator software which will be described in detail afterward. This software as thermal modeling software automatically calculate the corresponding U value for each component using predefined thermal conductivity values , thickness and type of consumed material. The λ value varies depends on type, density and surrounding temperature of material, since the case study does not provide any archived information on material specification, hence some assumption have to be made in order to specify thermal conductivity for energy stimulator software. (the engineering toolbox, 2003) Provided thermal conductivity for typical material in the building structure which summarized according to our case study requirement in Table 3.4 and respectively the U values of each element combination which forms envelope components will be derived through energy modeling software which subsequently will be explained in detail:

Table 3.4: Thermal conductivity for building's material (the engineering toolbox, 2003)

Material	**λ value (W/Mk)**
Clay blocks medium density	0.38
Clay blocks high density	0.44
Aerated concrete block	0.18
Cement mortar	0.72
Cement plaster	0.9
Gypsum plaster	0.7
Gypsum plaster board	0.3
Floor tiles	1.5
Parquet	0.27
Concrete	1.3
Glass	0.93
Wet sand	0.6

As far as onsite inspection of case study concerns, using nondestructive or semi destructive experiment and thanks to the parts that already was exposed due to the material breakdown and lack of building maintenance in the building, aforesaid characteristics have been analyzed and the summarized results are as follow: walls , roofs and floors structure: although most of the wall in all interior, exterior and partitioning types are the same but during onsite inspection it is observed that there are still walls from the same category with different constitutive element which could be as a result of material inefficiency substituted instead of typical material in the rest of the walls. Hence due to their slight impact on energy consumption in total, the assumption made based on the similarity of materials component on each category of building's envelope.

Table 3.5: Building's envelope components

envelope structure	envelope type	envelope component	remarks
wall structure	Exterior wall	Clay blocks, cement plaster 3 cm , finishing cement plaster 1 cm , paint	Heat insulation is provided
	Interior wall	Clay blocks, cement plaster 2 cm , gypsum plaster 2 cm, paint	no insulation have been found
	Partitioning wall	Aerated cement blocks , gypsum plaster board 2 cm , paint	no insulation have been found
roof structure	ceiling	Concrete slab 15 cm , gypsum plaster 2 cm , paint	no insulation have been found
	rooftop	Concrete slab 15 cm , mortar 3 cm , damp roof membrane 1 cm	water resistant insulation
floor structure	floors	Concrete slab 15 cm , sand 5 cm , mortar 2 cm , mosaic 4 cm	no insulation have been found

Table 3.5 summarized envelope's components based on the categorized envelope's structure.

Openings structure (doors and windows): two general type of windows identified in the building in which the frames are made of UPVC material with 6 cm thickness and without any thermal breaks to improve energy efficiency by controlling heat transfer between indoor and outdoor environment. window's glass but classified into two major group which includes offices and main staircases and classrooms covered with double glazed windows which may improve energy saving, reduce moisture condensation and noise pollution at the same time by trapping the heat in winter and unrepaired ability characteristic of these type of glasses they could cause several issues .and the rest of the area mainly covered with single glazed windows. Doors in the building are majorly typical wooden doors with mainly 3 to 4 cm thickness including skylight frame on top of the doors for all offices, classroom , labs and lavatories also there are some aluminum doors embedded in hallway intersection where it connect to corridors or the rooftop. Table 3.6 summarized opening's structures of the building.

Table 3.6: Building's opening components

opening structure	**opening type**	**openings component**	**remarks**
windows structure	single glazed	UPVC frame 6 cm , single glazed	no thermal break or insulation
	double glazed	UPVC frame 6 cm , double glazed	no thermal break with insulation
doors structure	aluminum glass	aluminum frame 5 cm , single glazed glasses	no thermal break or insulation
	wooden	wooden doors 4 cm thickness , top skylight frame with single glazed	no thermal break or insulation

HVAC (Heating, ventilation and air conditioning) structure: HVACs are alone accountable for up to the 50% of energy consumption in the buildings (Pérez-Lombard, Ortiz, & Pout, 2008) and according to (Australia Government, 2013) HVAC energy consumption breakdown is as Figure 3.9.

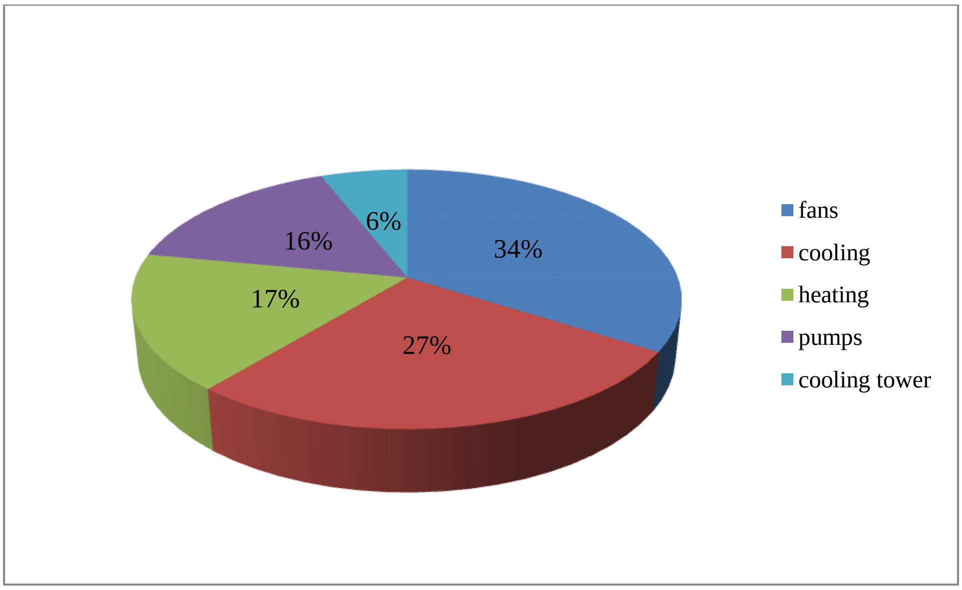


Figure 3.9: HVAC energy consumption breakdowns

And also based on the study on Cyprus dwellings 23% of entire energy consumption of the buildings allocated to heating procedure and 51% assigned for cooling process which is directly related to the climatic condition of the region (Menicou et al., 2015). Therefore HVACs as a prime source of energy consumption in the buildings has great potential in implementing energy efficiency measures.

Heating system: the heating of the site is supplied through two liquid gas fuel low pressure heating boiler (since the boiler pressure is less than 80 bars) that installed in the ground floor on year 2013.the LPG gas which stored in the tanks outside the building will instilled to the combustion chamber that could rise the heat to several hundred degrees in very short time and boil the water inside the boiler tank up to the level that thermostat allows and from that point onward, heated water will be transferred through appropriate pipe size Burner with a pump pressure partially toward the air handling unit (AHU) on the roof top which will direct it to amphitheater and the other part transferred directly toward fan coils inside the offices and classrooms .it is notable that regardless of significance of all the elements involved in heating system , boilers and AHU details as two major components of heating system in the buildings have great potential in performing energy conservation measure, hence, in order to propose energy retrofitting measure on heating system of HVACs on later stages the specification of boilers and AHU in case study is demonstrated as Table 3.7.

Table 3.7: Boiler and AHU specification

Boiler specification		
Capacity	800000	Kcal/h
Operating pressure	5.2	Bars
Rated output power	930	Kw
Design pressure	6	Bars
Test pressure	8.5	Bars
Flow temperature	90	Degree C
Return water temperature	70	Degree C
AHU specification		
Heating load	40	Kw
Cooling load	59	Kw
Asp air Debi	6600	m3/h
Motor power	1.5	Kw
Van air Debi	6600	m3/h
Motor power	0.75	Kw

Since the major components of each central heating system using water circulation are comprised of boilers (to heat the water in the system) , water pump (to circulate heated water) and fan coil (to release the heat into the a air) and in order to operate each component consuming different type of fuel (electricity , gas or oil), therefore to measure more accurate monetary index for heating energy consumption the assumption has to be considered to allocate a ratio of total energy consumption to electricity and LPG as two different source of energy which consumed in case study heating system. In this study out of three major components that will generate heating, pumps and fan coils operate with electricity and boiler is operating with LPG. To allocate specific percentage of total energy consumption to electricity in heating system, the average of electricity consumption in traditional fan coil has been considered as 0.06 KW/h and for water pump it is 3 KW/h. the following rough calculation indicates the ratio of electricity consumption in heating system:

Number of fan coils in the building: 137, Number of water pump in the building: 4, Operational hours per day for fan coils: 6, Operational hours per day for pumps: 9, Total electricity consumption for fan coils:

$$\boldsymbol{E_f}\left(\frac{\mathbf{kw}}{\mathbf{h}}\right) = \mathbf{AVG}\ \boldsymbol{E_f} \times \boldsymbol{N_f} \times \mathbf{OH}_{\boldsymbol{f}} \qquad \textbf{(3.3)}$$

It will be approximately 6411 Kw for entire cold season.

$$\boldsymbol{E_p}\left(\frac{\mathbf{kw}}{\mathbf{h}}\right) = \mathbf{AVG}\ \boldsymbol{E_p} \times \mathbf{N}_{\boldsymbol{p}} \times \mathbf{OH}_{\boldsymbol{p}} \qquad \textbf{(3.4)}$$

And will become nearly 14040 Kw for pumps. So the total energy consumption from electricity is 20451 Kw which yield almost 17.87 % of total energy consumption for heating procedure in building (114425 Kw).

Cooling system: the entire building's cooling system operates based on three air cooled chiller units which comprised of total 13 reciprocating compressors, 3 condensers, 26 fans and evaporators. Air cooled chillers located outside the building since they dump the unwanted heat straight to the ambient atmosphere. . the major principle of cooling system based on chilling the water where they entering the chiller with environment's temperature and will be cooled down to almost 2 degree Celsius from that point , chilled water will direct to fan coil units (FCU) or air handling units (AHU) using main pumps . By the time they reached to FCUs or AHUs the waters temperature will rise up to 6 degree Celsius and the rest of cooling procedure will be done by the help of FCUs or AHUs located in the building. Table 3.8 indicates all three cooling units' specifications:

Table 3.8: Cooling system specification

Unit number	**1**	**2**	**3**
Number of compressors	5	2	6
RLA	44.9 (1)-46.8 (1)- 65.5 (3)	67.9 (2)	46.8 (3)-65.5(3)
LRA	134 (1)-152 (1)-207 (3)	207 (2)	152(3)-207 (3)
Refrigeration system	60.3 and 62.1 kg	23.6 and 24.5 kg	69.4 and 73.5 kg
Number of fans	10	6	10

Ventilation system: the concept of ventilation in the buildings refers to an intentional provision of fresh air to the building in order to maintain indoor air quality by diluting indoor contaminations, providing oxygen for breathing and removing CO2 from breathing out, excessive heat removal and so on as well as increasing thermal comfort and dehumidification. The introduction of fresh air into the building could be provided by either of mechanical, natural or combination of both known as hybrid ventilation system. Mechanical ventilation is defined as a ventilation of the building using mechanically powered equipment such as motor driven fans and blowers while natural ventilation refers to introduction of fresh air through three major principles as wind driven cross ventilation, buoyancy driven stack ventilation and finally single sided ventilation with the help of intentional embedded opening in building envelope such as doors, windows , chimneys and etc. (Emmerich, Dols, & Axley, 2001).

Hybrid ventilation with combining the manually or automatically controllable openings like windows along with some form of mechanical ventilation system if installed appropriately may ensure consistent supplementation of fresh air into the building and energy conservation as well (Russell, Sherman, & Rudd, 2007) From another point of view the ventilation system could be categorized as exhaust, supply or balanced ventilation system, where exhaust ventilation system using depressurization (reducing the inside air pressure below outside air pressure) extract indoor air along with its moisture specifically in summer and perform infiltration through unintentional or intentional connective area into the outdoor environment. On the contrary supply ventilation system performs with pressurizing principle and will use the fans to force outside air into the building and meanwhile balanced ventilation system neither pressurize nor depressurize the building, but will equalize the quantity of fresh outside air and polluted inside air (Hometips, 2015).

The ventilation system in the case study is somehow a combination of hybrid and balanced ventilation system, where since most of the area in the building covered by windows, they ensure fresh air supplementation throughout the year on the other hand the fan coils operate as exhaust ventilation system to withdraw pollutants and moistures from indoor air. Also an air handling unit will supply enough fresh air for more crowded area such as amphitheater to form a balanced ventilation system in the building.

Lighting system: building entire areas are randomly equipped with either of three different form of lighting, T8 fluorescent tubes, high efficiency standard or reflector incandescent and compact fluorescent lamps (CFL). Form the total 467 existing lights in the building 154 (32%) is from classic or CFLs from 16 up to 75 W and the rest is from T8 fluorescent tubes from 16 up to 36 W. It is also has been notice that in three major connective corridors and 4 toilets motion detector sensors has been installed which are mainly out of service. Finally all the collected information from technical visit will be applied on stimulating software to prepare accurate model of existing building.

Interview with occupants: to initiate the building modeling stimulation the third prerequisite is to conduct interviews with staffs, and key management personnel to observe how building is used, operated and managed on daily basis and subsequently identifying the potential energy saving through alteration in occupants behaviors and management system (Gul & Patidar, 2015). It is also recommended that the depth and details of interview is subjected to the type of energy audit. For example, the interview performed in level II energy audit in compare with walkthrough audit must be more in detail. In this study two type of interviews are carried out which are interview with technical or facility manager of the building to find out schedule planning, technical planning of the building, and also an occupants behavior interview performed, to explore how the behavior of occupants will affect the energy consumption pattern of the building and eventually discover the deficits in occupants and technical managers behavior. As a result based on conducted interviews with both the parties following result is concluded.

From the occupant’s behavior point of view:

- Most of the windows in office areas will left open during working hours while the air conditioners are still working.
- The heating system is maximum set on 30 degree but selecting temperature is manually done in each area. Since during the year the windows will left open specially in the offices so the room temperature rarely reaches to 30 degree to stop heating process and eventually lots of energy will be wasted during operational hours to keep the room in specified temperature. The same issue applied to cooling system where the minimum temperature could be set on 16 degree but due to aforementioned problem the room temperature never reaches the desirable amount and cooling system will continuously working all day long.
- There is no supervisor for checking the building for lights, appliances or ACs once the operational hours is finished.
- Some of the occupants witnessed that Building’s elevator runs automatically after working hours also some of motion detectors in the corridors are out of order.
- There are too many lighting bulb or tubes are out of order and maintenance of the HVACs are rarely performed on scheduled time.

From the technical management points of view:

- In the lighting system due to shortage of motion or lighting control devices occasionally will left on.
- There no set point for lighting, cooling, heating and ventilation system.
- The heating and cooling system will be shut down by the end of operational hours each day.
- Since the heating system start only once the cooling system completely shut down for the year hence there will not be any overlapping on cooling and heating process.
- The working hours in the building officially starts at 8:00 and finishes at 17:00 for the majority of employees and students.
- The lunch break will take about an hour from 12:00 to 13:00 .at this period most of the offices and classroom is empty but the light, air conditioner and other appliances in the offices will left on.
- During the week, each day about 30% of total classrooms and labs are occupied by students in average.

The collected information through occupants and technical manager's interviews could be either used as an input for building's thermal modeling or considered as a potential area for energy conservation and retrofitting proposition.

3.3.2 Energy Consumption Analysis

Building energy analysis refers to whole building excepted energy demand with respect to building's geometry, climate, type, envelope properties and its active systems such as HVAC and lighting. There has been so many studies on energy analysis approaches, for instance in 1997 The Association of Engineers in Climate, Ventilation and Cooling (AICVF), proposed a guideline for feasibility study and general decision making in nonresidential buildings. In this guideline the energy analysis approaches were classified into three general groups as approximate assessment, detailed assessment and Dynamic stimulation (Visier & Sesolis, 2003) where approximate assessment was based on professional practices using very few fundamental parameters and detailed assessment method was more sophisticated which required computer calculation and possibly spreadsheet software that employed larger number of sensitive parameters that could influence the amount of energy consumption in comparison with approximate assessment. In compare with conventional approaches the dynamic stimulation method were enable investors and analyst to consider the interrelation effect of different parameter on each other and on the output together, along with numerous other features that could increase the accuracy of energy demand prediction.

In this study the main concentration would be on dynamic stimulation approaches and the recent development in thermal modeling software. Recent attention on building energy retrofit generated a wide spectrum of energy evaluation tools by public, private and utility sectors which due to lack of accessibility for SMBs, public unavailability and deficiency in respect to interactions between various energy and service system in the building they are not all applicable for small and medium building (SMB) energy retrofit analysis (S. H.Lee, Hong, & Piette, 2014). The general energy analysis process includes model creation based on collected data and examines the result using real life energy consumption bills. Thermal modeling of building could be performed through either of conformed input or output approaches, where in both of them building modeling process employs collected data to create a prototype model of the building and the only difference that distinguishes these two method from each other is in conformed output approach that will enable energy auditor to alter given input data to compensate the deviation of the result from real life energy bills while in conformed input approach no modification is allowed after stimulation to balance the model with real life energy consumption (Clement & Clément, 2012) . Since error propagation in entire energy audit process is unavoidable and subsequently the possibility of major deviation of the result from real life energy consumption is high therefore utilizing the conformed output approach for building energy stimulation appears to be preferable option to mitigate error in the stimulated model.

3.3.2.1 Errors and Validation in Energy Modeling

In building energy modeling even if calculated and actual energy consumption is balanced due to simultaneous act of error possible offsetting errors prevent a definitive conclusion about the models accuracy. The possible error source in thermal modeling categorized into external and internal error groups, where external errors indicate the climate data, schedule, control strategy, occupant's behavior and physical properties of the building differences between actual building and input to computer software. Internal errors but refer to differences between actual and simplified version in modeling process of thermal transfer mechanism, HVAC system along with inaccuracies of mathematical solution of the model and errors in coding (Ron Judkoff, 2009).

(Clement & Clément, 2012) Classified the errors by considering their amount of generated deviation in the modeled building in compare with actual building performance and quantified the possible deviation in percentage term from accuracy and compatibility with actual building. Form this point of view error in thermal modeling categorized into three major group of default value, data acquisition and calculation errors which respectively could generate up to 5%, 30% and 10%

inaccuracy in modeled building vs. actual building energy consumption. Hence considering all probable existing sources of error in thermal modeling the deviation of result in modeled building from actual building energy consumption could increase up to total 45% which if it is ignored at the end may lead to financial investment disaster. Meanwhile evidently result validation as the other comparative side of scale plays a crucial role in existing possible error quantification. According to (Hensen, 2012) ,validation term refers to the efforts to create methodologies, tests and standards to justify the accuracy and reliability of the building stimulation result which could yield from the from the juxtaposition of the result from building stimulation and actual energy consumption of the building based on the real life energy bills. In conclusion considering all aforementioned statement on possible source of error and validation process will justify that conformed output approach will provide more flexibility by allowing the auditors to modify the proposed stimulated model based on existing energy bill until the hypothesis will match the actual energy consumption. Based on (Azari, 2019) the stimulated modeled considered fairly calibrated and verified if the calculated result falls within 5% of actual measured energy data.

3.3.2.2 Why Design Builder

The complexity of energy consumption sources such as heating, cooling, lighting and all other appliances in building an also the interrelated effect of each source on the other proves that neither approximate assessment and nor even detailed assessment using spreadsheet could meet the auditor’s need to design a base case scenario for building energy consumption and accordingly modify the prototype to evaluate the effect of each retrofitting scenario on base case model. In recent decade but with technology evolvement number of thermal modeling software which are capable of stimulating the building by considering large amount of parameter that influenced the result solely and their interrelation effect on the final energy consumption of building developed. In (Sousa, 2012) different characteristics of software such as ESP-r, IDA-ICE, IES and TRNSYS and compared and it is concluded that adopting each one of the aforementioned software required great deal of expertise. The Eastern Orlando Lawrence Berkeley national laboratory in 2014 reported that out of 89 recognized stimulation tools in retrofitting analysis only one tool, energy plus, could be adopted for small and medium building size but due to the lack of user friendly interface it could be used by trained experts (S. H. Lee et al., 2014).Among all existing thermal modeling software design builder is one of the most commonly used software due to its unique characteristics and interactive interface which built around the most competitive and accurate energy stimulation engine called energy plus.it is an advanced building performance simulation tools minimize modeling time and maximize productivity as a result of fully-integrated performance analysis including: energy and comfort, HVAC, day lighting, cost, design optimization, CFD, BREEAM and LEED credits, and reports complying with several national building regulations and certification standards (DesignBuilder Software Ltd, 2015). Design builder is also analyzed by ANSI/ASHRAE Standard 140-2017 Building Thermal Envelope and Fabric Load Tests, Air side heating, Ventilating and Air-conditioning Performance Analytical Verification Tests, Space-Cooling Equipment Performance Analytical Verification Tests, Space-Cooling Equipment Performance Comparative Tests and Space-Heating Equipment Tests. At the end The results indicates that Design Builder compares very well to the analytical results for all of the charts (ANSI, 2019) The software also recognized by U.S department of energy and adopted for different case studies.

3.3.2.3 Existing Building Energy Analysis

Thermal modeling of case study performed using design builder 6.100.006 version which is linked to energy plus engine 8.9 versions. Since thermal stimulation process itself is out of discussion it will be overlooked in this chapter and the main concentration would be on the general steps of procedure, assumptions and the result which obtained from the stimulation process. The first step of building thermal modeling in design builder is to design the building itself using the provided tools in software. Figure 3.10 illustrated the schematic design of Civil engineering department in Design builder software.

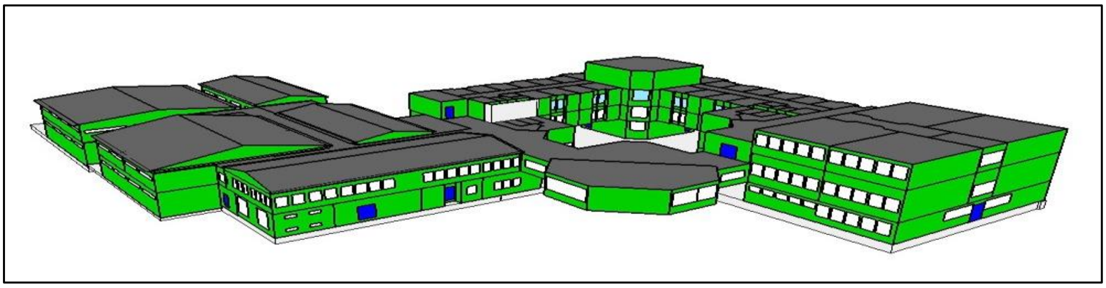


Figure 3.10: Schematic design of the case study

Afterward in the next step all the details which are belong to different building's components have to be defined for the software. The aforementioned details are include activities, materials, openings, lightings and HVACs which could be defined through embedded separated tabs in the software which illustrated in Figure 3.11 below.

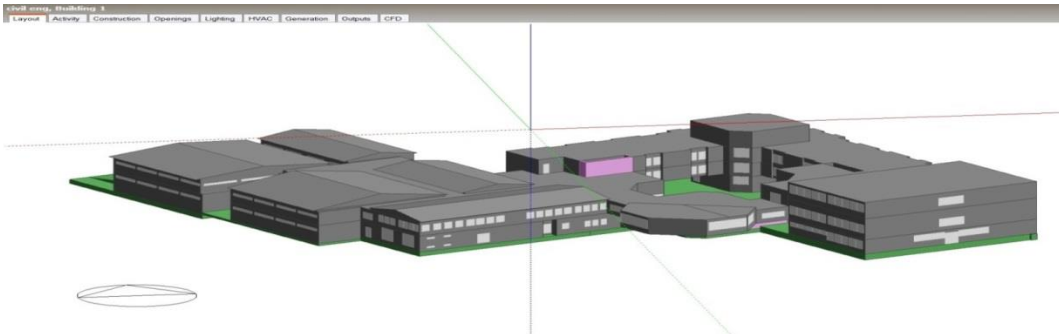


Figure 3.11: Building's component determination in Design builder

Since the corresponding U-value of the building material and openings has to be calculated based on the actual type of material which has been used in the site and reliability of the data collected from the pre-site and on-site inspection due to the lack of information of the authorities are ambiguous, therefore the type of material in building construction is assumed to be typical and accordingly the U-value of building's component is calculated by software as Table 3.9.

Table 3.9: U values for building's components (W/m^2k)

Building component	**U-value (W/m^2k)**
Exterior walls	1.612
Interior walls	0.78
Partition walls	0.35
Roofs	1.552
Floors	0.25
Single glazed windows	5.816
Double glazed windows	3.094

The annual energy consumption of the case study based on Kwh is distributed between four End-Users as it demonstrated in the Figure 3.12.

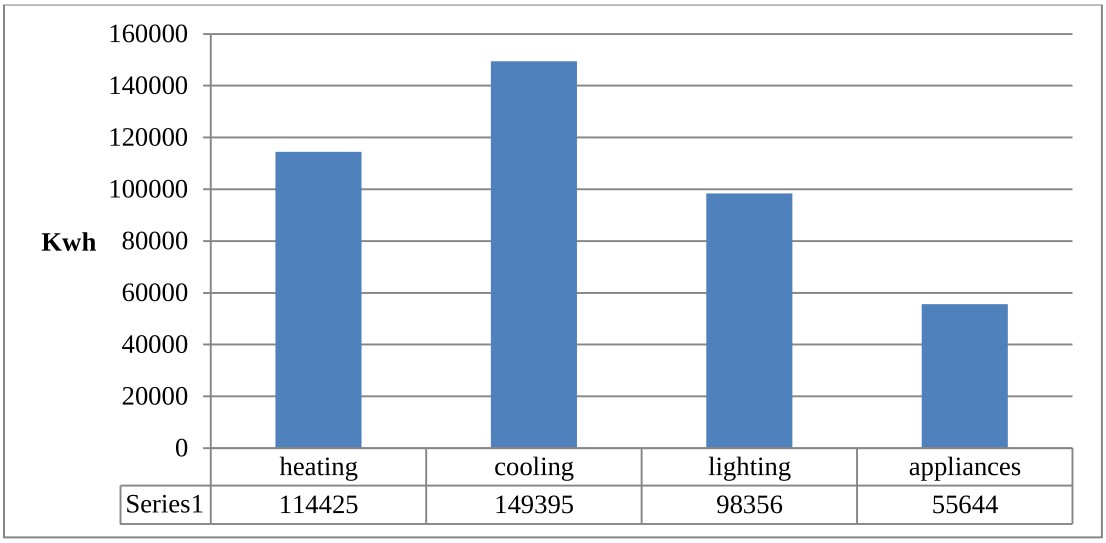


Figure 3.12: Base case energy consumption by end-users

The total annual energy consumption in the building is 417820 Kwh which as it expected building cooling process with 36% of total energy consumption has the highest share of energy consumption among other End-Users. Other End-Users such as heating, lighting and appliances respectively with 27%, 24% and 13% of total energy consumption ranked after cooling process. Figure 3.13 illustrated the total energy consumption among end-users.

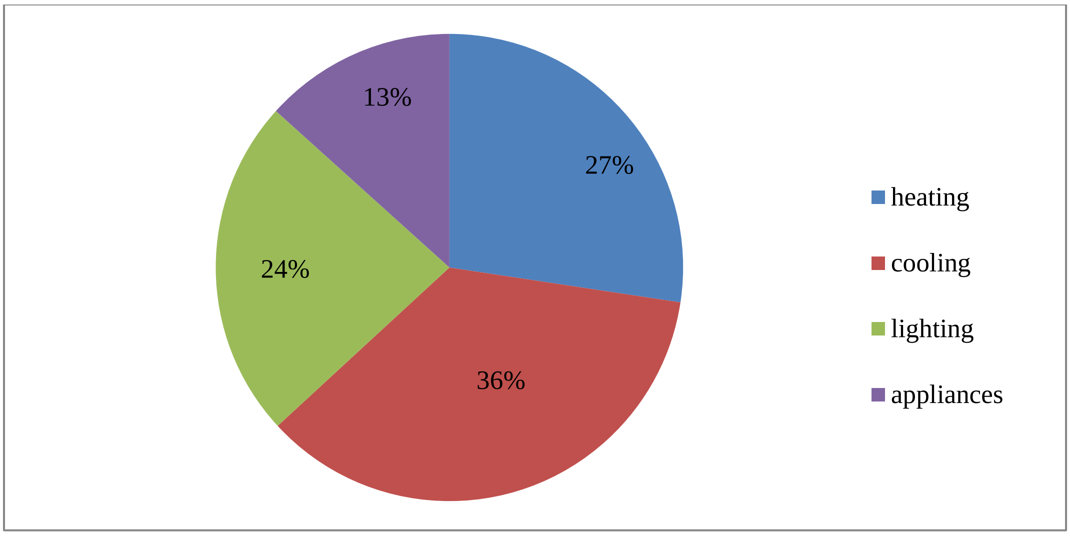


Figure 3.13: Total energy consumption for each end-user (percentage)

Since two source of energy (electricity and LPG) identified for the building, the share of electricity from the total energy consumption is 322,848 Kwh which is 77% of total energy demand in the building. Among all the End-Users cooling system with 149,395 Kwh and 46% of total electricity consumption, has the highest source of electricity consumption among others and heating system with 6% of total electricity consumption has the least demand due to less dependency of heating process (17%) to electricity. LPG but produces the rest of 94,973 Kwh or 23% of required energy demand for the building which is completely utilized in heating process. Electricity consumption by each End user is provided by following charts in Figure 3.14 and 3.15.

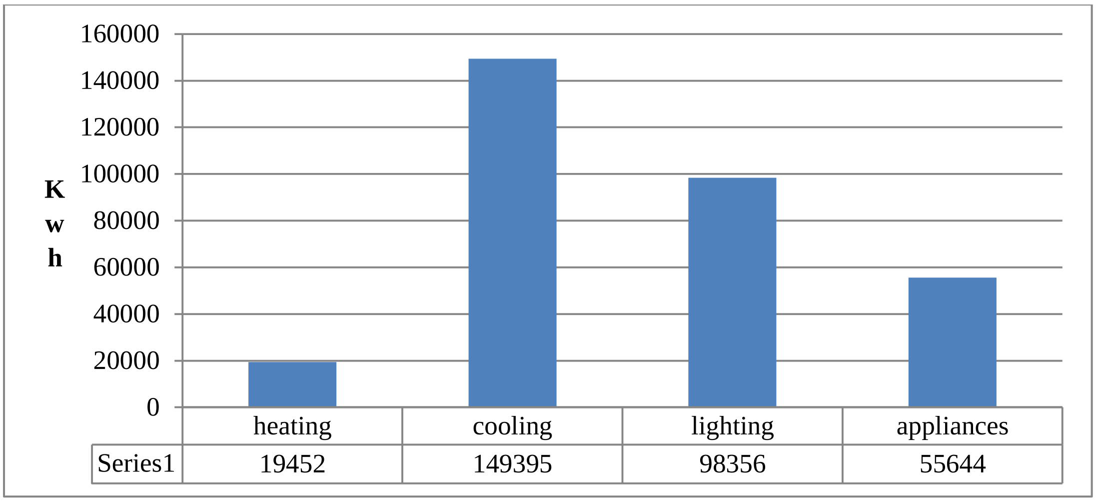


Figure 3.14: Electricity consumption by end-users (Kwh)

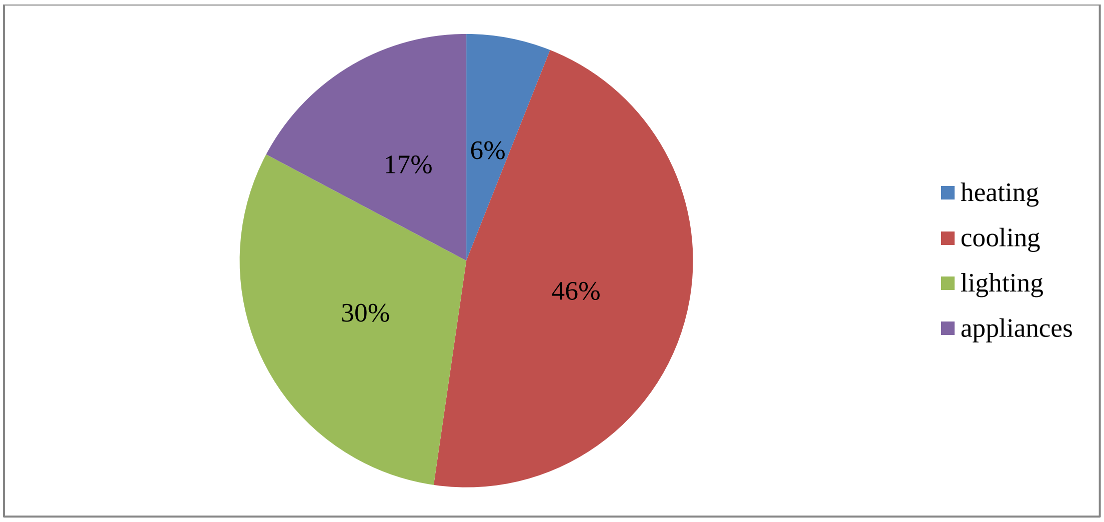
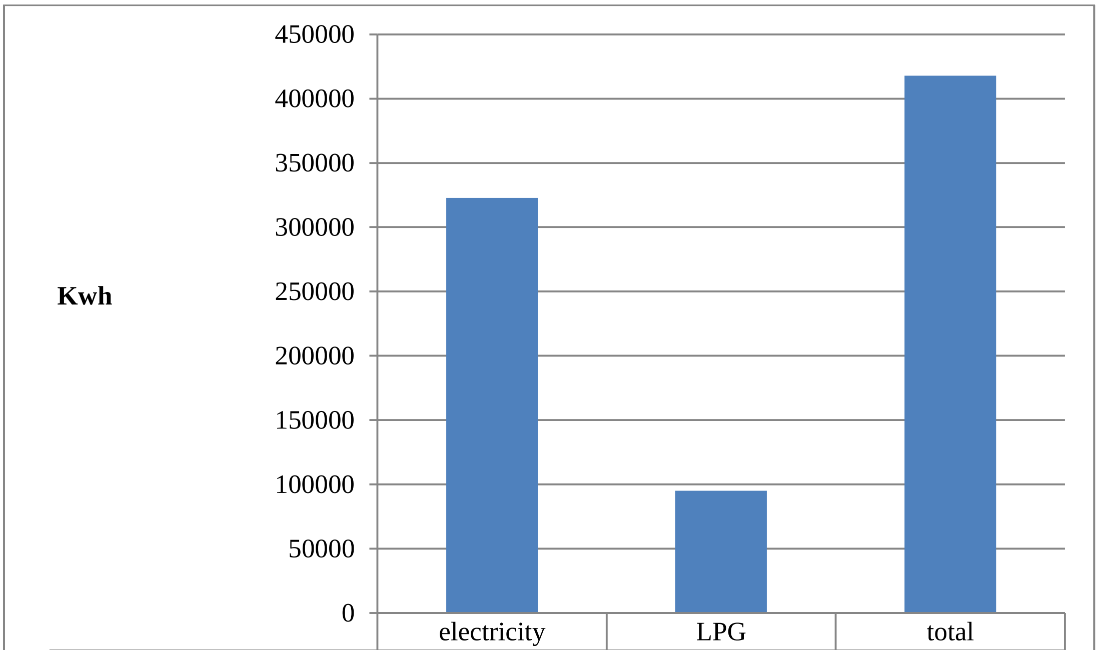


Figure 3.15: Total electricity consumption among end-users (percentage)

Also the share of each energy sources from total energy consumption illustrated as following Figure 3.16 and 3.17.



	electricity	LPG	total
energy consumption (Kwh)	322848	94972	417820

Figure 3.16: Share of each energy source from total consumption (Kwh)

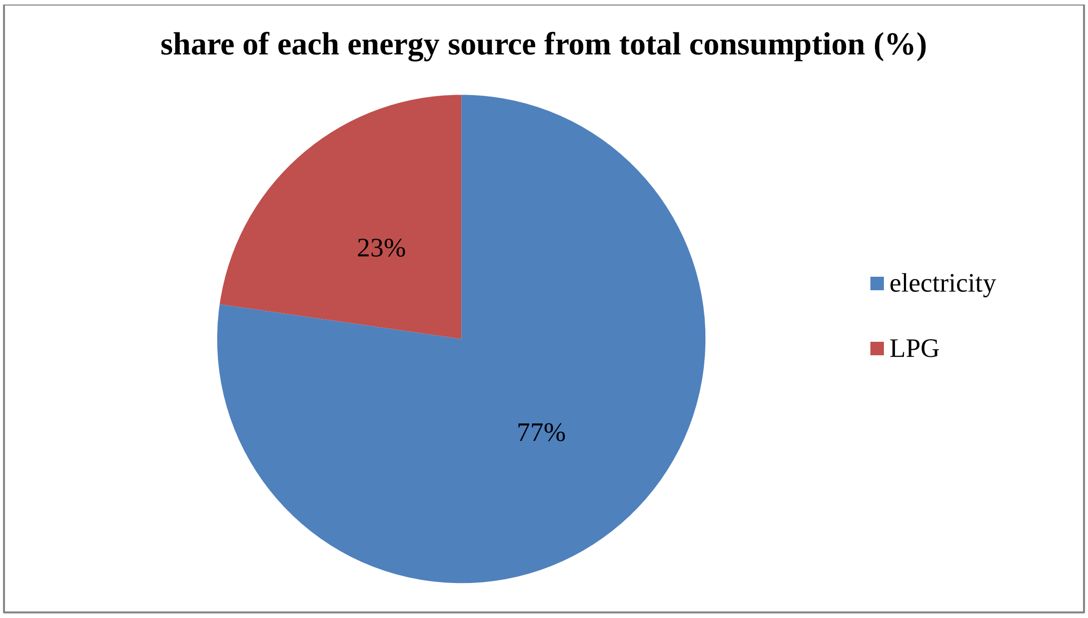
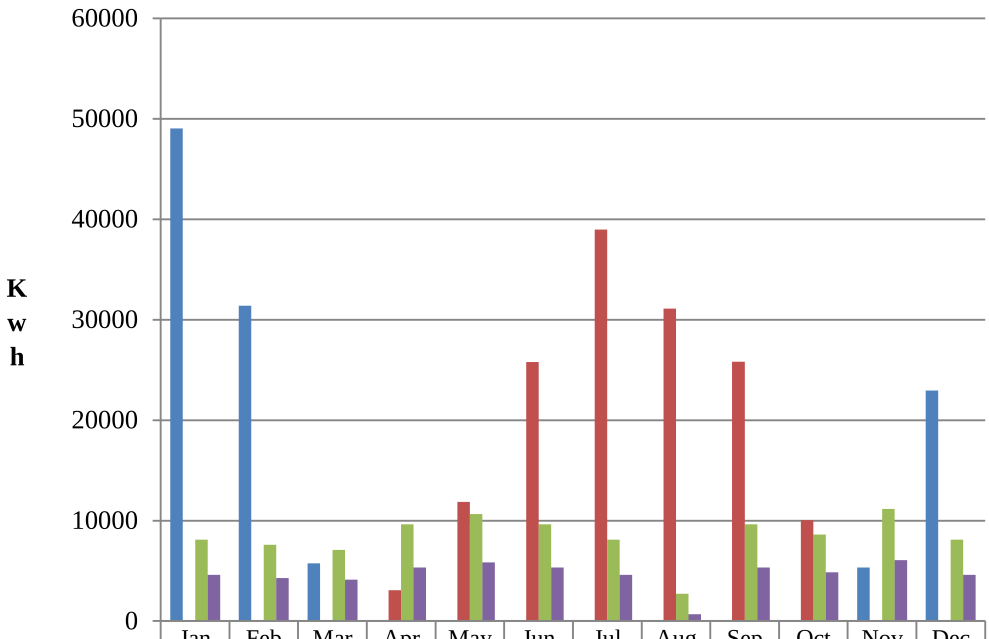


Figure 3.17: Share of each energy source from total consumption (percentage)

So far all the necessary information on base case scenario to perform financial evaluation is obtained from the software. Nonetheless the financial analysis of the base case scenario is yearly based yet monthly analysis of energy consumption distribution among End-Users will provide a privilege of better realization of energy consumption flow in the building during the year. Hence considering numerous features and characteristics of design builder software in terms of output proposition which could be sub hourly, hourly, monthly or yearly based, the total energy consumption distribution by end users on monthly basis is provided as following graph in Figure 3.18.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
heating	49031	31375	5743	0	0	0	0	0	0	0	5322	22954
cooling	0	0	0	3078	11876	25793	38976	31110	25803	10038	0	0
lighting	8112	7605	7098	9633	10647	9633	8112	2721	9633	8619	11154	8112
appliances	4609	4297	4119	5322	5835	5322	4609	686	5322	4854	6058	4609

Figure 3.18: Monthly energy consumption breakdown by end-users

The total amount of energy consumption as it depicted in the Table 3.20 matches total energy consumption in the building based on dedicated energy demand to each energy consumption source on monthly report and eventually the annual stimulated energy consumption which is 417,820 Kwh. from the Figure 3.21 it is evident that the energy consumption for heating process starts in November and peaks in January with 49,031 Kwh and finally lasts up to March from then onward the cooling process will start from April and by July it will reach its maximum amount where it comes to 25,793 Kwh and finishes by October end. Meanwhile the lighting and appliances energy consumption fluctuates between ″2,721 to 10,647″ Kwh for lighting and 686 to 6058 Kwh for appliances. It is notable that the stimulated energy consumption on the monthly basis demonstrated an unnecessary use of heating system in October in real life building operation which is most probably related to building orientation and natural heat gain by the building. The same result from another point of view also provided for the amount of monthly electricity and LPG consumption which eventually lead to the total of 417,820 Kwh per annum.

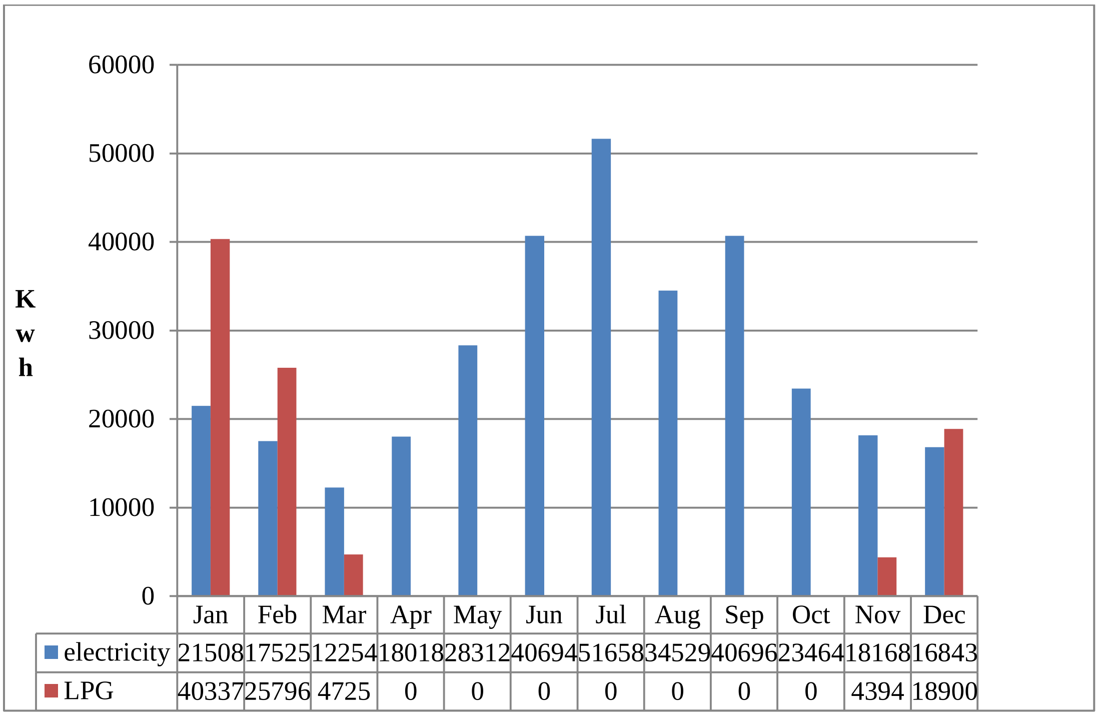
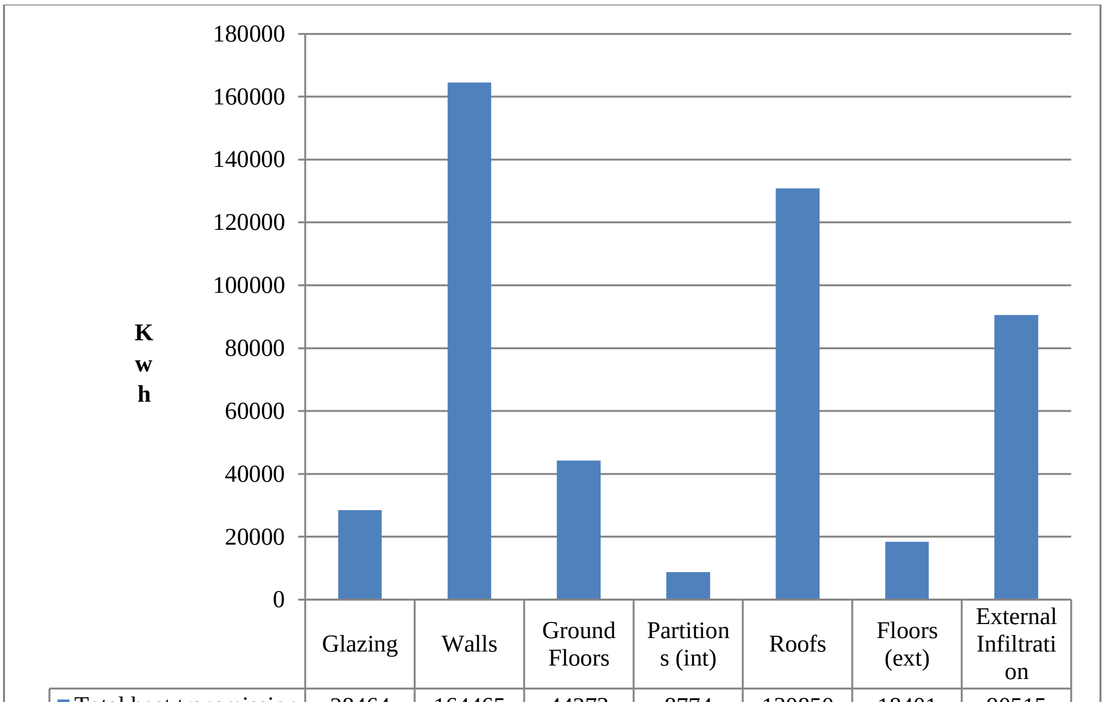


Figure 3.19: Monthly fuel consumption in Base case

From the other features that design builder could provide as an output external infiltration, zone sensible heating and cooling, heat gain and loss, solar gain, wet and dry bulb temperature on daily, monthly or yearly basis could be mention. Among all these features one of the most important result which could be extracted from the software outputs is the amount of heat transmission from the potential envelope areas which could be calculated through the summation of absolute value for heat gain and heat loss throughout the year. Once the amount and the areas of energy loss identified based on certain criteria and by taking into account this particular area as potential defective areas the retrofitting scenario should be proposed. Therefore identifying the potential heat transmission in the building will facilitate decision makers in effective retrofitting scenario proposition. The following graph in Figure 3.20 is illustrated the result from existing building's thermal modeling which indicated the amount of heat transmission in the building from the specified area in the building.



	Glazing	Walls	Ground Floors	Partitions (int)	Roofs	Floors (ext)	External Infiltration
Total heat transmission	28464	164465	44273	8774	130850	18401	90515

Figure 3.20: Total heat transmission in building (Kwh)

From thermal modeling results the most effective building component in heat transmission also identified as below pie chart in Figure3.21.

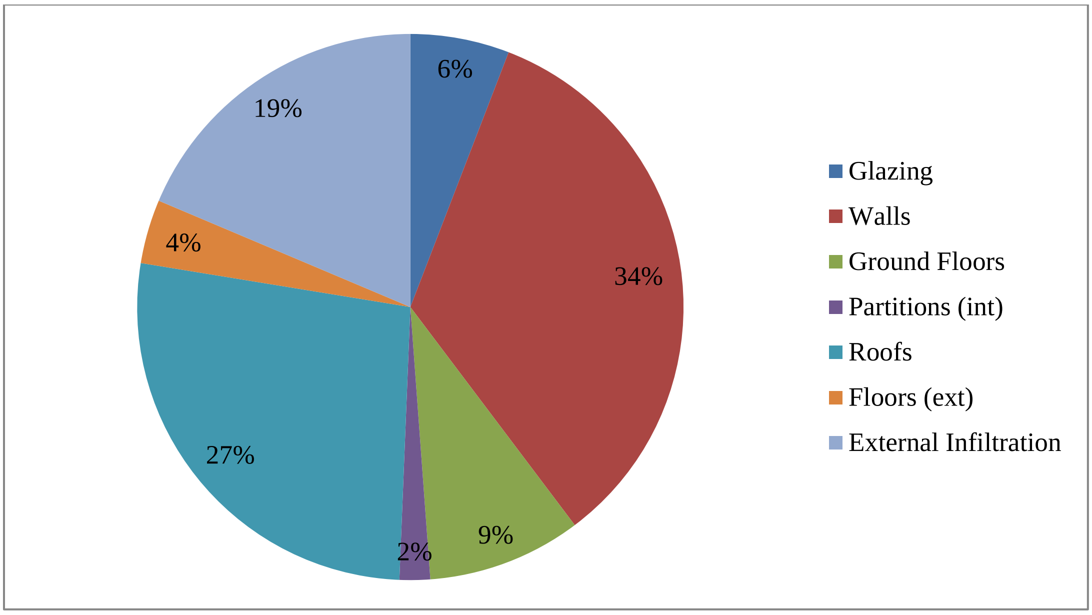


Figure 3.21: Heat transmission participators in building's envelope (percentage)

The pie chart illustrated that walls, roofs and external infiltration have the most contribution among other building components in heat transmission with almost 80% of total heat transmission. Therefore, these areas could be considered as most potential areas in retrofitting scenario development. Also from another point of view in hot seasons when the building need cooling system heat gain considered to be a disadvantage. So identifying the most influential building's envelope in terms of heat gain would assist in selecting precautionary measure to control heat flow inside the building. The below charts from Figures 3.22 and 3.23 represent the amount of heat gain through each building envelope surface.it is also notable that the amount of heat gain in calculated for seven months as the software assessed the necessity of cooling system from April to October.

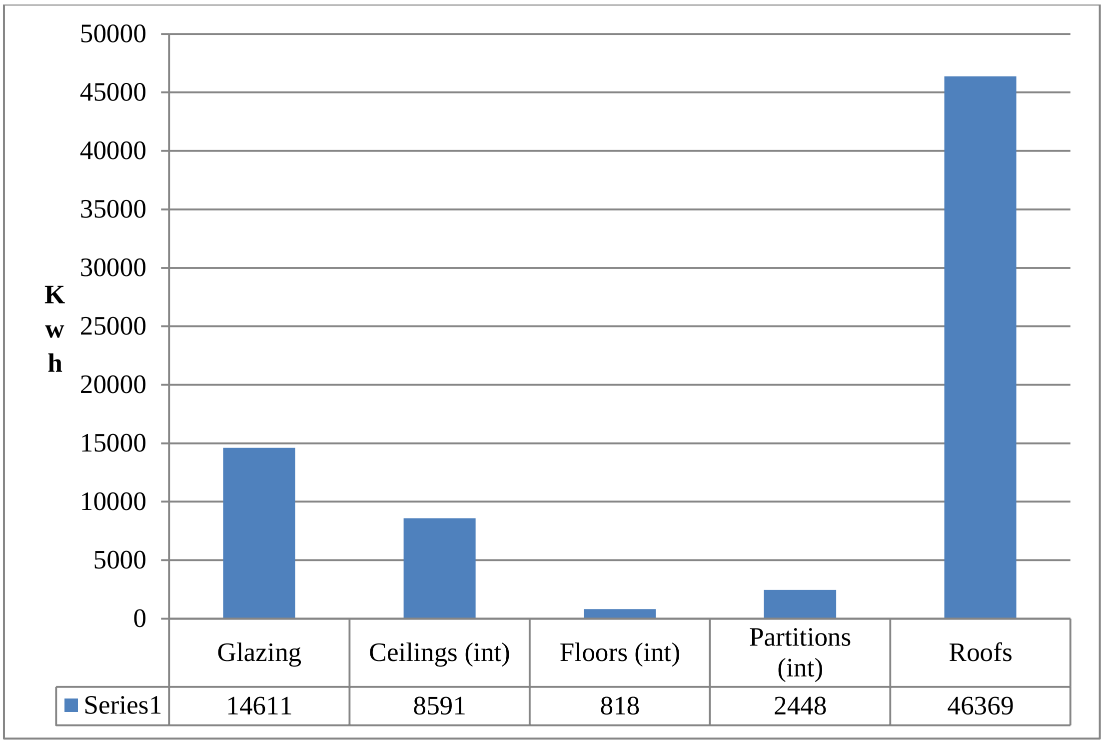


Figure 3.22: Building's envelope contribution in heat gain (Kwh)

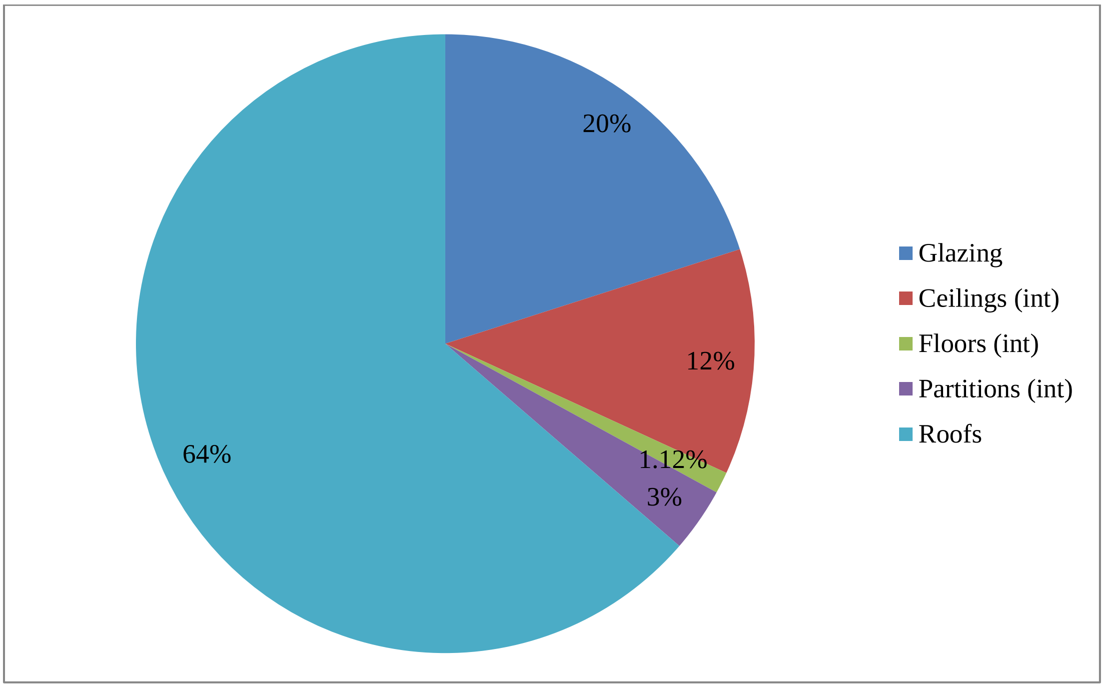


Figure 3.23: Building's envelope contribution in heat gain (percentage)

From the result, roof and glazing with 64% and 20% of total envelope heat gain could be identified as the most potential area in terms of heat gain which could eventually have considered as most possible retrofitting alternatives. On the contrary heat loss through building's envelope could also be considered as a disadvantage in cold seasons where due to heat loss through building's components it will be increasing the load on heating system by creating the temperature imbalance in contrast with adjusted set points. Figures 3.24 and 3.25 from thermal modeling results is illustrated the contribution of each effective building's envelope in heat loss process during the cold season of island which considered being from November to March.

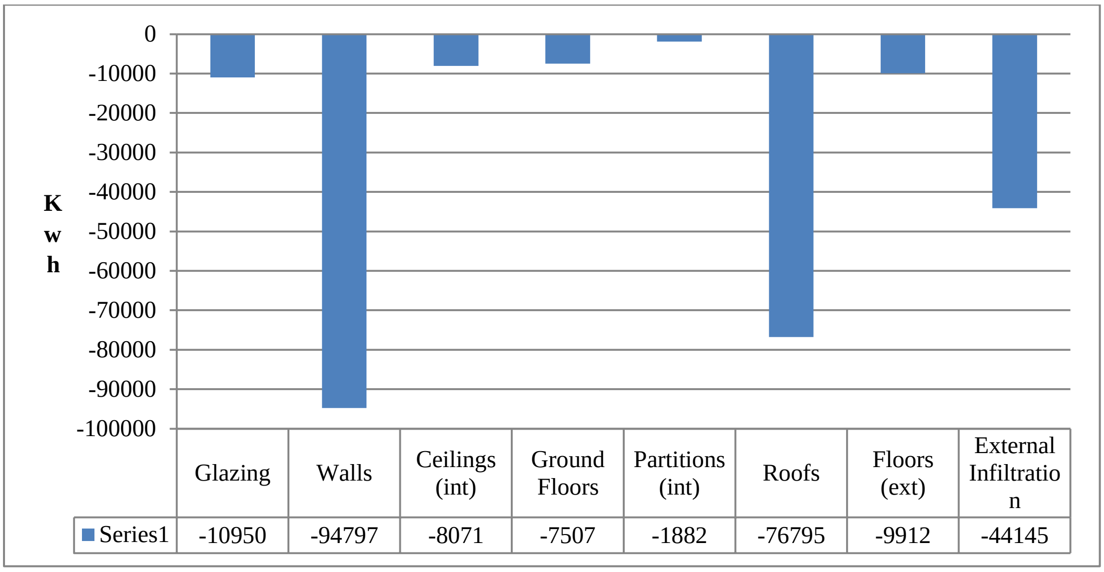


Figure 3.24: Building's envelope contribution in loss (Kwh)

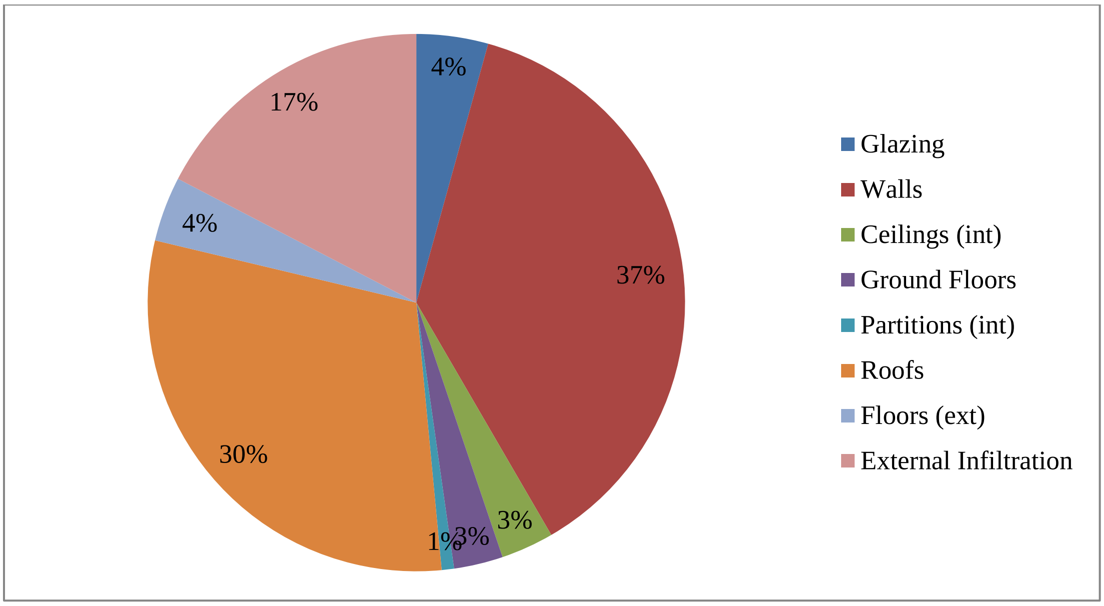


Figure 3.25: Building's envelope contribution in loss (percentage)

From the result it is evident that walls and roofs with 37% and 30% of contribution are the most influential factors in term of heat loss in the building. Considering the potential of roofs in both, heat loss and heat gain illuminates the significance of this envelope section in imposing extra load on heating and cooling systems. Thus from analyzing of results for heat transmission in general and heat loss and gain through building's component, non-insulated parts of building which could affect in creating extra load on heating and cooling system could be identified and accordingly the required action in term of retrofitting process should be proposed.

3.3.2.4 Validation of Results

As it previously stated validation process is comprised of comparing the stimulation result for existing building with real life energy bills to assess how resembled is the outcome from thermal modeling to actual building energy consumption. In order to perform result validation both side of the equation must be presented. The actual energy bills for the building is collected during data collection and as it already explained there are some issues in terms of the availability of required data to initiate the validation process. For electricity bill, provided bill is belong to six buildings including five engineering departments and one health center. The total amount of energy consumption for each month is mentioned as accumulated amount for entire six buildings.to ensure about the validity of produced output from thermal modeling electricity bill have to calculated for civil engineering building. Thus the first set of assumption have been made that, electricity consumption distributed based on total existing area of each building. Since the total annual electricity consumption based on Kwh is presented in the bill therefore, by dividing total amount of electricity consumption to each building area, the approximate electricity consumption of each building will be obtained. Table 3.10 summarized adjusted electricity bills for each building.

Table 3.10: Adjusted electricity bills for each building (Kwh)

Area distribution (m^2)		**Electricity consumption for each building (Kwh)**
Electrical department	7575	246,746
Computer department	7575	246,746
Architectural department	7106	231,469
Civil department	8860	288,601
Mechanical department	5028	163,780
Health center	1371	44,657
Total area	**37515**	**1,222,000**

Also from the bill, the percentage of energy consumption for each month is obtained as it demonstrated in Table 3.11.

Table 3.11: Percentage of energy consumption for each month

Share of energy consumption for each month from total (percentage)	
January	7%
February	5%
March	1%
April	9%
May	10%
June	9%
July	12%
August	11%
September	9%
October	12%
November	7%
December	6%

At the end normalized electricity bill for civil engineering building would be as following Table 3.12.

Table 3.12: Adjusted annual electricity bill for building (Kwh)

Civil engineering electricity consumption (Kwh)	
January	20,783
February	15,587
March	3,306
April	26,924
May	28,813
June	26,924
July	34,481
August	33,064
September	27,396
October	33,536
November	19,366
December	18,421
Total	288,602

On the other hand for another fuel source of the building (LPG) the acquired information is even more defective. LPG bill is existed in the form of purchase invoice in monthly basis for total five buildings include four engineering building and one health center. It means that the invoice could not even indicate the periods that LPG consumed in those building. So at first, total purchasing invoice converted to liter of LPG using a unit price for bulk LPG which is 3.55 TL. Table 3.13 illustrated the LPG invoice for 2018 for total five buildings.

Table 3.13: LPG invoice in 2018

LPG invoice (TL)	
January	8,565
February	6,555
March	29,305
April	86,132
May	0
June	0
July	3,581
August	0
September	0
October	0
November	0
December	66,056
Total	200,194

The total LPG consumption for a year is 56,388 Liter, since all the energy consumption calculated in thermal modeling is based on Kwh, the LPG consumption from Liter has to be converted to Kwh. The conversion unit for each Liter of bulk LPG to Kwh is 7.08 therefore the total LPG consumption for all the buildings is 399,227 Kwh. The next step is to allocate specific amount of LPG consumption to each building according to their total area as it performed for electricity bills. Table 3.14 showed the corresponding LPG consumption based on m^2 of each building.

Table 3.14: Adjusted LPG bill for each building (Kwh)

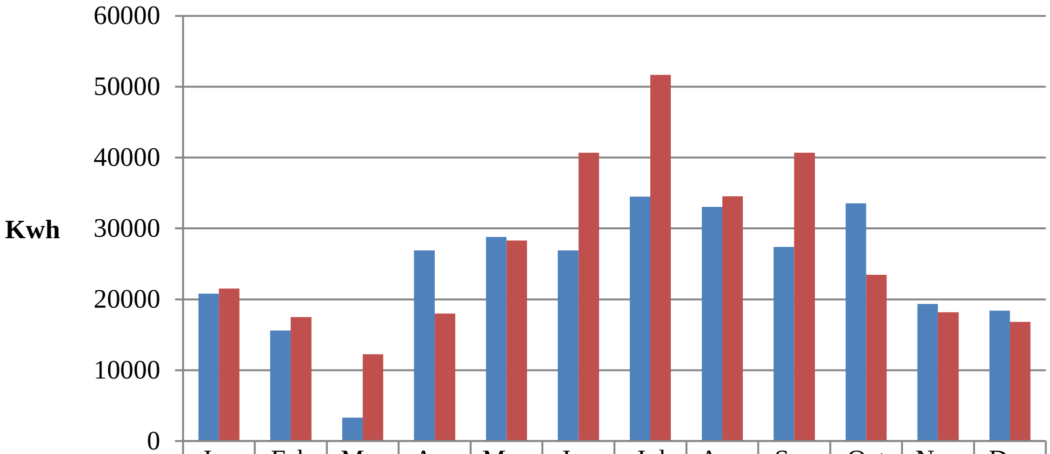
Area distribution (m2)		**LPG consumption for each building (Kwh)**
Electrical department	7575	93,088
Computer department	7575	93,088
Architectural department	7106	87,324
Civil department	8860	108,879
Health center	1371	16,848
Total area	**32487**	**399,227**

Finally in order to produce sample of LPG bill for the entire year, total duration of six month in which heating system is working in university assumed to be a LPG consumption period and LPG is equally consumed throughout this six month. Table 3.15 showed the normalized LPG bill for year 2018.

Table 3.15: LPG normalized bill for year 2018 (Kwh)

civil engineering LPG consumption (Kwh)	
January	18,146
February	18,146
March	18,146
April	0
May	0
June	0
July	0
August	0
September	0
October	18,146
November	18,146
December	18,146
Total	108,879

Inasmuch as both electricity and LPG consumption bills are created based on different assumption the comparison between thermal modeling results and assumed energy consumption bills could not be accurately justified, but still in terms of electricity bills which provided based on monthly consumption it could provide slight insight on modeled building. The only result which seems to be comparable between actual life building energy consumption and modeled building energy consumption is from total energy consumption point of view. The result validation for electricity consumption on monthly basis demonstrated in Figure 3.26 and 3.27 which indicates the similar pattern of electricity consumption in every month between real case and stimulated case the total amount of electricity consumption based on stimulated case is 323,668 Kwh which shows 10.83% increase in compare with real life bills. Since the flow of electricity consumption throughout the year for both the cases are almost similar the reason for 10.83% difference could be from wrong allocation of the amount of electricity consumption to each department as it supposed to be based on the total area of each building.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
real life bills	20783	15587	3306	26924	28813	26924	34481	33064	27396	33536	19366	18428
stimulation result	21508	17525	12254	18018	28312	40694	51658	34529	40696	23464	18168	16843

Figure 3.26: Electricity consumption comparison on monthly basis

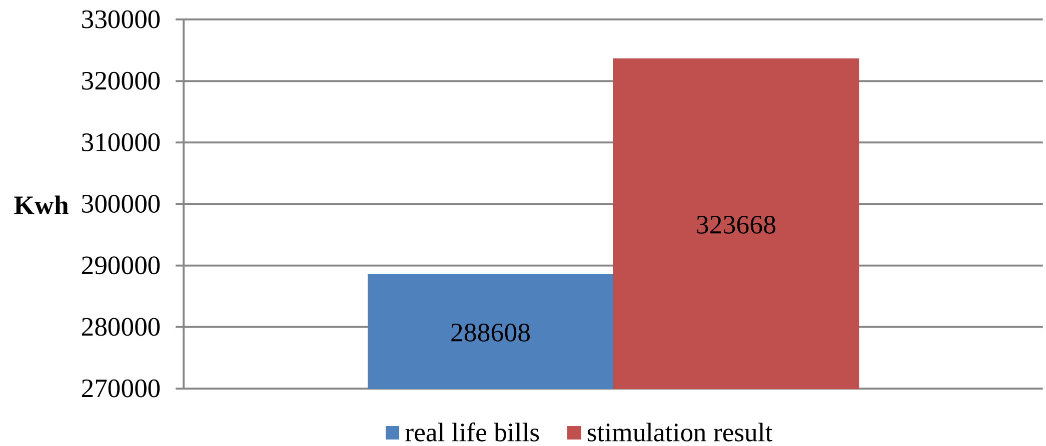


Figure 3.27: Total electricity consumption comparison on annual basis

For LPG consumption but the consumption flow for each month is not compatible with real life bills due to equal distribution of LPG consumption among all cold seasons but as it could be observed in the graph the stimulation LPG consumption flow does make sense by itself since the LPG consumption starts at November and gradually increases until it reaches its peak in January and eventually decreases to its least in March when the hot season starts. On the other hand the total LPG consumption comparison in Figure 3.28 and 3.29 shows 13.53% deviation from real life total LPG consumption result which could be related to excluding October as beginning of the cold season in region.

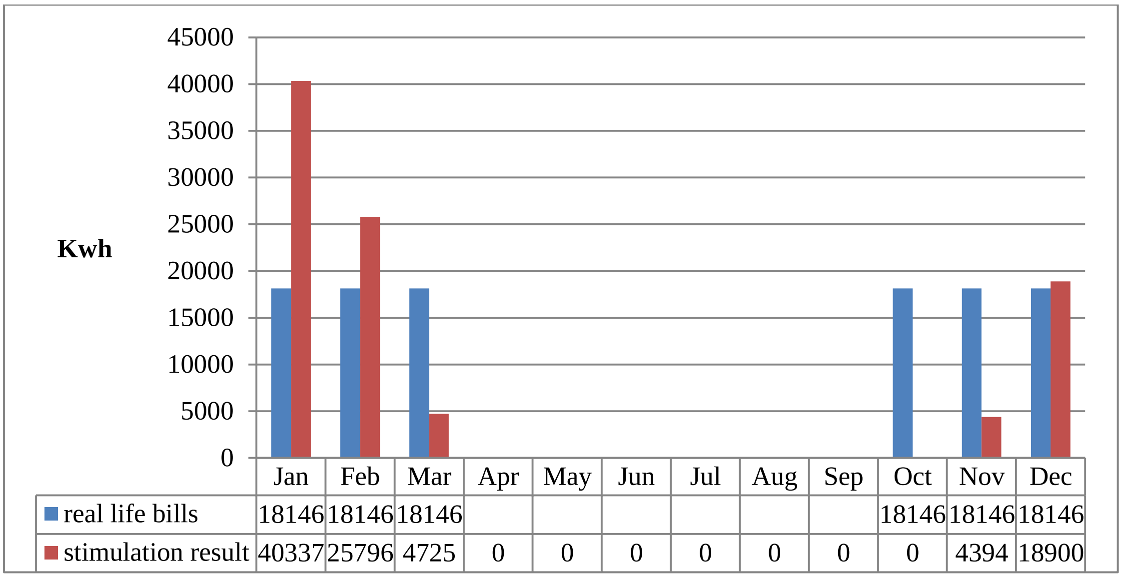


Figure 3.28: LPG consumption comparison on monthly basis

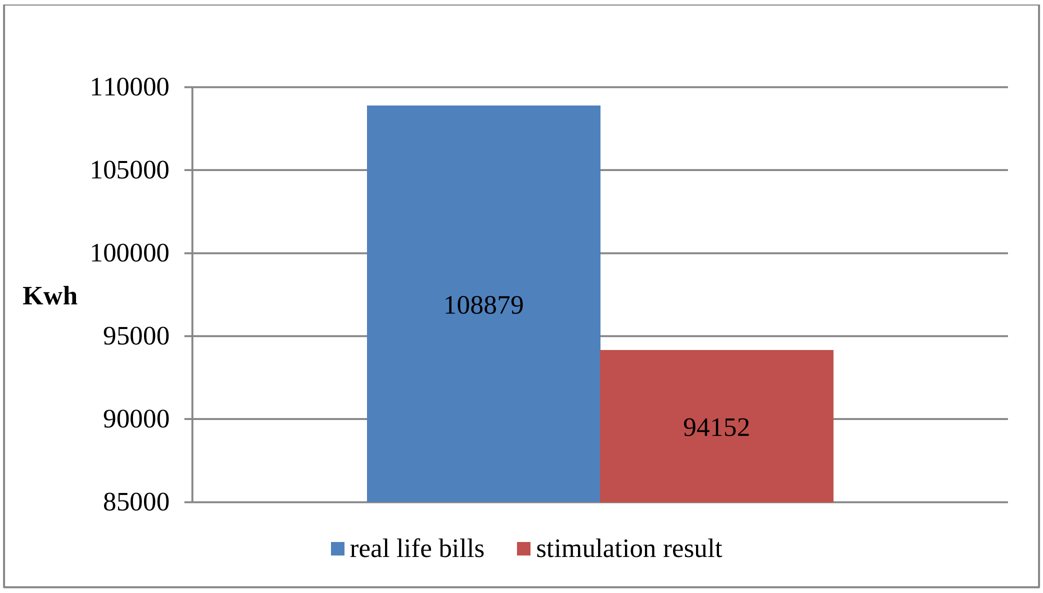


Figure 3.29: Total LPG consumption comparison on annual basis

The most significant indicator for stimulation result validation when the proper detailed bill is not provided is the comparison of total energy consumption of stimulated building and the summation of total energy sources of the real bills. As it already explained, if the deviation of the result from stimulation falls within the 5% of actual bills, it considered an accurate and accepted stimulation. In this study the result from thermal modeling indicated of 397,487 Kwh of total energy consumption where the summation of total electricity and LPG consumption from actual bills is 417,820 Kwh and the difference indicated 20,333 Kwh which is 5.12% of deviation between stimulated building and actual presented bill therefore the validity of the modeled building is considered to be verified. The comparison between thermal modeling's result and actual energy consumption of building is provided in Figure 3.30.

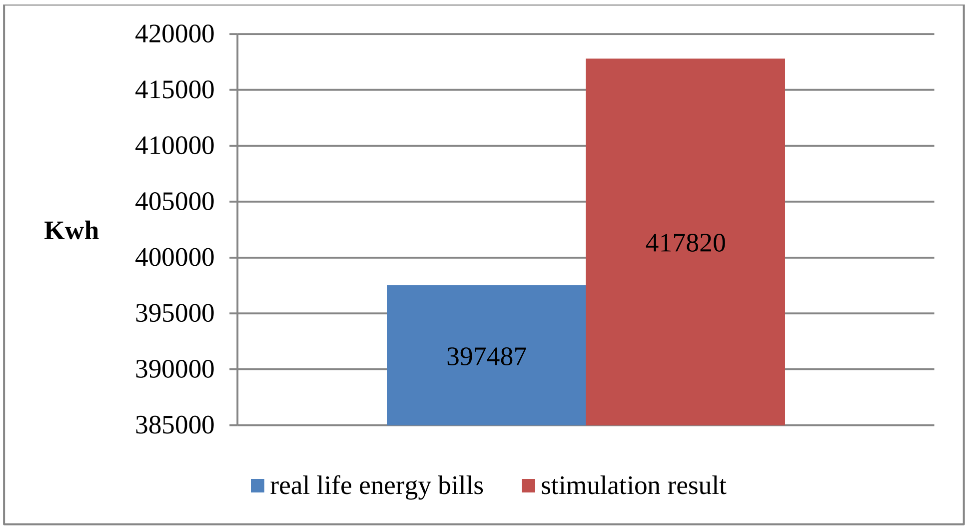


Figure 3.30: Total energy consumption comparison on annual basis

3.3.3 Recommendation and Evaluation on Retrofit Scenarios

Once inventory of fixtures and baseline energy consumption of building as two significant prerequisite steps of energy retrofitting in an existing building performed and an overview of overall energy consumption of the building which decomposed by each sources acquired, the next step is to evaluate the feasibility of diverse retrofit scenarios on the building. Notwithstanding each particular proposed retrofitting option may decrease the amount of energy consumption in the building and It is also notable that the number of practices that could be undertaken within the scope of retrofit process grow along side with technological progression and they could be adopted as individual alternative or the combination of distinguished solution from different categories depends on building’s characteristics, scope of retrofit and the criteria which action will serve, but indeed all these not necessarily the superlative alternative since, they have to tackle mainly great source of expenses as well as pointing out on practical defects to correct based on if they are technically feasible or not. According to (Clement & Clément, 2012) appropriate recommended retrofit alternative have to address three major criteria at least to a certain extent:

• Reduction in energy expenses through decreasing energy consumption

• Technical defects and technical implementation feasibility

• Timeline

And only when these criteria met by a retrofitting option, it could be analyzed and assessed eventually. (Aste & Del Pero, 2013) defined the process of energy retrofitting measure selection as following steps:

1. Analyzing the most prevalent energy retrofitting measure.
2. Selecting and refining those scenarios which match with technical and context specific constraints of the building such as instant restructuring necessity, adaptability of alternative with continuity of tasks inside the building, cost effectiveness of intervention, budget compatibility, interference with building regulation and so forth.
3. Classification of selected alternative based on their functionality according to aforementioned limitation.

The categorization of the general possible retrofitting action is provided by various researchers from different points of view for example (Alanne, 2004) classified these actions according to lighting, heating and cooling, electromechanical equipment and general enhancement or in other study (Rey, 2004) combined series of actions which led to specific result categorized in three strategy type as:
Stabilization strategy (STA) comprised of the actions which do not alter the building appearance, substitution strategy (SUB) include a group of alternatives that could change the building appearance extensively and finally the double skin façade strategy (DSF) which refers to appending a new glass skin. Therefore as a general comment, mainly due to diversity of problem's complexity and existing variable a

global and holistic approach toward adopting a series of retrofitting action sounds meaningless and most of the efforts for energy efficiency and enhancement of building performance are concentrated on identifying a particular action or group of actions which exclusively appropriate for that specific building. In this study but to recommend and evaluate the series of applicable ERMs for the case study referred to classification of ERMs by (Kolokotsa et al., 2009) who provided a list of commonly proposed retrofitting solution which is classified based on potential building's components in energy conservation and could be adopted by decision makers on their preferences and priorities that summarized in Table 3.16.

Table 3.16: Recommended ERMs by (Kolokotsa et al., 2009)

Building's component	**Strategy type**	**Action plan**
Envelope and design aspects	Insulation	Increasing insulation in roof , walls and ceilings
	Glazing	Installing supplemental glazing on windows and doors
	Air leakage reduction	Decreasing air leakage of envelope structure using recent or old active measures such as high efficiency windows and sealing gap materials
	Advanced building envelope technologies	Such as chromogenic glazing , cool materials
	Exploitation of sunlight	1. To reduce cooling load by installing external and internal shading device as well as solar control film on existing glazing. 2. For daylight using light pipes, diffusers, translucent roofs and walls, light shelves and shading. 3. To increase passive solar heating by installing combination of sunlight absorbers and reflectors inside the windows as well as utilizing the building with solar enclosures to benefit from heat.
Building services	HVAC	Upgrading the HVAC system using thermostat temperature and installation of heat recovery system and so on
	Mechanical equipment	Boilers and chillers type and maintenance upgrade
	Office equipment	Control of operating time and adopting high efficiency office equipment
	Motors	Optimizing overall performance of motors by reducing the operating time and using high energy efficiency motors
	Electrical system	Increasing the electrical efficiency of the system using new active measure in control and reduce energy consumption of electrical equipment
Energy management tools	Monitoring and controlling building operation	Adoption of new technology such as sensors ,programmable thermostats and control signal pooling to reduce building operational energy consumption

The second step in alternative proposition is to select the most compatible alternatives by considering the existing constraint of the building as it explained previously, therefore by taking into account the major area of energy consumption in the building as potential's area through the baseline energy consumption's result and also related limitation in ERMs implementation in institutional buildings a set of action regarded to envelope and building service modification is cited from other studies which are compatible with constraint associated to institutional building and climatic condition that are almost similar in some ways with the case study. (El-Darwish & Gomaa, 2017) revealed that in general, thermal comfort plays a crucial role in energy consumption; hence by adding slight modification to the building it is feasible to improve the thermal comfort with less energy consumption and subsequently increase energy efficiency. From this paper three strategies from envelope and design aspects are selected to apply on the case study to demonstrate how they could affect energy demand reduction in three institutional buildings in hot and dry climate condition.

Insulation: the major issue related to high thermal mass structures is that they act as thermal bridge and this thermal bridge will create a path of least resistance for heat transfer. Therefore an approach such as radiant barriers and reflective insulation system in hot climate could reduce the radiant heat transfer through the envelope but since this insulation type could be utilized in unfinished envelope (new construction) the other alternatives such as concrete block insulation, extruded polystyrene foam boards (XPS) or SIPs will aid to mitigate the issue. The department of energy in US (DOE) classified the insulation types based on their material and applicability in 10 groups and explained them with their advantages in detail which summarized as Table 3.17.

Table 3.17: Building insulation materials (Paul Norton, 2018)

TYPE	MATERIAL
Blanket: Batts and rolls	fiberglass , mineral wool , plastic fiber, natural fiber
concrete block insulation and insulated concrete block	foam boards
foam board or rigid board	polystyrene, Polyisocyanurate ,Polyurethane
insulating concrete forms (ICFs)	Foam boards or foam blocks
loose fill and blown in	Cellulose ,Fiberglass, Mineral (rock or slag) wool
reflective system	Foil-faced Kraft paper, plastic film, polyethylene bubbles, or cardboard
rigid fibrous or fiber insulation	Fiberglass ,Mineral (rock or slag) wool
sprayed foams and foamed in place	Cementitious, Phenolic, Polyisocyanurate ,Polyurethane
structural insulated panels (SIPs)	Foam board or liquid foam insulation core, Straw core insulation

(Aditya et al., 2017) also classified most recent developments on the building's thermal insulation from different point of views and rated them according to their potential for building insulation.in conclusion based on aforementioned studies from the group of foam board and rigid board, extruded polystyrene foam board (XPS) with the wide range of applicability for thermal insulation as well as building's air, moisture and sound barrier ,has been chosen to be applied as first retrofitting scenario on the roofs and under top chord of truss with 5 cm thickness. The other reason for selection of XPS over other type of insulation is its easy accessibility and fair material and installation price. Extruded polystyrene foam board (XPS) offers very high R value ranging from 4 to 6.5 per inch which means they can offer the decent R-value among other type of insulation and subsequently points out to the great potential of energy saving of this material. Ease of application and its environmental friendly nature of XPS made it one of the most favorite insulation types among others. Also in addition to decrease energy consumption due to its acceptable heat conductivity, its anti-penetration performance cause very low water and moisture absorbance rate.

Window glazing: almost 50% of energy lost in the buildings is wasted through envelope opening such as windows due to being a communication path between indoor and outdoor environment (Shaeri, Habibi, Yaghoubi, & Chokhachian, 2019). Being an aesthetic component of the buildings; windows also regulate ventilation and daylight within the buildings environment. Among all other associated benefits of high performance windows, minimization of heat loss in winter and heat gain in summer could significantly reduce the amount of energy demand in the buildings. The (“Windows: Heat loss & Heat gain,” 2018) disclosed the number of way that heat loss and heat gain could occur through the windows.as far as heat loss concerns, this phenomenon may occur by radiation through glazing, conduction through glazing space bars , air leakage around the opening lights and frame and finally the conduction through the window’s frame. The heat gain but is mostly transmitted through glazing which is classified as primary and secondary transmittance, respectively, through direct solar gain and indirect conversion of absorbed energy of convention and radiation. Therefore it could be articulated that modification of glazing could remarkably improve the heat loss and gain process through the windows. (El-Darwish & Gomaa, 2017) Introduced the combination of advanced static glazing such as triple glazed windows with two layers of low e-glass and high solar heat gain along with insulated window system like low conductive frame which already being applied and proven across the Europe. In this study as third scenario those are with single the replacement of those areas with single glazed windows to double glazed low-e windows will be examined and accordingly the change in energy consumption calculation will be assessed at the end of this topic.

Replacement of Luminaries and installing lux and lighting control sensors: an energy audit performed on the case study of an institutional building with 7020 square meter by an energy audit team (EAT) demonstrated the second large source of energy consumption in commercial buildings in the buildings after HVACs is lighting and plug in equipment such as computers, printers and in general non-HVAC components (Alajmi, 2012) they also realized that replacing existing luminaries with high performance lights such as T-5 fluorescent light could significantly affect the level of energy consumption in the building. Other study on institutional building in Indonesia investigated the impact of installing motion detector sensors in an institutional building and proved that the simple installation of commercially available motion detector sensors could remarkably contribute in reducing electricity consumption through lighting in the buildings (Riyanto, Margatama, Hakim, Martini, & Hindarto, 2018). (Kaminska & Ozadowicz, 2018) categorized several common control strategies which are applied in modern building into four groups: manual switching and dimming, presence and occupant detection, daylight exploitation and finally constant luminance. The study also suggested application of building automation and control system (BACS) according to the EN15232 standard will reduce energy demand of the building from lighting up to 28% for nonresidential buildings and 24% for educational buildings. Since the case study is utilized with just couple of motion detectors in office corridors and WCs, as well as the old generation of luminaries such as T-8 fluorescents, the third proposing scenario will be allocated to employing a combination of lux control and daylight sensors as well as any kind of dimmable ballast from 1 to 10 V with new generation of T-5 fluorescents which could offer superior lighting performance in the classes, all corridors and offices to reach to desired level of lighting. So many studies stated that a target level of minimum 500 lux is necessary for writing and reading without stress and by employing these combination the day light sensor and lux control device will send signal to dimmable ballast to provide required artificial light in addition to daylight which is already existed through windows to reach to optimal set level.

It is remarkable that as it previously stated, considered scenario should be compatible with instant restructuring necessity, adaptability of alternative with continuity of tasks inside the building, cost effectiveness of intervention, budget constraints, interference with building regulation and so forth. Therefore in our case study the assumption is none of proposed scenarios are in conflict with current circumstances building and allocated budget to retrofitting process. Finally the amalgamation of all considered scenario could be summarized as follow:

- **Scenario 1**: insulation of roofs and trusses by applying 5 cm of Extruded polystyrene foam board (XPS)
- **Scenario 2**: improving glazing to double low-e insulation for those windows with single glazed.
- **Scenario 3**: utilizing the entire building with lux and lighting control sensors and T-5 dimmable fluorescents lighting.
- **Scenario 4:** combination of all aforementioned scenarios

3.3.4 Evaluation of Energy Demand Alteration by Applying the Retrofitting Scenarios on the Base Case Model

In the last step of technical feasibility assessment of the building, each proposed scenario must be applied on predefined stimulated model which validated in previous steps. The result extracted from applying of each retrofitting scenario will be compared to the base case scenario result to assess the improvement of energy consumption in the building pre and post retrofitting. The following results classified according to number of proposed scenarios and a summary of retrofitting impact on building energy demand is provided along with each result.

Scenario 1 (insulation of roof and trusses with 5 cm of XPS): by applying first scenario on stimulated building, the result as it demonstrated in Figure 3.33 indicates up to 10% reduction in total energy consumption of the building from 417820 Kwh to 376376 Kwh, which is directly related to reduction in cooling and heating system load.

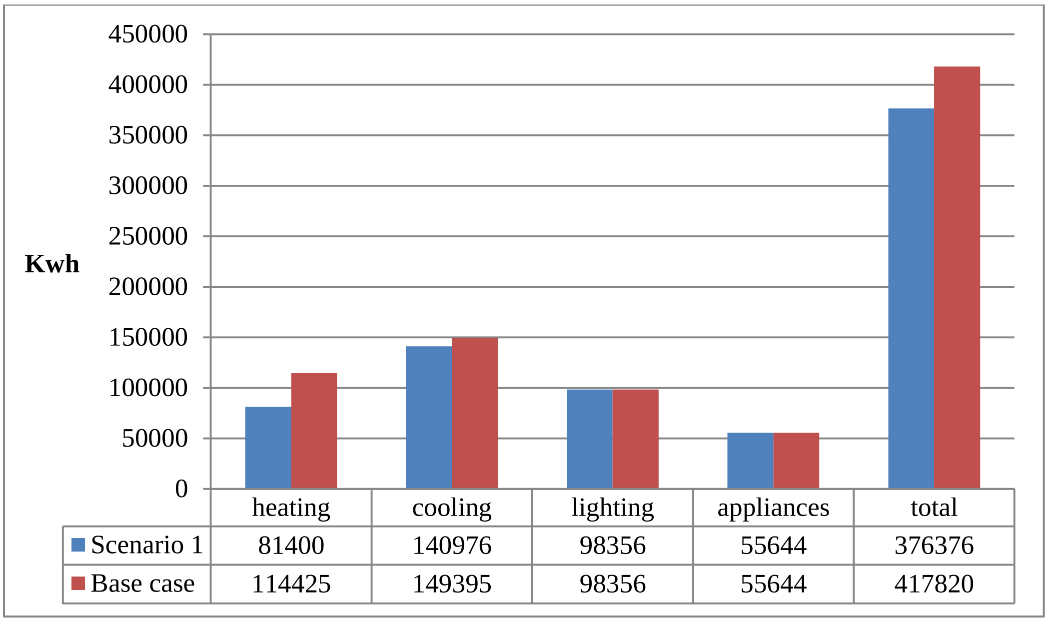
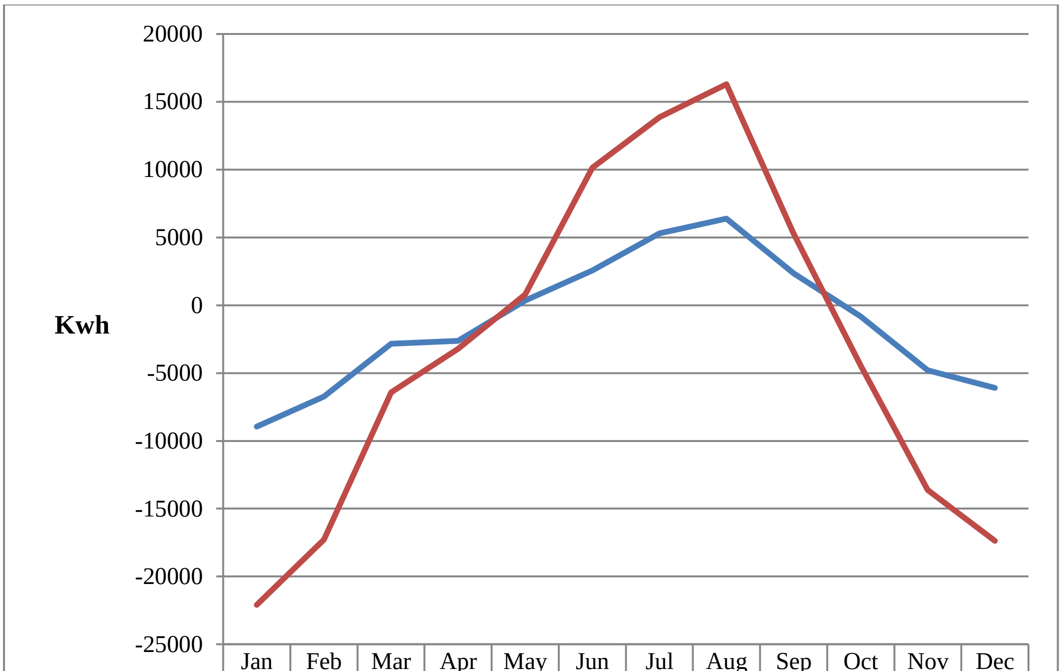


Figure 3.31: Comparison between building energy consumption in base case and after implementing scenario 1

As it shows in the results energy consumption for heating process reduced from 114,425 Kwh to 81,400 Kwh which is around 29% decrease while for cooling process it lessened from 149,395 Kwh to 140,976 Kwh which is 5.6%.there is no visible change in the amount of lighting and appliances energy consumption. This reduction in heating and cooling load comes from the fact that applying the XPS on roofs and trusses will increase resistibility of these surfaces against heat transfer. As it shown in Figure 3.3 the amount of heat loss (negative numbers) and heat gain (positive numbers) have significantly changed after applying XPS. It means that by decreasing the amount of heat loss in cold seasons the pressure on heating system will subsequently be less and on the contrary for cooling system in hot seasons.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scenario 1	-8953	-6743	-2834	-2637	332	2565	5307	6388	2352	-836	-4806	-6101
Base case	-2209	-1727	-6436	-3220	793	10133	13864	16296	5283	-4466	-1360	-1738

Figure 3.32: Annual heat transfer from roof

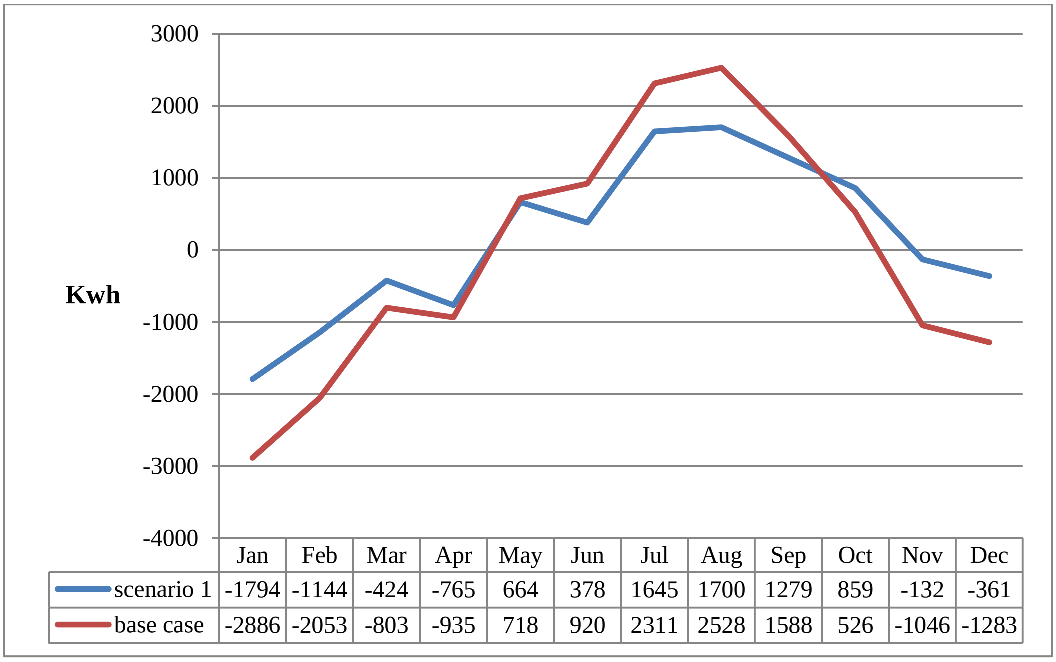


Figure 3.33: Annual heat transfer from trusses

As it shown in both Figures 3.32 and 3.33 the more the tendency of graph toward X axis the less the amount of heat transfer and eventually better implementation of the insulation. Also as a support for the claim Figures 3.34 to 3.37 depicted the effect of insulation on the amount of average surface temperature during the year as well as the solar gain for both the cases.

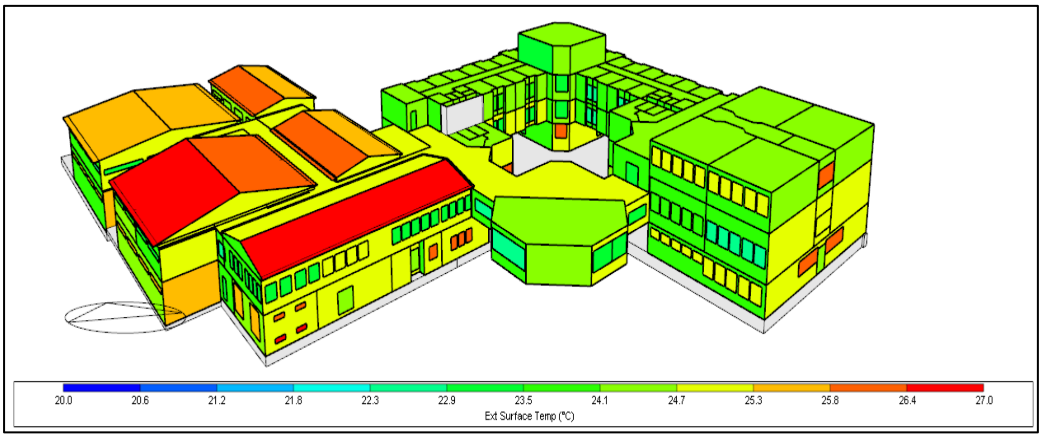


Figure 3.34: Average annual surface temperature in base case (c^o)

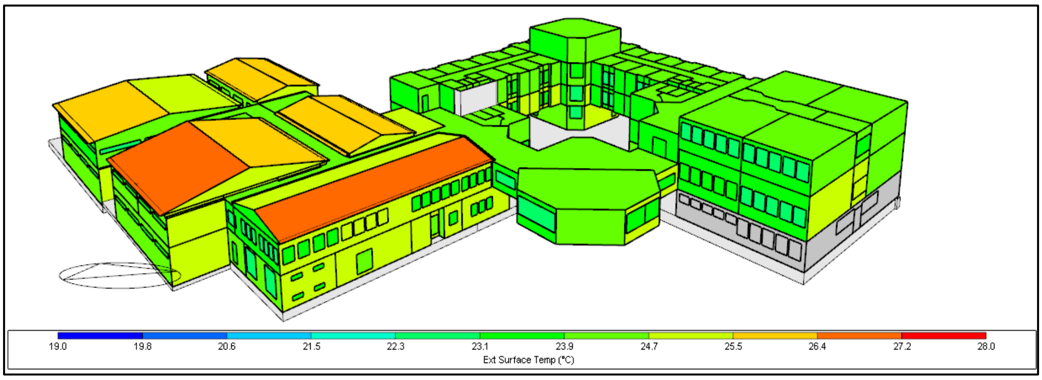


Figure 3.35: Average annual surface temperature after applying roof insulation (c°)

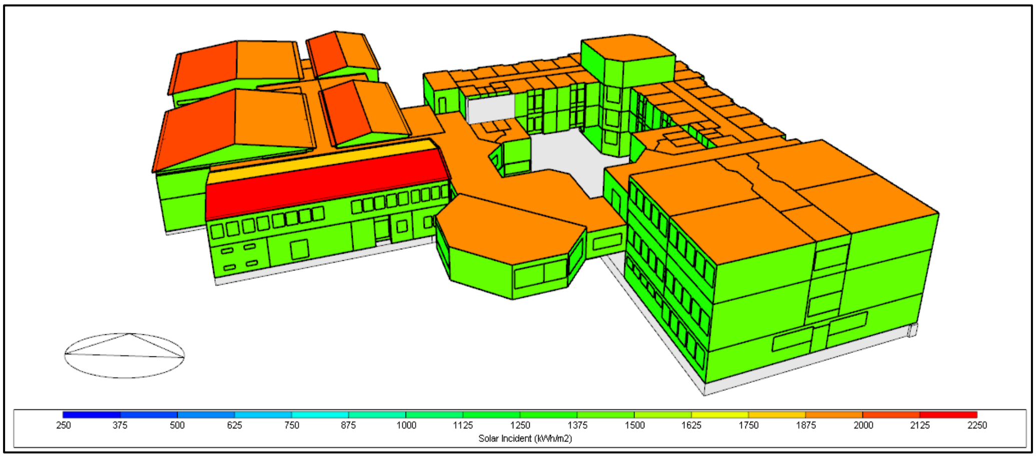


Figure 3.36: Average annual solar gains in the base case (Kwh/m2)

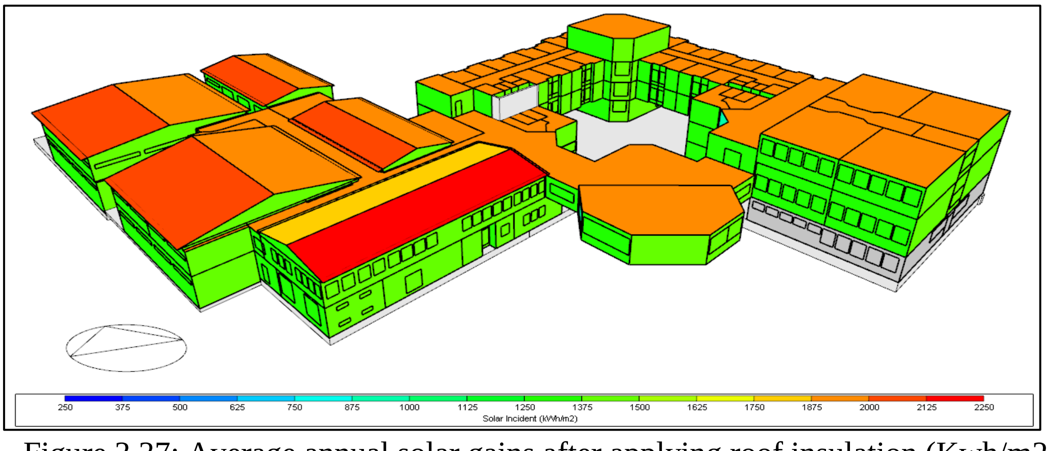
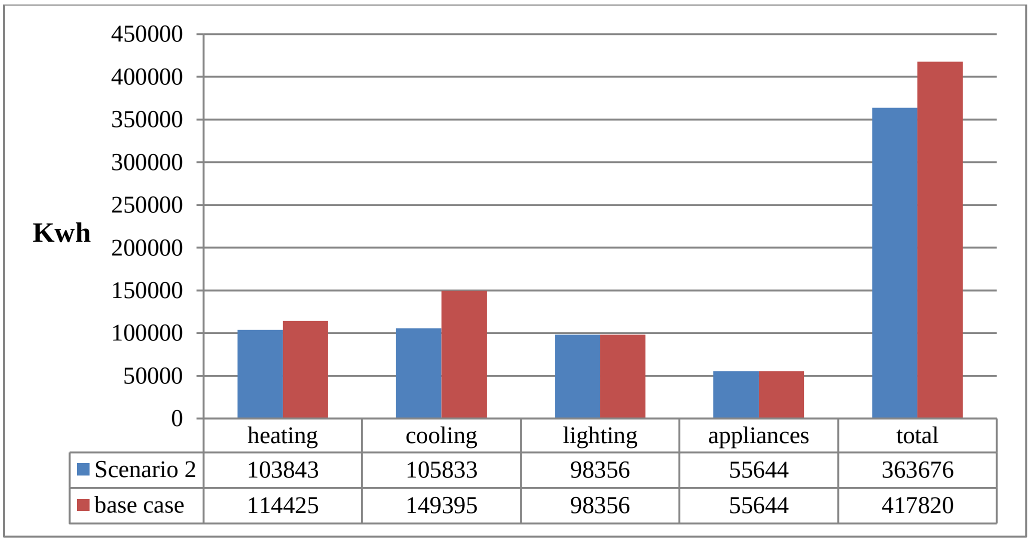


Figure 3.37: Average annual solar gains after applying roof insulation (Kwh/m2)

Scenario 2(replacing single glazed windows to double glazed low –e windows): base on the result depicted in Figure 3.38 applying the second scenario will directly influence on heating and cooling load as well . In which it will reduce heating energy consumption to 103,843 Kwh (9.2%) and for cooling energy consumption it shows the amount of 105833 Kwh which is equivalent to 29% of reduction . the result does not show any change in the amount of lighting and appliances energy consumption. In total improving the building to double glazed low-e windows lead to total of 12.9% reduction in energy consumption from 417820 Kwh in base case to 363676 Kwh.



	heating	cooling	lighting	appliances	total
Scenario 2	103843	105833	98356	55644	363676
base case	114425	149395	98356	55644	417820

Figure 3.38: Comparison between building energy consumption in base case and after implementing scenario 2

The following graphs in Figure 3.39 and 3.40 indicate the impact of improving building's windows to double glazed low-e on reducing the heat transfer and solar gains from external windows. As it illustrated in the Figure 3.40 the major impact of implementation of scenario 2 on heating and cooling load is related to reduction in the amount of heat transfer through the glazing (15.3%) and external infiltration (18.9 %) and slight reduction from 253,962 Kwh to 247,869 Kwh (approximately 2.3%) in solar gain from exterior windows.

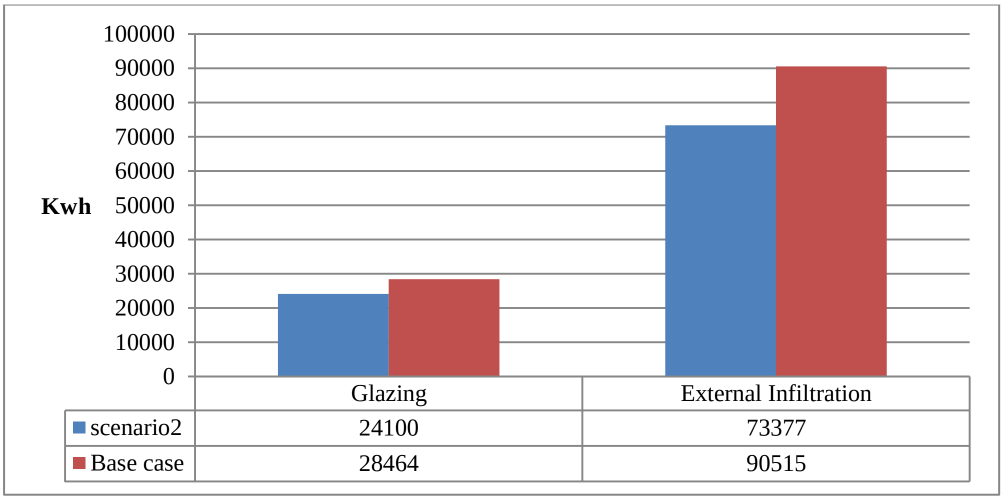


Figure 3.39: Annual heat transfer through glazing and external infiltration

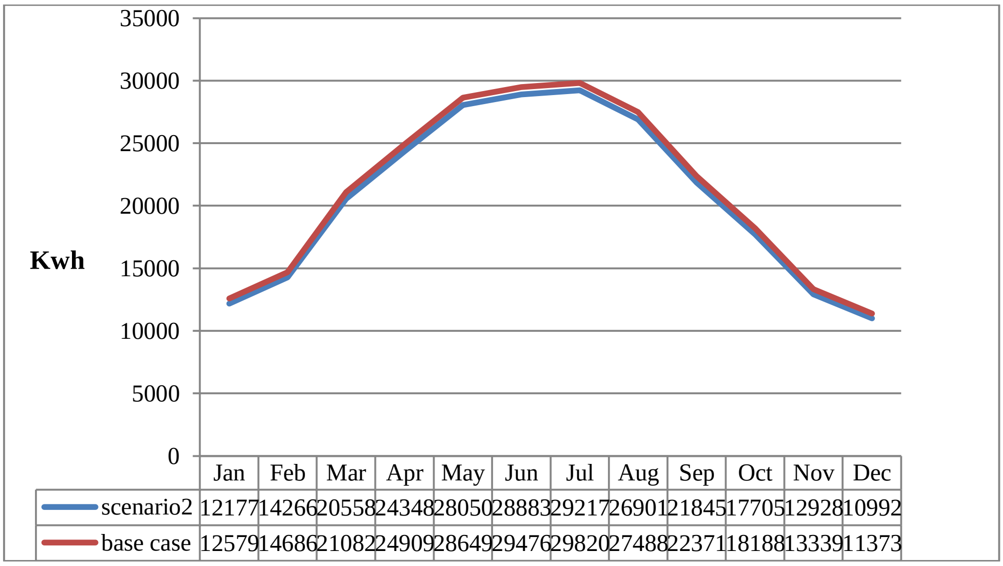
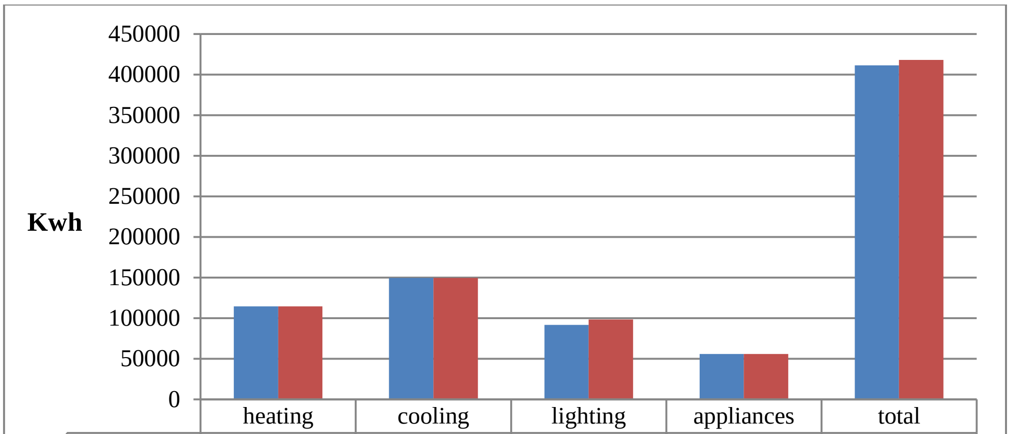


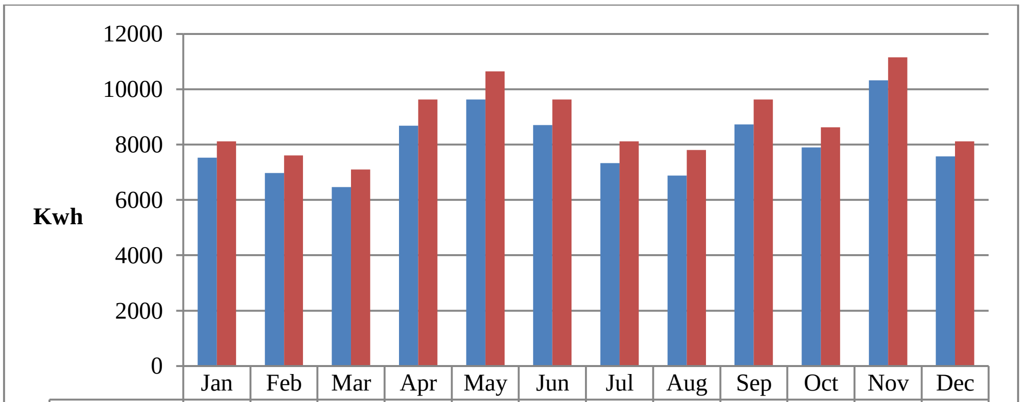
Figure 3.40: Annual solar gains through exterior windows

Scenario 3 (embedding lux and lighting control sensors with dimmable T5 fluorescents): the effect of applying this scenario is only on lighting energy consumption where reduces lighting demand from 98,356 Kwh to 91,676 (6.7%) and the rest will remain constant. In conclusion embedding lux and lighting control in the building so far will have the least impact on total energy saving of the building which according to the Figure 3.41 the total of 1.5% reduction on building energy consumption would be expected from implementing this scenario.



	heating	cooling	lighting	appliances	total
Scenario 3	114425	149395	91676	55644	411140
Base case	114425	149395	98356	55644	417820

Figure 3.41: Comparison between building energy consumption in base case and after implementing scenario 3



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scenario 3	7529	6974	6467	8683	9625	8702	7333	6877	8727	7899	10323	7570
Base case	8112	7605	7098	9633	10647	9633	8112	7802	9633	8619	11154	8112

Figure 3.42: Heat gain breakdown from scenario 3

The effect of implementing scenario on the heat gain from lighting also investigated and the result shows around 8.6% reduction in heat gain from the general lighting the annual breakdown of heat gain for both the scenarios is illustrated in Figure 3.42.

Scenario 4 (combination of all the scenarios): at first glance implementing multiple retrofitting scenarios on the building is expected to provide maximum amount of energy saving. In reality but due to mutual interaction between each scenario the same positive effect of applying solitary scenario, in multiple alternative scenarios may reduce as a result of overlapping impact from one to another. For instance application of combination of first three scenarios on the case study caused an impressive increase in cooling energy consumption (141,004 Kwh) in compare with implementing scenario 2 alone (105,833 Kwh), on the contrary implementation of combined retrofitting alternatives in this case lead to achieving the minimum energy demand for heating process in compare with all existing alternatives (67,501 Kwh). The Figure 3.43 demonstrated the effect of applying the combination of above scenarios on End-User energy consumption in compare with base case scenario.

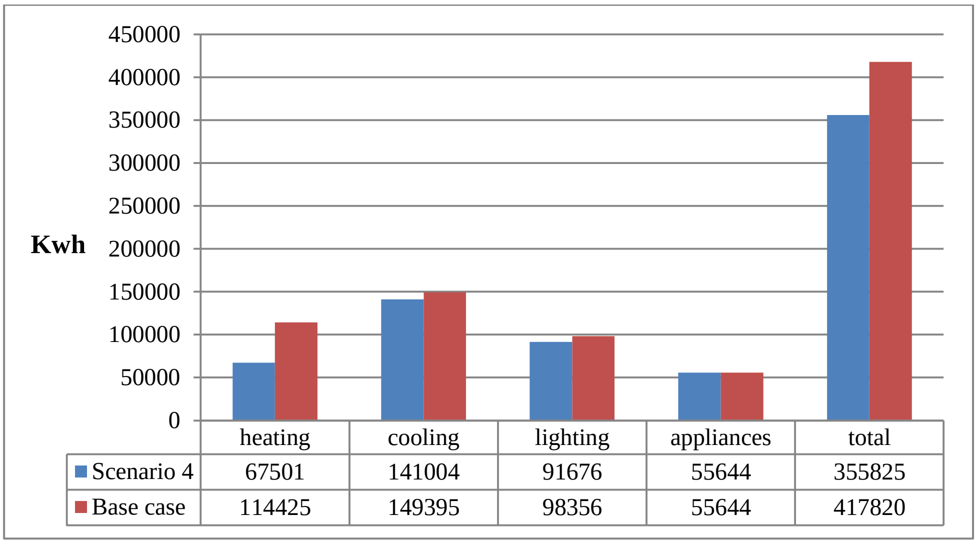


Figure 3.43: Comparison between building energy consumption in base case and after implementing scenario 4

Unexpected increase in cooling energy consumption in this scenario comparing to scenario 2 detected to be from simultaneous effect of different scenarios in heat gain and heat loss of the building. Since major pressure on the cooling system results from high temperature difference between inside and outside environment of the building and heat gain and loss play crucial in creating this imbalance by analyzing the result from both heat gain and loss in Figure 3.44 and 3.45 in predetermined hot seasons of region it is concluded that although the last scenario causes a massive 63% reduction in heat gain of the roofs in compare with scenario 2 yet , it creates an inverse effect on glazing heat gain by increasing it up to 30% and in parallel for heat loss, which may assist in reducing the cooling load during hot seasons, scenario 4 caused a negative impact on building’s component which lead to major reduction in total heat loss through the building. Therefore, as a result of composition the cooling energy consumption could increase accordingly.

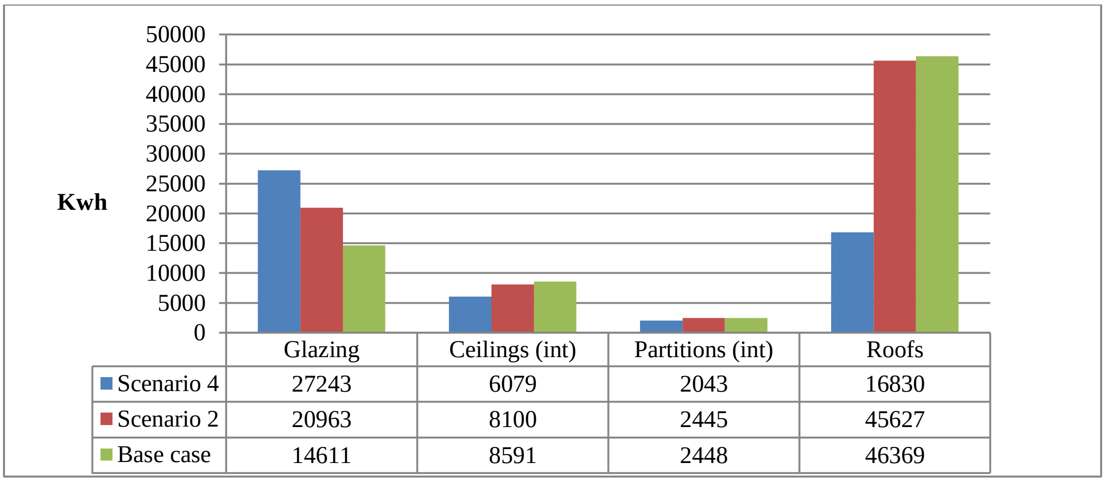


Figure 3.44: Heat gain breakdown from scenario 4

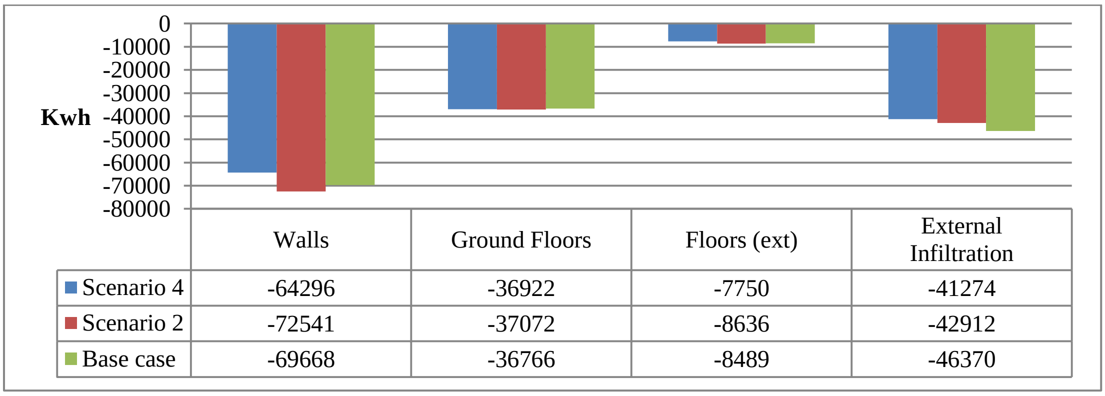


Figure 3.45: Heat loss breakdown from scenario 4

Table 3.18: Base case energy consumption (Kwh)

	End-Users	Kwh	Percentage from total
Base case	Heating	114,425	27%
	Cooling	149,395	36%
	Lighting	98,356	24%
	Appliances	55,644	13%
	Total	417,820	100%

Table 3.19: Scenario 1 energy consumption (Kwh)

	End-Users	Kwh	Percentage from total	Amount of saving from base case %
Scenario 1	Heating	81,400	22%	29%
	Cooling	140,976	37%	6%
	Lighting	98,356	26%	0%
	Appliances	55,644	15%	0%
	Total	376,376	100%	10%

Table 3.20: Scenario 2 energy consumption (Kwh)

	End-Users	Kwh	Percentage from total	Amount of saving from base case %
Scenario 2	Heating	103,843	29%	9%
	Cooling	105,833	29%	29%
	Lighting	98,356	27%	0%
	Appliances	55,644	15%	0%
	Total	363,676	100%	13%

Table 3.21: Scenario 3 energy consumption (Kwh)

	End-Users	Kwh	Percentage from total	Amount of saving from base case %
Scenario 3	Heating	114,425	28%	0%
	Cooling	149,395	36%	0%
	Lighting	91,676	22%	7%
	Appliances	55,644	14%	0%
	Total	411,140	100%	2%

Table 3.22: Scenario 4 energy consumption (Kwh)

	End-Users	Kwh	Percentage from total	Amount of saving from base case %
Scenario 4	Heating	67,501	19%	41%
	Cooling	141,004	40%	6%
	Lighting	91,676	26%	7%
	Appliances	55,644	16%	0%
	Total	355,825	100%	15%

At the end the amalgamation of the technical evaluation of the case study that could be utilized in the next step (financial assessment) as inputs to calculate operational cost of building in different circumstances is presented in Tables 3.18 to 3.22.

Chapter 4

FINANCIAL ASSESSMENT

4.1 Introduction

Chapter 4 majorly discussed about the financial feasibility evaluation of each retrofitting scenario. Aforementioned financial assessment in this chapter began with developing financial model based on deterministic values for all the scenarios as well as existing building as base case scenario using Microsoft Excel spreadsheet. From financial model each one of the scenarios is investigated and their profitability are monitored by considering the calculated criterion such as NPV, IRR, and payback period and benefit cost ratio. In the next stage, the sensitivity of each independent input variable is examined through implementation of sensitivity analysis on each input variable of deterministic financial model. Finally, by performing Monte Carlo risk analysis on identified critical input variables using Crystal Ball software in this chapter, the probability distribution of each considered output criterion from deterministic financial model is denoted and subsequently optimum alternative is selected within results and discussion in the next chapter.

4.2 Financial Assessment

While technical evaluation of each retrofitting scenarios reveals the amount of energy saving in the existing building, financial evaluation on the other hand examines the economic merit of each retrofitting option. Financial assessment process as a complementary procedure is a critical step of each energy retrofitting planning. Although technical assessment provides the impact of each scenario on energy conservation in the building (percentage of reduction in energy consumption), yet, investors are mostly concerned about the monetary benefit of the project rather than other non-monetary result attained through the retrofitting procedure. Therefore in order to persuade them toward adopting energy retrofit measures on existing buildings, project plan should be consist of a meaningful financial appraisal along with a technical appraisal to illuminate both monetary and non-monetary profitability of the project. Also regardless of how much each retrofitting alternative affects the total building's energy consumption, it does not necessarily make it the best possible option since the financial parameter such as initial cost, discount rate, and change in energy prices and change in energy requirement within an investment horizon will also be influential in decision making process. (European Commission, 2014) Introduced an integrated financial analysis as an analysis which consists of three following steps:

1. Financial appraisal (based on deterministic values)
2. Sensitivity analysis
3. Risk analysis.

4.2.1 Input Parameters

Generally financial appraisal is the process of analyzing a flow of cash to estimate profitability of the projects. In this financial model there are certain input parameters that have to be taken into consideration as follow:

Investment horizon: when it comes to investigating of long term projects investment horizon is one of the outmost significant key data in financial analysis of such investments. Given the useful remaining life of the building and based on European guide in cost and benefit analysis (European Commission, 2014) investment horizon of 25 years for research purposes considered for this case study.

Therefore the study period proposed for this case study starts at year 2019 as the base year and ends at year 2044 where 2019 will be considered as study base year.

Discount rate: it is an interest rate adopted to discount the future values in cash flow to the base year. In most of the investment analysis even a fraction of fluctuation in the amount of discount rate may cause a major difference in costs and revenues and eventually expected outcomes (NPV, IRR and so on.). Therefore discount rate is considered to be intrinsically a critical variable among other key data related to the cash flow. Due to its sensitivity discount rate was extensively examined in other studies. Since the retrofitting project considered being self-funded, in this case normally, an appropriate amount of discount rate should be equivalent to capital cost of fund which refers to the interest rate paid by financial institutions for the funds that they use in other business. The selection of discount rate in investment appraisal has to be either by using nominal discount rate which is inflation included with nominal prices or by adopting real discount rate which is inflation excluded with real or constant prices. Either way the outcome of investment appraisal (NPV) should not be different because even if nominal discount rate and prices are utilized in financial model at the end all the existing values have to deflated using similar price index to eliminate the effect of inflation from the financial appraisal. A typical approach in cost benefit analysis is to express all the costs and revenues and discount rate for a project in real term to avoid any miscalculation on future course of inflation due to its uncertain and unpredictable nature (Harrison, 2010) Considering the dependent nature of northern Cyprus economy to turkey as the biggest supplier of the region and also with an identical currency unit, Turkish inflation and respectively its discount rate is chosen as proxy for this study. In this financial modeling two different approaches selected for adopting a real discount rate for cash flow projection. The first approach is to refer to average risk free rate of investment which indicates the capital cost of fund as a minimum interest an investor would expect from a risk free investment (considering all the investment carry even small amount of risk so the numbers are theoretical) in four years period from 2015 to 2019. (James Cherowbrier, 2019) Published a statistics overview on aforementioned subject which indicated that average risk free rate of investment fluctuates between 7.8% and 11.2% as it illustrated in the following Figure 4.1.

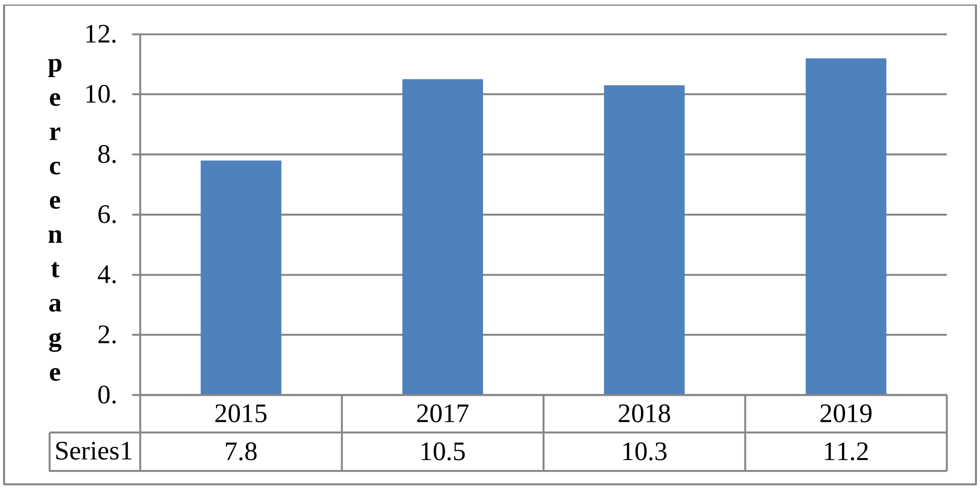


Figure 4.1: Average risk free rates in Turkey (percentage)

And the second approach is to calculate real discount rate from nominal discount rate using inflation rate. Therefore, considering the interest rate in financial institution for more than one year deposit could be a good indication of discount rate's magnitude, all the data for weighted average interest rate for deposit in Turkish Lira (TL) from Central bank of Turkey for year 2010 to 2019 have been extracted ("EVDS," 2019) and also inflation related data which indicated the relevant inflation for those years obtained from (InflationEU, 2019) and using below formula all nominal interest rate are converted to real (inflation adjusted interest rate) as it shows in the Table 4.1.

$$\mathbf{r = R + risk\ primeum + (1 + R + risk\ primium\ ) \times gpe} \quad \textbf{(4.1)}$$

Table 4.1: Real discount rate (percentage)

	Inflation rate for turkey (%)	Inflation (%)	Fixed deposit rate of return from central bank of turkey (%)	Real discount rate (%)
2010	6.4	6.40	9.30	8.68
2011	10.45	10.45	9.20	8.23
2012	6.16	6.16	10.10	9.46
2013	7.4	7.40	8.10	7.47
2014	8.17	8.17	9.90	9.08
2015	8.81	8.81	9.90	9.02
2016	8.53	8.53	11.00	10.06
2017	11.92	11.92	12.20	10.79
2018	20.03	20.03	16.20	13.33
2019	18.71	18.71	23.43	19.58

At the end by performing a descriptive statistical analysis on historical data for acquired real interest rate, the mean value of 10.77% obtained which indicated the most possible occurrence of the data among all the collected data for real interest rate within last 10 years. simple comparison between the results from both the approaches is an evidence of a rough similarity also from the expert's opinions up to year 2018 the most applicable real discount rate for investment appraisal in Turkey estimated between 8% to 10% with given uncertain and volatile economic circumstances that governs North Cyprus and Turkey all together supports selection of 10% real discount rate for this study.

Inflation: the value of a currency determined by what they can buy, and the general rise in the price level which known as inflation causes a reduction in purchasing power of that currency and eventually decreasing the value of that currency. As a result the effect of inflation in forming a cash flow projection could not be overlooked. Therefore as it previously stated it is better to remove impact of inflation from cash flow to avoid any miscalculation on future course of inflation due to its uncertain and unpredictable nature. In order to eliminate inflation effect from deterministic financial model both discount rate and existing prices in the model such as energy price, initial cost of investment and operational cost have been converted to real price.

Price of LPG: the average nominal price of LPG in year 2019 obtained from (Aytemiz, 2019) Website, since year 2019 assumed as a base year in financial model, and in the base year nominal prices are equivalent to real prices considering the price index in the base year is equal to 1 therefore in the model nominal price of year 2019 is the same price of real price. From this point onward all the prices calculated using unit price of LPG will remain based on constant price of year 2019. According to (Aytemiz, 2019) average unit price of LPG in 2019 was 3.71 TL/Liter, because all the calculation of energy consumption was based on Kwh and for bulk LPG every Liter is equivalent to 7.08 Kwh, therefore 0.52 TL/Kwh considered as the unit price of LPG for entire study duration.

Price of electricity: the same routine as LPG unit price applied for electricity unit price. The average unit price of electricity 0.98 TL/Liter is extracted from ("Tarife Arşivi – KIBRIS TÜRK ELEKTRİK KURUMU," 2019) for the year 2019 and it is adopted as real price. Since the electricity prices were on Kwh, there was no necessity for unit conversion.

Initial cost of scenario 1 (roof insulation): local market data has been used for initial cost of material and installation of XPS roof insulation. No annual maintenance cost is taken into calculation. The unit cost of XPS and other peripheral materials along with installation and workmanship is considered as 55 TL/m2.

Which include 15-25 TL/m 2 for the workmanship and installation, 1.5-2 TL/m2 for geotextile mesh on top of XPS and 25 TL for Extruded polystyrene foam (0.6 m×1.2 m). Total required roof area for insulation is 3,750 m2, therefore the total initial cost of implementing scenario1 will be calculated 206,250 TL.

Initial cost of scenario 2 (double glazed low-e windows): the state planning and organization price list for North Cyprus shows the rough estimation of unit price of white PVC framed windows with double glazed low-e glasses (4-12-4 mm) with thermal insulation along with the installation and workmanship is roughly 700 TL/m2. The total required area for changing the windows from normal single glazed to double glazed low-e with PVC frame is 393 m2 therefore the total initial cost of implementing scenario 2 will become 275,100 TL.

Initial cost of scenario 3 (lux and lighting control device): from the data obtained through electrical section of technical affairs the price for all necessary devices include motion detector sensors, daylight sensor, lux controller and dimmable ballast for each set is approximately 1,300 TL/m2 for each set which is depend on number of required ballast for each area will change with 120 TL/unit. There is also an additional price of 2,800 TL for setting up an integrated control system over entire building for remote controlling. These prices obtained from major supplier of lighting system in North Cyprus which known KNX. The total number of required package device for the building is 95 units that are calculated from the number of areas in the building which have windows facing outside of the building and the number of required T-5 fluorescents dimmable is estimated 303 units which in total the initial cost of implementing scenario 3 estimated to be 162,660 TL.

Initial cost of scenario 4 (combination of all the scenarios): since scenario 4 implied to combination of all the scenarios therefore summation of all the cost in other scenario will be considered as an initial cost for the last scenario which will become 644,010 TL.

Change in all independent input variable: in order to accommodate uncertainties, risks and change in future risk and sensitivity analysis for deterministic financial model, the change in real prices as well as real discount rate and building's energy requirement by each end user is formulated by Excel in financial model spreadsheet but, since the model is based on deterministic values, in primary financial analysis the unit price of energy sources will not be changed over time and eventually all the changes for entire independent variables should considered to be zero. It also could be interpreted that, notwithstanding, the change in independent input variables will not be taken into account in financial model since the model is based on deterministic values but the alteration of initial costs and their effect on financial model's outcome will be examined through sensitivity and risk analysis to evaluate the sensitivity of NPV and IRR as a dependent outcome with independent variables.

4.2.2 Financial Model Components

Cash flow: it is the most basic and an integral component of each investment appraisal that is required to calculate economic measure and demonstrates the flow of cash in and out of the business within the specific period of time. Normally cash flows capture all costs and revenues associated with the project within a predetermined investment horizon. Related costs and revenues to a certain project could be categorized into tax payments, loans repayments, and initial payments, operating costs, maintenance costs, depreciation cost and also revenues as grants, subsidies, salvage value and so forth. In this case however, the only cost associated with the project is an initial cost of implementation of retrofitting scenario and due to self-funded nature of the project as well as application of the case study as university's department, the existence of such expenditures such as taxes, loans and depreciation costs are ignored also retrofitting measures adopted in the project such as insulation and double low-e glasses do not necessarily required maintenance and in just one case which are lux and lighting control devices there might be a necessity of maintenance which since they have the least effect on energy consumption reduction in the building, so the maintenance cost also could be overlooked. On the other hand in this particular case the difference in operating cost of the building in each year for every retrofitting alternative accounted as the revenue generated by that specific alternative which could be readily calculated by multiplying the difference amount of energy consumption from base case with renovated building for each year with corresponding unit price of energy source. And due to privately funding nature of the project and lack of incentives from the government bodies to promote such an action, government grants and subsidies are also ignored.

Operational cost: Once the general economic data is determined the other non-economic data such as the amount of energy consumption for base case and other scenarios, for different End-Users such as heating, cooling, lighting and appliances from technical results have to be inserted in financial model to respectively calculate the annual cost of energy consumption (operational cost) and their deviation from the base case cost of energy consumption will be considered as saving or revenue of that specific alternative. The detail of annual energy consumptions for the building for the base case scenario and after applying each retrofitting scenario based on technical results are provided in the Tables below and accordingly the annual cost of energy consumption which referred to operational cost of the building in base year 2019 for existing building's End-Users and for other scenarios for year 2020 are computed using Excel spreadsheet using the unit price of required energy source and allocated percentage to each energy source's contribution based on following formula:

$$\mathbf{H}_{c} = (\boldsymbol{H_E} \times \mathbf{E}_{\boldsymbol{U}} \times \%\mathbf{E}_{\boldsymbol{H}}) + (\mathbf{H}_{\boldsymbol{E}} \times \mathbf{LPG}_{\boldsymbol{U}} \times \%\ \mathbf{LPG}_{\boldsymbol{H}}) \quad \textbf{(4.2)}$$

$$\boldsymbol{C_C} = \mathbf{C}_{\boldsymbol{E}} \times \mathbf{E}_{\boldsymbol{U}} \quad \textbf{(4.3)}$$

$$\mathbf{L}_{\boldsymbol{C}} = \mathbf{L}_{\boldsymbol{E}} \times \mathbf{E}_{\boldsymbol{U}} \quad \textbf{(4.4)}$$

$$\mathbf{A}_{\boldsymbol{C}} = \mathbf{A}_{\boldsymbol{E}} \times \mathbf{E}_{\boldsymbol{U}} \quad \textbf{(4.5)}$$

The reason why operational costs are calculated for the base case in 2019 and for the rest of retrofitting scenarios in 2020 is since the base year of financial model is considered as 2019 and at the same the base year is construction year itself therefore the operational cost imposed to each project in base year (construction year) is equivalent to the existing building's cost and the effect of retrofitting scenarios on the cost will emerge from year 1 in investment horizon which is year 2020.For example the parameter involved in annual cost of energy consumption of heating in the base case are: Energy consumption of heating in the base case (114,425 Kwh), unit price of electricity (0.98 TL/Kwh), unit price of LPG (0.52 TL/Kwh), contribution of LPG as primary energy source in heating 83% and contribution of electricity as secondary source of energy is 17%.Heating cost of energy consumption= (114,425×0.52×0.17) + (114,425×0.98×0.83) = 68,449 TL. Since heating is the only End-User which operates through both electricity and LPG , % of contribution have to be applied in its cost calculation but for the rest of End-Users the only source of energy is electricity therefore by just multiplying the total amount of energy to unit price of electricity the rest will be calculated easily. Annual cooling cost = 149395 Kwh×0.98 TL/Kwh= 146,407 TL. Annual lighting cost = 98365

Kwh×0.98 TL/Kwh= 96,388 TL. Annual appliances cost = 55,644 Kwh×0.98 TL/Kwh= 54,531 TL. Table 4.2 depicted the annual cost of energy consumption in the base case scenario.

Table 4.2: Annual cost of energy consumption in base case (Kwh)

Annual energy consumption (base case)	
Heating (Kwh)	114,425
Cooling (Kwh)	149,395
Lighting (Kwh)	98,356
Appliances (Kwh)	55,644
Total (Kwh)	417,820
Annual cost of energy consumption (base case)	
Heating (TL)	68,449
Cooling (TL)	146,407
Lighting (TL)	96,388
Appliances (TL)	54,531
Total (TL)	365,776

The same procedure applied for all other scenarios to calculate the operational cost of the building in year 2020 as first operational year after 2019 as construction year. Also the percentage of reduction in both energy consumption and the cost in compare to the base case scenario are indicated. It is notable that no matter operational cost for existing building scenario (base case) taken place in 2019 but since the operational cost for existing building in 2019 is same as other scenarios therefore the change in operational cost from year 2019 to 2020 for each scenario indicates the change as a result of implementing retrofitting scenarios on an existing building. Entire detail for energy consumption, change in energy consumption in compare to base case and respectively related cost of energy consumption for each retrofitting scenario provided in Table 4.3 to 4.10 below.

Table 4.3: Energy consumption and change in energy consumption for scenario 1 (Kwh)

Annual energy consumption (scenario 1)	
Heating (Kwh)	81,400
Heating saving from the base %	28.86%
Cooling (Kwh)	140,976
Cooling saving from the base %	5.64%
Lighting (Kwh)	98,356
Lighting saving from the base %	0.00%
Appliances (Kwh)	55,644
Appliances saving from the base %	0.00%
Total (Kwh)	376,376
Total saving from the base %	9.92%

Table 4.4: Cost related to energy consumption and change in cost for scenario 1 (TL)

Detailed annual cost of energy consumption TL (scenario 1)		**Saving in cost comparing to base case**
Heating (TL)	48,693	29%
Cooling (TL)	138,156	6%
Lighting (TL)	96,388	0%
Appliances (TL)	54,531	0%
Total (TL)	337,769	8%

Table 4.5: Energy consumption and change in energy consumption for scenario 2 (Kwh)

Annual energy consumption (scenario 2)	
Heating (Kwh)	103,843
Heating saving from the base %	9.25%
Cooling (Kwh)	105,833
Cooling saving from the base %	29.16%
Lighting (Kwh)	98,356
Lighting saving from the base %	0.00%
Appliances (Kwh)	55,644
Appliances saving from the base %	0.00%
Total (Kwh)	363,676
Total saving from the base %	12.96%

Table 4.6: Cost related to energy consumption and change in cost for scenario 2 (TL)

Detailed annual cost of energy consumption TL (scenario 2)		**Saving in cost comparing to base case**
Heating (TL)	62,118	9%
Cooling (TL)	103,716	29%
Lighting (TL)	96,388	0%
Appliances (TL)	54,531	0%
Total (TL)	316,755	13%

Table 4.7: Energy consumption and change in energy consumption for scenario 3 (Kwh)

Annual energy consumption (scenario 3)	
Heating (Kwh)	114,425
Heating saving from the base %	0.00%
Cooling (Kwh)	149,395
Cooling saving from the base %	0.00%
Lighting (Kwh)	91,676
Lighting saving from the base %	6.79%
Appliances (Kwh)	55,644
Appliances saving from the base %	0.00%
Total (Kwh)	411,140
Total saving from the base %	1.60%

Table 4.8: Cost related to energy consumption and change in cost for scenario 3 (TL)

Detailed annual cost of energy consumption TL (scenario 3)		**Saving in cost comparing to base case**
Heating (TL)	68,449	0%
Cooling (TL)	146,407	0%
Lighting (TL)	89,842	7%
Appliances (TL)	54,531	0%
Total (TL)	359,229	2%

Table 4.9: Energy consumption and change in energy consumption for scenario 4 (Kwh)

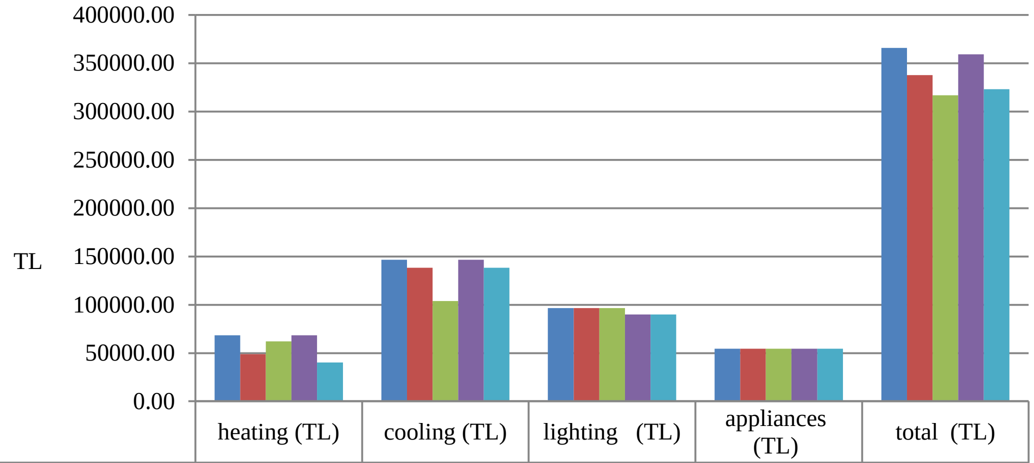
Annual energy consumption (scenario 4)	
Heating (Kwh)	67,501
Heating saving from the base %	41.01%
Cooling (Kwh)	141,004
Cooling saving from the base %	5.62%
Lighting (Kwh)	91,676
Lighting saving from the base %	6.79%
Appliances (Kwh)	55,644
Appliances saving from the base %	0.00%
Total (Kwh)	355,825
Total saving from the base %	14.84%

Table 4.10: Cost related to energy consumption and change in cost for scenario 4 (TL)

Detailed annual cost of energy consumption TL (scenario 4)		Saving in cost comparing to base case
Heating (TL)	40,379	41%
Cooling (TL)	138,183	6%
Lighting (TL)	89,842	7%
Appliances (TL)	54,531	0%
Total (TL)	322,936	12%

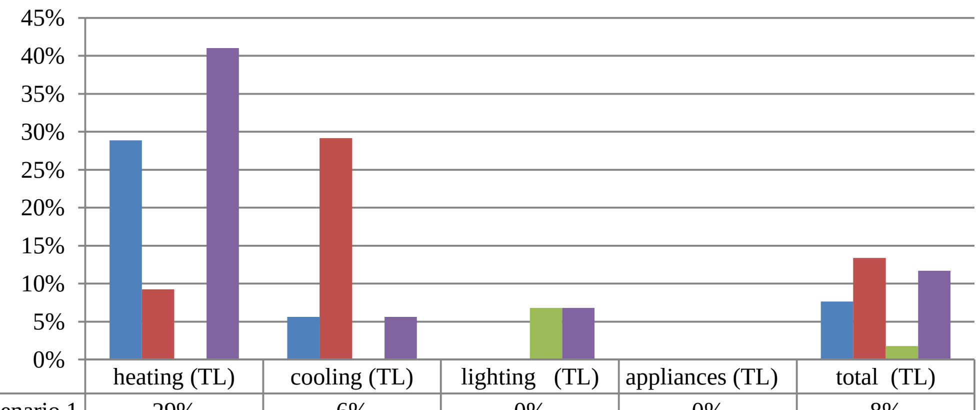
As it demonstrated in below Figure 4.2 and 4.3 the minimum amount of operational cost in compare to the base case scenario in heating is belong to scenario 4 with 40,379 TL which indicates 28,070 TL (41%) reduction as result of applying roof insulation, double glazed low-e windows and utilizing the building with lux and lighting control system. For cooling but, application of double glazed low-e windows minimized the cost to 103,716 TL that is 42,690 TL (29%) reduction from the base case scenario. In terms of lighting the only scenario which influence the cost of lighting is scenario 3and 4 where application of lux and lighting control reduces the cost to 89,842 TL which is 6,546 TL (7%) reduction comparing to base case scenario

.finally none of retrofitting scenario affected the amount energy consumption in appliances therefore the cost also will remain as same as base case scenario.



	heating (TL)	cooling (TL)	lighting (TL)	appliances (TL)	total (TL)
Base case scenario	68449.04	146407.10	96388.88	54531.12	365776.14
Scenario 1	48693.48	138156.48	96388.88	54531.12	337769.96
Scenario 2	62118.88	103716.34	96388.88	54531.12	316755.22
Scenario 3	68449.04	146407.10	89842.48	54531.12	359229.74
Scenario 4	40379.10	138183.92	89842.48	54531.12	322936.62

Figure 4.2: Annual operational cost of building (TL)



	heating (TL)	cooling (TL)	lighting (TL)	appliances (TL)	total (TL)
Scenario 1	29%	6%	0%	0%	8%
Scenario 2	9%	29%	0%	0%	13%
Scenario 3	0%	0%	7%	0%	2%
Scenario 4	41%	6%	7%	0%	12%

Figure 4.3: Annual reduction in operational cost of building (percentage)

From the total cost reduction in the base year 2019 scenario 2 with 316,755 TL of annual operation cost have the least cost among others which shoes the reduction of

49,020 TL (13%) in compare with total annual operational cost of base case scenario 365,776 TL.

Operational cost for the rest of cash flow duration (2021 to 2044): Based on constant unit price of electricity and LPG for the base case scenario an Excel spreadsheet is developed for year 2021 to 2044 to calculate the operational cost of each year as follow:

$$\mathbf{OC\ (n) = OC\ (n\text{-}1) \times (1 + \%COC)} \qquad \mathbf{(4.6)}$$

For the base case scenario, there are two point which has to be considered, the first one is since heating as an End-User in the building consumes two different type of energy sources (electricity and LPG) at the same time, therefore calculation of cost related to each energy source should be perform separately. That is because in case if the change in real price of both the energy sources are not the same, each one accurately could be calculated for sensitivity and risk analysis purposes. The second point is since the change in real price of energy in deterministic financial model has to be ignored hence; as an input, the % of change in the model is considered zero and subsequently all the result in the base case scenario will become the same as base year 2019. Once the operational cost for all the years are determined the summation of all discounted value indicates the net present value of entire operational cost for each End-User and finally the NPV of total operational cost for base case scenario. For other retrofitting scenarios also the same procedures applies with one difference which is the operational cost for base year 2019, since year 2019 is considered as an investment year for all retrofitting scenarios, the same operational cost as the base case scenario applied for all other investment scenario and for the rest of the years operational cost will be calculated based on the same procedure for base case scenario with replacement of related energy consumption for each End-Users after application of retrofitting scenarios. Table 4.11 below presented the total present worth of operational cost of each end-user for every existing alternative.

Table 4.11: Total present worth of operational cost (TL)

Type of End-Users	Heating	Cooling	Lighting	Appliances	Total
Total present worth of saving in base case scenario (TL)	0.00	0.00	0.00	0.00	0.00
Total present worth of saving in scenario 1 (TL)	179,321	74,891	0.00	0.00	254,213
Total present worth of saving in scenario 2 (TL)	57,459	387,505	0.00	0.00	444,964
Total present worth of saving in scenario 3 (TL)	0.00	0.00	59,421	0.00	59,421
Total present worth of saving in scenario 4 (TL)	254,791	74,642	59,421	0.00	388,856

As it expected from operational cost scenario 2 generated the highest amount of saving with 412,841 TL in 25 year of study life of the project.

Incremental cash flow: since all the costs and benefits associated with the project are determined, as per recommendation of (European Commission, 2014) an incremental cash flow should be developed to compare the counterfactual base line scenario in the absence of the projects (retrofitting scenario) with other scenarios including the projects (retrofitting scenarios). Without the project concept does not indicate that no action is undertaken if projects are not adopted but principally it refers to natural evolvement of relevant item and market if the projects left aside and other non-project aspects are taken into consideration (Jenkins & Harberger, 2011) in this context two state of nature have to be conceptualized where in both all costs and benefits related to counterfactual baseline and project adopted scenario have to be clearly stated to enable investors to monitor financial progression , regression or depression as a result of utilizing the project and consequently facilitate investors them with better knowledge of the effect of each retrofitting scenario on existing building in best alternative selection. As far as the existing circumstances of the building concerns without considering any retrofitting scenario, the operational cost which happened to occur from base year due to absence of any retrofitting measure, and known as benchmark saving comparison for the rest of situations, will not change, therefore the expected saving as a result of reduction in operational cost will become zero and remains the same for entire study life of project (25 years). For the rest of alternatives all the costs (initial cost of retrofitting) and revenues (difference between operational cost in existing building and scenario included situation) are pictured in the cash flow for 25 years. The only significant point in the cash flow is, change in amount of energy consumption which reflects operation cost and eventually the amount of saving in each scenario will start right after construction period that is assumed to be at year zero (base year 2019). It means revenues in the cash flow in base year is equal to zero while for the rest of the year from year 1 to year 25 it reflects the amount of saving for each alternative which is a constant number for entire period due to deterministic nature of cash flow because the inflation effect is removed and change in real price did not considered in financial modeling.

4.2.3 Financial Model's Output

The preliminary conclusion drawn from financial model exercise's results manifestly points out that scenario 2 (replacement of single glazed windows with double glazed low-e windows) requires second highest investment with 275,100 TL in construction phase (base year 2019) after scenario 4 which ranked first in highest investment cost with 644,010 due to extensive nature of retrofitting measures included in this scenario. As a result scenario 2 generates the highest return among others as the only scenario with positive NPV (169,864 TL) with maximum internal rate of return 17.50% which is higher than assumed discount rate (10%) and minimum payback period of 5.61 years as well as decent benefit cost ratio of 1.62 (since it is above 1). All together these evidences indicated the economic merits of scenario 2 from deterministic financial appraisal and made it an interesting alternative for further investigation in sensitivity and risk analysis. The other closest scenario to scenario 2 in terms of profitability is scenario 1 which generated (47,963 TL) net present value and very close to discount rate IRR (10.94%) . the other criterion for scenario 1 are also close to accepting border but since scenario 2 made huge difference in terms of profitability it is more acceptable. However other two scenarios (3 and 4) have negligible financial returns with very long duration of payback period hence from financial model comparison it is evident that they have to be rejected. Summary of the results for all the scenarios from financial modeling demonstrated in the Table 4.12.

Table 4.12: Financial model's output summery

Scenario	**Initial cost of investment (TL)**	**Present worth of savings (TL)**	**NPV (TL)**	**IRR (%)**	**Payback period (years)**	**Benefit cost ratio**
1	206,250	254,213	47,963	12.93%	7.36	1.233
2	275,100	444,964	169,864	17.50%	5.61	1.62
3	162,660	59,421	-103,238	0.05%	24.85	0.37
4	644,010	388,856	-255,153	4.37%	15.03	0.60

4.3 Sensitivity Analysis

To accommodate the uncertainty among different variables, instead of static value, for each input variable in economic model (cash flow) a range of values should be assigned to determine how different values of an independent variable (inputs) influence a specific dependent variable (outputs) under a provided set of assumptions. Sensitivity analysis will also assist analysts in debugging financial model by tracing any abnormal deviation in dependent variable (output) with changing in the range of an independent variable (input). But the major purpose of performing sensitivity analysis is to discover most sensitive inputs among others with respect to output deviation from the base point which known as critical variables. The range of independent variables (inputs) for sensitivity analysis extracted from either of the percentage change in set of variables from historical data or using verified range of variables from other studies. It also could be retrieved from expert's opinions. In this study the range for input variables such as real discount rate, change in real price of electricity and change in LPG's real price retrieved from year to year percentage change of historical data. Converting nominal electricity and LPG price in which they extracted from data bases to real price is taken place as follow:

From the historical data a year should be considered as base year to convert nominal prices to real prices, in this case since collected LPG historical prices starts from year 2010, the same year 2010 selected as base year to calculate price index. Price index of each year calculated using inflation for each year by adding or subtracting inflation with unit price index for the base year which is 1.00. And also because the historical data for electricity was available from year 2006 the following price indices in Table 4.13 are calculated for both electricity and LPG historical data.

Table 4.13: Price index

Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Inflation %	9.65	8.39	10.06	6.53	6.40	10.45	6.16	7.40	8.17	8.81	8.53	11.92	20.03	18.7
Price index	0.69	0.77	0.87	0.94	1.00	1.06	1.17	1.23	1.30	1.39	1.47	1.56	1.68	1.88

In the next step using below formula and calculated price index the real price of each year electricity and LPG is obtained and respectively the amount of year to year change in real price is achieved as it is shown in below Tables 4.14 and 4.15 to define an appropriate range for sensitivity analysis variable:

$$\textbf{Real price} = \frac{\textbf{Nominal price}}{\textbf{price index}} \tag{4.7}$$

Table 4.14: Real price of LPG (TL/ Kwh)

Years	Average LPG nominal price TL/Kwh	Inflation	Price index	Real price of LPG TL/ Kwh
2010	2.11	6.40%	1.00	0.29
2011	2.35	10.45%	1.06	0.31
2012	2.45	6.16%	1.17	0.29
2013	2.77	7.40%	1.23	0.31
2014	2.84	8.17%	1.30	0.30
2015	2.46	8.81%	1.39	0.25
2016	2.58	8.53%	1.47	0.24
2017	3.13	11.92%	1.56	0.28
2018	3.51	20.03%	1.68	0.29
2019	3.71	18.71%	1.88	0.27

Table 4.15: Real price of electricity (TL/ Kwh)

Years	Average electricity nominal price TL/Kwh	Inflation	Price index	Real price of electricity TL/Kwh
2006	0.24	9.65%	0.69	0.35
2007	0.35	8.39%	0.77	0.45
2008	0.44	10.06%	0.87	0.51
2009	0.76	6.53%	0.94	0.81
2010	0.68	6.40%	1.00	0.68
2011	0.52	10.45%	1.06	0.49
2012	0.6	6.16%	1.17	0.51
2013	0.58	7.40%	1.23	0.47
2014	0.61	8.17%	1.30	0.47
2015	0.68	8.81%	1.39	0.49
2016	0.58	8.53%	1.47	0.39
2017	0.58	11.92%	1.56	0.37
2018	0.7	20.03%	1.68	0.42
2019	0.98	18.71%	1.88	0.52

Table 4.16: Real discount rate (percentage)

	Inflation	Fixed deposit rate of return from central bank of Turkey	Real discount rate
2010	6.40	9.30	8
2011	10.45	9.20	8
2012	6.16	10.10	9
2013	7.40	8.10	7
2014	8.17	9.90	9
2015	8.81	9.90	9
2016	8.53	11.00	10
2017	11.92	12.20	10
2018	20.03	16.20	13
2019	18.71	23.43	19

Historical data for real discount rate as well collected from year 2010 and presented in Table 4.16.

For initial cost of retrofitting due to unavailability of historical data, this range acquired from (Menicou et al., 2015) where it considered fluctuation between ±30 percent for all initial costs of retrofitting. Once variables ranges are determined using what if function in excel spreadsheet for each variable sensitivity analysis will be perform to monitor the impact of each variable on the NPV. Following Tables 4.17 and 4.18 depicted the results for all independent variables from financial model and its impact as a percentage of change created by that variable to accurately assess the sensitivity of each output (NPV) for every scenario to that certain variable.

Table 4.17: Sensitivity analysis result for change in real price of electricity (TL)

change in real price of electricity	NPV scenario 1	NPV scenario 2	NPV scenario 3	NPV scenario 4
-20.0%	22,996	89,163	-115,122	-296,158
-15.0%	29,238	109,338	-112,151	-285,907
-10.0%	35,479	129,513	-109,180	-275,656
-5.0%	41,721	149,689	-106,209	-265,405
0%	47,963	169,864	-103,238	-255,153
5.0%	54,204	190,040	-100,266	-244,902
10.0%	60,446	210,215	-97,295	-234,651
15.0%	66,688	230,391	-94,324	-224,400
20.0%	72,929	250,566	-91,353	-214,149

Table 4.18: Effect of change in real price of electricity on NPV (percentage)

change in real price of electricity	% change NPV 1	% change NPV 2	% change NPV 3	% change NPV 4
-20.0%	-52.05%	-47.51%	-11.51%	-16.07%
-15.0%	-39.04%	-35.63%	-8.63%	-12.05%
-10.0%	-26.03%	-23.75%	-5.76%	-8.04%
-5.0%	-13.01%	-11.88%	-2.88%	-4.02%
0%	0.00%	0.00%	0.00%	0.00%
5.0%	13.01%	11.88%	2.88%	4.02%
10.0%	26.03%	23.75%	5.76%	8.04%
15.0%	39.04%	35.63%	8.63%	12.05%
20.0%	52.05%	47.51%	11.51%	16.07%

For change in real electricity prices as it illustrated in Tables 4.19 and 4.20 with reduction in real price of electricity the productivity of the projects will eventually reduce, vice versa, increasing the real price will elevate the total NPV of the projects. The impact of change in real price of electricity is more obvious with scenario 1 and 2 where each 5% increase or decrease in real price of electricity will affect the NPV of those scenarios with almost double amount. It is considerable that the percentage of change in NPVs is a deviation of the amount of NPV from the base point where the percentage is 0. The amount of change in each scenario NPV is as result of contribution of each scenario in energy consumption reduction in End-Users where electricity is a major energy sources such as cooling, lighting and appliances. Apart from scenario 3 which has least sensitivity among others to change in real price of electricity in general change in real price of electricity could be considered as a critical variable in this case.

Table 4.19: Sensitivity analysis result for change in real price of LPG (TL)

change in real price of LPG	NPV scenario 1	NPV scenario 2	NPV scenario 3	NPV scenario 4
-20%	22,087	161,573	-103,238	-291,920
-15%	28,556	163,646	-103,238	-282,728
-10%	35,025	165,719	-103,238	-273,537
-5%	41,494	167,791	-103,238	-264,345
0%	47,963	169,864	-103,238	-255,153
5%	54,432	171,937	-103,238	-245,962
10%	60,901	174,010	-103,238	-236,770
15%	67,370	176,083	-103,238	-227,579
20%	73,839	178,156	-103,238	-218,387

Table 4.20: Effect of change on NPV (percentage)

change in real price of LPG	% change NPV 1	% change NPV 2	% change NPV 3	% change NPV 4
-20%	-53.95%	-4.88%	0.00%	-14.41%
-15%	-40.46%	-3.66%	0.00%	-10.81%
-10%	-26.97%	-2.44%	0.00%	-7.20%
-5%	-13.49%	-1.22%	0.00%	-3.60%
0%	0.00%	0.00%	0.00%	0.00%
5%	13.49%	1.22%	0.00%	3.60%
10%	26.97%	2.44%	0.00%	7.20%
15%	40.46%	3.66%	0.00%	10.81%
20%	53.95%	4.88%	0.00%	14.41%

Change in real price of LPG as shown in the Table has the maximum effect on scenario 1 NPV due to the significant reduction in heating energy consumption caused by implementing roof insulation (29%) and heating system dependency to LPG consumption. For every 5% reduction or increase in real price of LPG up to 14 percent of total NPV will be reduced or increased in scenario 1. It is notable that even though the amount of heating energy consumption with scenario 4 is even more than scenario 1(41.01%) but due to its higher amount of initial cost of retrofitting, change in real price of LPG will not reflect as much as scenario 2 percentage change in NPV for scenario 4. Evidently, NPV for Scenario 3 will not be influenced by change in real price of LPG, because implementation of this scenario did not show any reduction in heating energy consumption. In conclusion change in real price of LPG also should be considered as critical variable as well.

As far as real discount rate concerns usually a little bit of reduction or increase in the amount of discount rate will cause dramatic effect on the outcome of the cash flow. In this case also depend on both the amount of saving which each scenario generates and the amount of initial cost of investment for each scenario; discount rate will affect that particular scenario. Below Tables 4.21 and 4.22 clearly demonstrated the impact of each percent reduction or increase in amount of real discount rate on all the scenarios where scenario 1 with 4% increase in NPV for each one percent reduction in real discount rate and inversely -4% decreases in NPV. Although in compare to other independent variable change in real discount rate presented less effect on the outcome of the scenarios yet, since the changes ‘s range is smaller it also could be considered as other critical variable in financial model.

Table 4.21: Sensitivity analysis result for change in real discount rate (TL)

change in real discount rate	**NPV scenario 1**	**NPV scenario 2**	**NPV scenario 3**	**NPV scenario 4**
-4%	55,988	183,911	-101,362	-242,878
-3%	53,942	180,330	-101,840	-246,007
-2%	51,923	176,796	-102,312	-249,096
-1%	49,930.	173,308	-102,778	-252,144
0%	47,963	169,864	-103,238	-255,153
1%	46,021	166,465	-103,692	-258,124
2%	44,103	163,109	-104,140	-261,057
3%	42,210	159,796	-104,582	-263,953
4%	40,341	156,524	-105,019	-266,811

Table 4.22: Effect of change on NPV (percentage)

change in real discount rate	% change NPV 1	% change NPV 2	% change NPV 3	% change NPV 4
-4%	17%	8%	2%	5%
-3%	12%	6%	1%	4%
-2%	8%	4%	1%	2%
-1%	4%	2%	0%	1%
0%	0%	0%	0%	0%
1%	-4%	-2%	0%	-1%
2%	-8%	-4%	-1%	-2%
3%	-12%	-6%	-1%	-3%
4%	-16%	-8%	-2%	-5%

Change in initial cost of each scenario as it showed in Tables 4.23 and 4.24 caused tremendous effects on each scenario's result. In general, when initial retrofitting cost of each scenario increases, NPV of that particular scenario will decrease. on the contrary in case of reduction in initial cost of each scenario, respectively the NPV will raise. The amount of alteration of the outcome is highly depends on the saving that each project will generate. In this case study for each 5% increase or decrease in initial retrofitting cost up to 22% rise or fall will take place in the amount of NPV in scenario 1which indicates max effect among other scenarios. In conclusion since the least impact of initial cost on NPV for each 5% change is about 8%, hence, initial cost as well should be accounted as critical variable.

Table 4.23: Sensitivity analysis result for change in initial cost of scenarios (TL)

Change in initial cost of scenarios	NPV scenario 1	NPV scenario 2	NPV scenario 3	NPV scenario 4
-30%	109,838	252,394	-54,440	-61,950
-25%	99,525	238,639	-62,573	-94,151
-20%	89,213	224,884	-70,706	-126,351
-15%	78,900	211,129	-78,839	-158,552
-10%	68,588	197,374	-86,972	-190,752
-5%	58,275	183,619	-95,105	-222,953
0%	47,963	169,864	-103,238	-255,153
5%	37,650	156,109	-111,371	-287,354
10%	27,338	142,354	-119,504	-319,554
15%	17,025	128,599	-127,637	-351,755
20%	6,713	114,844	-135,770	-383,955
25%	-3,599	101,089	-143,903	-416,156
30%	-13,911	87,334	-152,036	-448,356

Table 4.24: Effect of change on NPV (percentage)

Change in initial cost of scenarios	% change NPV 1	% change NPV 2	% change NPV 3	% change NPV 4
-30%	129%	49%	47%	76%
-25%	108%	40%	39%	63%
-20%	86%	32%	32%	50%
-15%	65%	24%	24%	38%
-10%	43%	16%	16%	25%
-5%	22%	8%	8%	13%
0%	0%	0%	0%	0%
5%	-22%	-8%	-8%	-13%
10%	-43%	-16%	-16%	-25%
15%	-65%	-24%	-24%	-38%
20%	-86%	-32%	-32%	-50%
25%	-108%	-40%	-39%	-63%
30%	-129%	-49%	-47%	-76%

Finally, the last group of independent variables are include change in energy requirement for each End-user that apparently for heating and cooling resulted in tremendous change in the outcome of financial model from the sensitivity analysis generally with reduction in energy requirement the effect of implementing each scenario on existing building will reduce eventually. Vice versa increasing in energy requirement will increase the profitability of those scenarios that had impact of energy consumption's reduction on the building.

Table 4.25: Sensitivity analysis result for change in heating energy requirement (TL)

Change in heating energy requirement	NPV scenario 1	NPV scenario 2	NPV scenario 3	NPV scenario 4
-30%	-5,833	152,627	-103,238	-331,592
-25%	3,133	155,500	-103,238	-318,852
-20%	12,099	158,373	-103,238	-306,112
-15%	21,065	161,246	-103,238	-293,373
-10%	30,031	164,119	-103,238	-280,633
-5%	38,997	166,992	-103,238	-267,894
0%	47,963	169,865	-103,238	-255,154
5%	56,929	172,738	-103,238	-242,414
10%	65,895	175,611	-103,238	-229,675
15%	74,861	178,484	-103,238	-216,935
20%	83,828	181,357	-103,238	-204,196
25%	92,794	184,230	-103,238	-191,456
30%	101,760	187,102	-103,238	-178,716

Table 4.26: Effect of change on NPV (percentage)

Change in heating energy requirement	% change NPV 1	% change NPV 2	% change NPV 3	% change NPV 4
-30%	-112%	-10%	0%	-30%
-25%	-93%	-8%	0%	-25%
-20%	-75%	-7%	0%	-20%
-15%	-56%	-5%	0%	-15%
-10%	-37%	-3%	0%	-10%
-5%	-19%	-2%	0%	-5%
0%	0%	0%	0%	0%
5%	19%	2%	0%	5%
10%	37%	3%	0%	10%
15%	56%	5%	0%	15%
20%	75%	7%	0%	20%
25%	93%	8%	0%	25%
30%	112%	10%	0%	30%

Table 4.27: Sensitivity analysis result for change in cooling energy requirement (TL)

Change in cooling energy requirement	NPV scenario 1	NPV scenario 2	NPV scenario 3	NPV scenario 4
-30%	25,495	53,613	-103,238	-277,546
-25%	29,240	72,988	-103,238	-273,814
-20%	32,984	92,364	-103,238	-270,082
-15%	36,729	111,739	-103,238	-266,350
-10%	40,474	131,114	-103,238	-262,618
-5%	44,218	150,489	-103,238	-258,886
0%	47,963	169,865	-103,238	-255,153
5%	51,707	189,240	-103,238	-251,421
10%	55,452	208,615	-103,238	-247,689
15%	59,196	227,991	-103,238	-243,957
20%	62,941	247,366	-103,238	-240,225
25%	66,685	266,741	-103,238	-236,493
30%	70,430	286,117	-103,238	-232,761

Table 4.28: Effect of change on NPV (percentage)

Change in cooling energy requirement	% change NPV 1	% change NPV 2	% change NPV 3	% change NPV 4
-30%	-47%	-68%	0%	-9%
-25%	-39%	-57%	0%	-7%
-20%	-31%	-46%	0%	-6%
-15%	-23%	-34%	0%	-4%
-10%	-16%	-23%	0%	-3%
-5%	-8%	-11%	0%	-1%
0%	0%	0%	0%	0%
5%	8%	11%	0%	1%
10%	16%	23%	0%	3%
15%	23%	34%	0%	4%
20%	31%	46%	0%	6%
25%	39%	57%	0%	7%
30%	47%	68%	0%	9%

Table 4.29: Sensitivity analysis result for change in lighting energy requirement (TL)

Change in lighting energy requirement	NPV scenario 1	NPV scenario 2	NPV scenario 3	NPV scenario 4
-30%	47,963	169,865	-121,064	-272,980
-25%	47,963	169,865	-118,093	-270,009
-20%	47,963	169,865	-115,122	-267,038
-15%	47,963	169,865	-112,151	-264,067
-10%	47,963	169,865	-109,180	-261,096
-5%	47,963	169,865	-106,209	-258,125
0%	47,963	169,865	-103,238	-255,153
5%	47,963	169,865	-100,266	-252,182
10%	47,963	169,865	-97,295	-249,211
15%	47,963	169,865	-94,324	-246,240
20%	47,963	169,865	-91,353	-243,269
25%	47,963	169,865	-88,382	-240,298
30%	47,963	169,865	-85,411	-237,327

Table 4.30: Effect of change on NPV (percentage)

Change in lighting energy requirement	% change NPV 1	% change NPV 2	% change NPV 3	% change NPV 4
-30%	0%	0%	-17%	-7%
-25%	0%	0%	-14%	-6%
-20%	0%	0%	-12%	-5%
-15%	0%	0%	-9%	-3%
-10%	0%	0%	-6%	-2%
-5%	0%	0%	-3%	-1%
0%	0%	0%	0%	0%
5%	0%	0%	3%	1%
10%	0%	0%	6%	2%
15%	0%	0%	9%	3%
20%	0%	0%	12%	5%
25%	0%	0%	14%	6%
30%	0%	0%	17%	7%

Sensitivity analysis in which depicted in Tables 4.25 to 4.30 for each End-user indicated the significance of change in heating and cooling energy requirement where it shows the most impact on scenario 1 and 2. As far as lighting concerns due to the effect of only scenario 3 on energy consumption reduction in lighting only scenario 3 and 4 as combination of all scenarios are slightly influenced by change in energy requirement in lighting area. Finally, since none of the scenarios have effect on appliances energy consumption change in appliances energy consumption will not cause any change in profitability of each scenario, therefore appliances could be removes from critical variable list for risk analysis.

4.4 Risk Analysis

As it recommended by (European Commission, 2014) the last step of every developed financial analysis is risk analysis where each suggested candidates to be included as critical input parameter from sensitivity analysis will take a range of value rather than a single determined value (static value) to accommodate existing uncertainty and using one of the stimulation approaches (in this case Monte Carlo stimulation) different combination of values will be assigned to the model to monitor how they will affect the outcome.it is noteworthy here to mention that, nevertheless sensitivity analysis evaluates the impact of one or two parameters at the time on model’s outcome but it cannot accommodate the nature of risk in a financial model, due to its shortcoming such as lack of capability in processing multiple critical variable at the same time or ignoring the correlation between variables. On the contrary risk analysis is facilitated with the abilities such as attaching probability distribution to critical variables in order to estimate their future behavior, simultaneous alteration of different critical variables at the time to evaluate their impact under more uncertain circumstances and also considering the correlation between variables all at once which utilize decision makers with better understanding of existing possibilities due to uncertain nature of entire critical variables. On the other hand it is indispensable that the construction of entire Tables in the financial model should be linked to the Table of parameters (inputs) based on the related formula and equations to maintain integrity of financial model for sensitivity and risk analysis. Therefore along with significant role of sensitivity analysis in identification of critical variables its contribution to check whether or not financial model has been developed accurately is also quite remarkable.

In this study risk analysis has been performed through the add-on software from Oracle called Crystal ball fusion edition 11.1.2.1.000. It is plug inn software which will be attached to Excel spreadsheet and utilize it with the ability of performing risk stimulation and statistical analysis on set of selected data. Once sensitivity analysis performed the following essential general steps have to be taken to implement an accurate risk analysis.

4.4.1 Identification of Critical Variables Based on their Risky and Uncertain Natures

A variable called risky in nature if it has significant impact on the project's outcome, on the other hand uncertainty in variable's nature refers to unpredictability of the variable. In this study seven independent variables comprised of real discount rate, change in real price of LPG and electricity, initial cost of retrofitting scenario 1 to 4 and change in heating, cooling and lighting energy requirements identified as risky and uncertain variables. To capture the range in which critical variables will change in future, several contrivances could be adopted by analysts. The most common solution to this problem is to utilize probabilistic or stochastic modeling to discover the nature of parameter's value. Aforementioned process generally taken place by collecting historical data for particular variable and assigning the probability of occurrence that each specific variable will materialize. It also has to be taken into consideration that Although in depth comprehension of the variable’s underlying nature will provide a clear insight for future projection of change in variable yet, necessarily what happened in past might not happen again in future specifically when projection’s duration will become as long as 25 years so, at this point logic and intuition as two complementary factors provided by the experts in field will assist to adjust appropriate probability distribution for a set of most likely data in terms of possibility of occurrences. Crystal ball provided two general solutions for assigning probability distribution to each variable. First is manual and the second is automatic allocation probability distribution fitting which will be discussed below.as far as critical variables in this study concerns the allocated probability distribution for each one of them is as follow:

Change in real discount rate: in general, change in real discount rate is a product of different parameters such as supply and demand, inflation and government’s policy. Being highly volatile in nature, real discount rate required more rigorous attention in determining probability distribution’s fit. Since change in discount rate itself is directly related to the region’s economic stability and other factors such as inflation and government’s policy, it is vital to select an appropriate period of time in order to fit the best probability distribution for real discount rate. Therefore to prevent any misunderstanding in probability distribution which calculated using historical data both intuition and logic have to be taken into account to utilize the best possible set of data which may lead to the best probability distribution’s fit for risk analysis. In this study a set of historical data collected from year 2010 to 2019 when the real discount rate in turkey stabilized in a reasonable range for couple of years.

Furthermore, out of two possible approaches for probability distribution's fitting due to disability of Crystal ball software in automatically fitting the probability distribution for less than 15 historical data as well as sensitive nature of discount rate the best possible action is to manually fit the existing set of data. In order to define probability distribution for real discount rate as it mentioned previously a set of data calculated for real discount rate is determined (Table 4.31) and eventually using data analysis tab in Excel a regression analysis performed on collected set of historical data to identify its trend over years and accordingly make an informed judgment about the future alteration of real discount rate. Where based on predicted and residual outputs a deviation is calculated for each value which expressing the deviation of that particular value from the trend. In the next step from a set of deviations using 2k>n rules, where n defines number of historical data and k represents number of classes, certain number of class will be calculated to categorize calculated deviations in those class (Table 4.32) and finally by creating frequency distribution using histogram , the probability of occurrence of each class will be determined and by adjusting frequencies with the help of solver tab in Excel expected values will be equal to the deterministic value of risk variable (Table 4.33). Once the entire step performed, resulted Table for minimum and maximum range for each class along with their allocated probability of occurrences could be adopted in risk analysis assumptions. As it previously stated, historical data of real discount rate for Turkey which was calculated based on inflation rate of Turkey and fixed deposit rate of return for more than one year acquired from central bank of Turkey as well as the regression analysis result and histogram for real discount rate are collected and demonstrated in below Tables 4.31, 4.32, 4.33.

Table 4.31: Historical data for real discount rate (percentage)

	Inflation	Fixed deposit rate of return from central bank of turkey	Real discount rate
2010	6.40	9.30	8
2011	10.45	9.20	8
2012	6.16	10.10	9
2013	7.40	8.10	7
2014	8.17	9.90	9
2015	8.81	9.90	9
2016	8.53	11.00	10
2017	11.92	12.20	10
2018	20.03	16.20	13
2019	18.71	23.43	19

Table 4.32: Regression analysis table for real discount rate

Observation	Predicted Y	Residuals	deviation
1	6.529725388	2.15072574	32.94%
2	7.427537732	0.807410208	10.87%
3	8.325350076	1.130565523	13.58%
4	9.22316242	-1.750164282	-18.98%
5	10.12097476	-1.044243692	-10.32%
6	11.01878711	-2.001325477	-18.16%
7	11.91659945	-1.859748811	-15.61%
8	12.8144118	-2.020273125	-15.77%
9	13.71222414	-0.382473244	-2.79%
10	14.61003648	4.969527159	34.01%

n	10		**range**	52.99%
min	-0.19		**k**	4
max	0.34		**class size**	13.25%

Table 4.33: Histogram table for real discount rate

min	max	mid	max	Frequency	probability	expected value
-19%	-6%	-12%	-0.057	6	57%	-7.00%
-6%	8%	1%	0.075	1	10%	0.09%
8%	21%	14%	0.208	2	17%	2.47%
21%	34%	27%	0.340	2	16%	4.44%
			More	0		
			total	10	100%	0.00%

From the existing range of values and their corresponding probability following custom distribution from Crystal ball gallery selected and based on minimum and maximum range for each class, and their related probability, below probability distribution defined for change in real discount rate. It is also considerable that as the project is getting bigger in terms of size and investment the sensitivity of selecting best fit for probability distribution increases and fitting existing historical data with either of risk analysis software itself or other complementary statistical software seems to be more necessary. Also increase in number of historical data will provide clearer picture for the trend that those variables were following in the past.

Change in LPG price: normally prices in every financial appraisal could be influenced by two different factors. The first one is inflation in which the effect have been removed from the financial modeling of the case study using constant real prices and the second one is the change in real prices due to an imbalance in demand and supply of the goods or services. In order to estimate the trend's change in real price of LPG same process is applied to historical data collected for real LPG prices and the result for regression analysis, histogram is provided in Tables 4.34, 4.35, and 4.36.

Table 4.34: Historical data for real LPG price (TL/Kwh)

Years	Average LPG nominal price	Inflation	Price index	Real price of LPG TL/ Kwh
2010	2.11	6.40%	1.00	0.29
2011	2.35	10.45%	1.06	0.31
2012	2.45	6.16%	1.17	0.29
2013	2.77	7.40%	1.23	0.31
2014	2.84	8.17%	1.30	0.30
2015	2.46	8.81%	1.39	0.25
2016	2.58	8.53%	1.47	0.24
2017	3.13	11.92%	1.56	0.28
2018	3.51	20.03%	1.68	0.29
2019	3.71	18.71%	1.88	0.27

Table 4.35: Regression analysis table for real LPG price

Observation	Predicted Y	Residuals	deviation
1	0.305675	-0.00765	-3%
2	0.301916	0.01004	3%
3	0.298156	-0.00201	-1%
4	0.294397	0.023661	8%
5	0.290637	0.016954	6%
6	0.286878	-0.03615	-13%
7	0.283119	-0.03588	-13%
8	0.279359	0.004178	1%
9	0.2756	0.019779	7%
10	0.27184	0.007082	3%

n	10		**range**	21%
min	-13%		**k**	4
max	8%		**class size**	5%

Table 4.36: Histogram table for real LPG price

min	max	mid	max	Frequency	probability	expected value
-13%	-7%	-10%	-0.07	1.88	19%	-2%
-7%	-2%	-5%	-0.02	0.98	10%	0%
-2%	3%	0%	0.03	2.91	29%	0%
3%	8%	5%	0.08	4.22	42%	2%
			More	0		
			total	10	100%	0.00%

Change in price of electricity: as it explained for change in real price of LPG, change in real price of electricity also follows the same procedure since the numbers of available data are less than 15. Tables 4.37, 4.38 and 4.39 respectively depicted the historical data, regression and histogram analysis for real price of electricity.

Table 4.37: Historical data for real electricity price (TL/Kwh)

years	Average electricity nominal price	Inflation	Price index	Real price of electricity
2006	0.24	9.65%	0.69	0.35
2007	0.35	8.39%	0.77	0.45
2008	0.44	10.06%	0.87	0.51
2009	0.59	6.53%	0.94	0.63
2010	0.68	6.40%	1.00	0.68
2011	0.52	10.45%	1.06	0.49
2012	0.54	6.16%	1.17	0.46
2013	0.58	7.40%	1.23	0.47
2014	0.61	8.17%	1.30	0.47
2015	0.68	8.81%	1.39	0.49
2016	0.58	8.53%	1.47	0.39
2017	0.58	11.92%	1.56	0.37
2018	0.7	20.03%	1.68	0.42
2019	0.98	18.71%	1.88	0.52

Table 4.38 Regression analysis table for real electricity price

Observation	Predicted Y	Residuals	deviation
1	0.543534	-0.19378	-36%
2	0.536154	-0.08167	-15%
3	0.528774	-0.02343	-4%
4	0.521394	0.290571	56%
5	0.514014	0.165986	32%
6	0.506634	-0.01791	-4%
7	0.499254	0.014225	3%
8	0.491874	-0.02037	-4%
9	0.484494	-0.01674	-3%
10	0.477114	0.013577	3%
11	0.469734	-0.07622	-16%
12	0.462354	-0.09037	-20%
13	0.454974	-0.03791	-8%
14	0.447594	0.074043	17%

n	14		**range**	91%
min	-36%		**k**	4
max	56%		**Class size**	23%

Table 4.39: Histogram table for real electricity price

min	max	mid	max	Frequency	probability	expected value
-36%	-13%	-24%	-0.12807	3.434571	25%	-5.9%
-13%	10%	-1%	0.100387	7.353393	53%	-0.7%
10%	33%	21%	0.328842	2.141357	15%	3.3%
33%	56%	44%	0.557297	1.070679	8%	3.4%
			More	0		
			total	14	100%	0.00%

Change in price of initial cost for scenario 1, 2 and 3: there are several reason associated with fluctuation of cost in retrofitting investment. The parameter such as deficiencies and inaccuracies in design and performance of retrofitting process, unforeseen cost of installation and damages through the process and also unavailability tools and equipment which indirectly increase the initial cost of retrofitting scenarios. By considering expert's opinion the change in initial investment cost for retrofitting it assumed to be between ±10 percent for the entire scenarios. Still it should be taken into account that initial cost for scenario 4 is the summation of all initial costs for other scenarios therefore changing in initial cost of each scenario will automatically reflected in scenario 4 so it is not necessary to perform probability distribution analysis for scenario 4. For the rest of scenarios since there is no record of historical data for initial cost of investment therefore a uniform distribution model is adopted to evenly distribute the possibility of occurrence for each value for later risk analysis in Crystal ball.

Change in energy requirement: change in climate condition, occupant's behavior, building and its service system related characteristics and also change in number of occupants might be considered as influential factors in increasing or decreasing energy requirement in buildings. In this study a range of ±30 percent change has been considered depend on aforementioned unquantifiable parameters. The range is adopted based on the similar study on residential buildings in Republic of Cyprus in 2014 (Menicou et al., 2015). Since change in appliance's energy requirement did not take into account since it does not make any difference in financial model's outcome. For probability distribution model as well it is same as the model for initial cost investment change, it means, a uniform probability distribution for the range of -30%

to +30% change due to lack of historical data considered to be applied in risk analysis for probability change's occurrence in future.

4.4.2 Defining Correlation Among Related Critical Variables

Definition of a correlation for the variables that are associated together would be the next step. It is one other advantage of risk analysis software which enables analysts to incorporate the relation between each two or more variable set in their risk analysis model to calculate more sophisticated and accurate result for decision makers. The coefficient for correlation between each set of data calculated using the CORREL function in Excel. In order to define a correlation between different variable some criteria have to be met, firstly we can define two variables as correlated variable when both of them tend to move together over specific period of time also both the data set should be expressed in real terms. In this model real price of electricity and LPG are considered to be correlated. From the historical data, correlation coefficient is calculated as 0.33 and in the next step this correlation will be established in risk analysis as Figure 4.9.

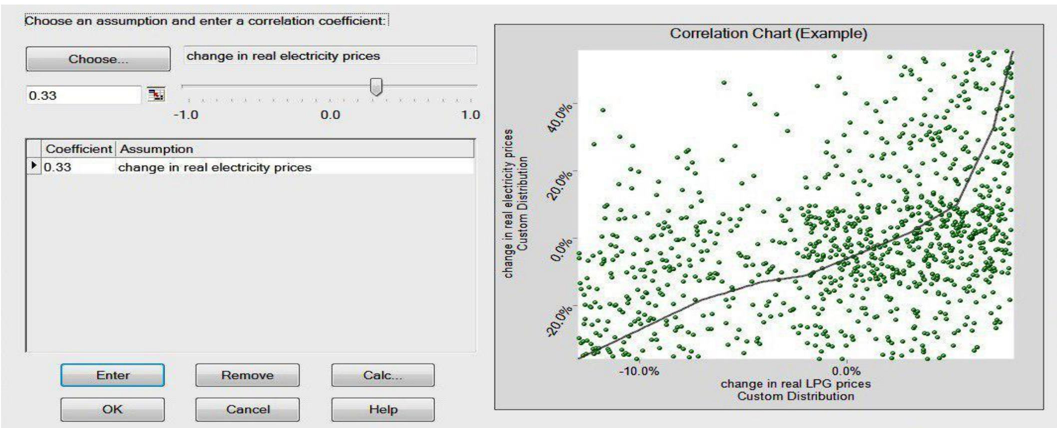


Figure 4.4: Variable correlation adjustment

4.4.3 Projecting the Alteration of Each Critical Variable Within the Considered Investment Horizon in the Study

Next step in implementing risk analysis is to extend the probability distribution for each variable to entire related input within the investment horizon so that random selection of values within the allocated probability for each variable will repeat to all the input associated with that specific variable for entire study time. This procedure will be performed by using COPY and PASTE tab in Crystal ball, where the selected probability distribution for each critical variable will be copied and consequently pasted on the same related variables for the entire investment horizon. Once the establishment of critical variables and their correlation is over, next step is to define risk related outcome for analysis. In this study two significant criterion NPV and IRR for all the scenarios have been evaluated in risk analysis to accommodate all the uncertainties associated with independent variable and their influence on the outcome of financial model. The result from risk analysis will determine how dependent outcome of the model will evolve with different alteration in independent variables.

4.4.4 Running Risk Analysis

The last step of risk analysis is to run risk analysis and create final report for the results. This procedure starts with defining necessary number of iteration (trials) and setting up the configuration for risk analysis performance and reporting. In conclusion the result of risk analysis could be displayed as both in statistic details and by charts which have to be interpreted and explained.

Chapter 5

RESULT AND DISSCUSSION

5.1 Introduction

Chapter 5 provides an accumulation of the entire results for both technical and financial feasibility assessment. The result from each step is fed into the next step as an input and each step's result is discussed in detail. At the end of this chapter an overall summary from risk analysis is provided where the probability distribution of NPV and IRR for all the retrofitting alternatives as final answers to selecting best scenario for decision makers are presented.

5.2 Results and Discussion

So far the entire process of evaluating different retrofitting scenarios step by step performed and the result from each step utilized as an input to implement the next step. An overview on technical assessment of the building indicated that input parameters such as segregated amount of energy consumption by each End-user eventually adopted to calculate the operational cost of the building. The results from technical assessment as it demonstrated in Table 5.1 adopted to form a cash flow for building's operational expenditure and saving cost as a result of implementing each retrofitting scenario within the specified investment horizon. As far as operational cost of the building with respect to different scenario concerns as it mentioned in previous chapter all the scenarios have the same operational cost in base year 2019 which is calculated operational cost of the base case. The reason for employing base case scenario's operational cost for all retrofitting scenarios in 2019 was because the year 2019 considered to be a construction year for all retrofitting scenarios therefore, since in construction year retrofitted building is not operational so the same operational cost as per existing building will be applied in cash flows. From year 2019 to end of investment period but all calculated operational cost as it demonstrated in Table 5.2 will be applicable in each scenario's cash flow. Following Table 5.1 retrieved from technical assessment chapter showed the amount of energy consumption for all existing scenarios as well as the percentage of energy saving in compare to base case scenario for all retrofitting alternatives. Following information are utilized to calculate the operational cost of each circumstance using the formula which discussed in chapter 4 and explained briefly in below paragraph. Solely by consideration of energy conservation potential of each retrofitting measure it is clear that scenario 4 which suggested combinational retrofitting measure of scenario 1, 2 and 3 generated highest amount of energy saving in compare to other scenarios. However the question which will arise from this assessment is: Does higher amount of energy conservation potential in retrofitting alternatives singly prioritize them over other existing alternatives? The answer is simply NO since necessarily higher amount of energy conservation does not make higher benefit for investors.

Table 5.1: Energy consumption and percentage of energy saving for all scenarios

annual energy consumption (base case)			
heating (Kwh)	114,425		
cooling (Kwh)	149,395		
lighting (Kwh)	98,356		
appliances (Kwh)	55,644		
total (Kwh)	417,820		
annual energy consumption (scenario 1)		**annual energy consumption (scenario 3)**	
heating (Kwh)	81,400	heating (Kwh)	114,425
heating saving from the base %	28.86%	heating saving from the base %	0.00%
cooling (Kwh)	140,976	cooling (Kwh)	149,395
cooling saving from the base %	5.64%	cooling saving from the base %	0.00%
lighting (Kwh)	98,356	lighting (Kwh)	91,676
lighting saving from the base %	0.00%	lighting saving from the base %	6.79%
appliances (Kwh)	55,644	appliances (Kwh)	55,644
appliances saving from the base %	0.00%	appliances saving from the base %	0.00%
total (Kwh)	376,376	total (Kwh)	411,140
total saving from the base %	9.92%	total saving from the base %	1.60%
annual energy consumption (scenario 2)		**annual energy consumption (scenario 4)**	
heating (Kwh)	103,843	heating (Kwh)	67,501
heating saving from the base %	9.25%	heating saving from the base %	41.01%
cooling (Kwh)	105,833	cooling (Kwh)	141,004
cooling saving from the base %	29.16%	cooling saving from the base %	5.62%
lighting (Kwh)	98,356	lighting (Kwh)	91,676
lighting saving from the base %	0.00%	lighting saving from the base %	6.79%
appliances (Kwh)	55,644	appliances (Kwh)	55,644
appliances saving from the base %	0.00%	appliances saving from the base %	0.00%
total (Kwh)	363,676	total (Kwh)	355,825
total saving from the base %	12.96%	total saving from the base %	14.84%

Therefore, in order to perform rigorous examination of profitability for each alternative a comprehensive financial and risk analysis seems to be inevitable. Table 5.2 indicated the corresponding operational cost for each scenario which calculated based on the amount of energy consumption and unit price of energy sources involve in each End-User. It also provided the amount of saving in operational cost for each retrofitting scenario in compare to the base case. From this point, before taking any further action, it is clear that scenario 2 generated more saving (13%) on annual bases in compare to other retrofitting scenarios which justified previous statement on avoiding prejudice on the result of technical assessment.

Table 5.2: Annual operational costs and saving for all scenarios

annual operational cost for base case scenario (TL)		
heating (TL)	68,449	
cooling (TL)	146,407	
lighting (TL)	96,388	
appliances (TL)	54,531	
total (TL)	365,776	
annual operational cost for scenario 1 (TL)		**saving in cost comparing to base case**
heating (TL)	48,693	29%
cooling (TL)	138,156	6%
lighting (TL)	96,388	0%
appliances (TL)	54,531	0%
total (TL)	337,769	8%
annual operational cost for scenario 2 (TL)		**saving in cost comparing to base case**
heating (TL)	62,118	9%
cooling (TL)	103,716	29%
lighting (TL)	96,388	0%
appliances (TL)	54,531	0%
total (TL)	316,755	13%
annual operational cost for scenario 3 (TL)		**saving in cost comparing to base case**
heating (TL)	68,449	0%
cooling (TL)	146,407	0%
lighting (TL)	89,842	7%
appliances (TL)	54,531	0%
total (TL)	359,229	2%
annual operational cost for scenario 4 (TL)		**saving in cost comparing to base case**
heating (TL)	40,379	41%
cooling (TL)	138,183	6%
lighting (TL)	89,842	7%
appliances (TL)	54,531	0%
total (TL)	322,936	12%

Deterministic financial assessment of the building which performed based on static values by considering a variety of calculated and assumed inputs such as investment horizon, real cost of LPG and electricity, real discount rate, initial cost of investment for each scenario and contribution of each energy sources in providing energy for End-users indicated that among four different proposed scenarios, the most profitable one is scenario 2 where it generates the highest amount of return in the shortest time among other scenarios. Following Table 5.3 presented the result for deterministic financial appraisal of all scenarios. From the result evidently scenario

2 and 1 respectively produced highest NPV and IRR in shortest time however scenario 4 and 3 respectively generated least NPV and IRR in longest time which could be interpreted as cases which are unworthy of investment. So far it has been proved by deterministic financial analysis that scenario 2 generates highest benefit among other scenarios but to appropriately evaluate each alternative all the risk and uncertainties should be taken into account therefore final decision making is depends on the result from risk analysis none of the alternatives could be judged up to this stage.

Table 5.3: Result summary from deterministic financial appraisal

scenario	initial cost of investment (TL)	present worth of savings (TL)	NPV (TL)	IRR (%)	Payback period (years)	benefit cost ratio
1	206,250	254,213	**47,963**	**12.93%**	**7.36**	**1.233**
2	275,100	444,964	**169,864**	**17.50%**	**5.61**	**1.62**
3	162,660	59,421	**-103,238**	**0.05%**	**24.85**	**0.37**
4	644,010	388,856	**-255,153**	**4.37%**	**15.03**	**0.60**

In the next step, sensitivity analysis determined the most influential parameters on the outcome of deterministic financial model and accordingly each critical variable allocated with probability distribution range for risk analysis. As it previously mentioned based on the (European Commission, 2014) a reliable result for financial appraisal of the project should consider the result from risk analysis where it calculate the probability of profitability or failure of the project based on forecasted independent variables. As a final result for retrofitting investment in this study, both NPV and IRR criterion have been investigated in risk analysis. The result for each scenario’s NPV and IRR presented in the graph and statistical value and explained in detail. After 100,000 trial using Crystal ball software, the statistical result for scenario 1 for both the NPV and IRR are as in Table 5.4.

Table 5.4: Risk analysis statistical result for scenario 1

Forecast: NPV for scenario 1		**Forecast: IRR for scenario 1**	
Statistic	Forecast values	Statistic	Forecast values
Trials	100,000	Trials	100,000
Base Case	47,963	Base Case	0.12
Mean	30,900	Mean	0.11
Median	32,587	Median	0.11
Standard Deviation	50,086	Standard Deviation	0.02
Variance	2508673530	Variance	0.001
Skewness	-0.18	Skewness	0.42
Kurtosis	2.76	Kurtosis	3.15
Coeff. of Variability	1.62	Coeff. of Variability	0.21
Minimum	-161,362	Minimum	0.04
Maximum	200,025	Maximum	0.26
Mean Std. Error	158.39	Mean Std. Error	0

From the result in Figure 5.1and 5.2, in terms of NPV for scenario 1 the calculated mean value after considering all the parameterized risk is 30,900 TL with standard deviation just above 50,000 TL which indicates the possibility of falling forecasted below or above the mean. For IRR 11.8% for mean value with standard deviation of 2.5% is calculated. Also the maximum possible profitability of scenario 1 estimated to be 200,025 TL within the specified period as well as the maximum possible loss of this scenario is estimated 161,362 TL. The probability distribution of both NPV and IRR for scenario 1 is presented in below Figures 5.1 and 5.2 which indicates there is 73.11% chance that scenario 1 create positive NPV and for IRR the chance of generating IRR above 10% which is considered real discount rate is 75.6%.

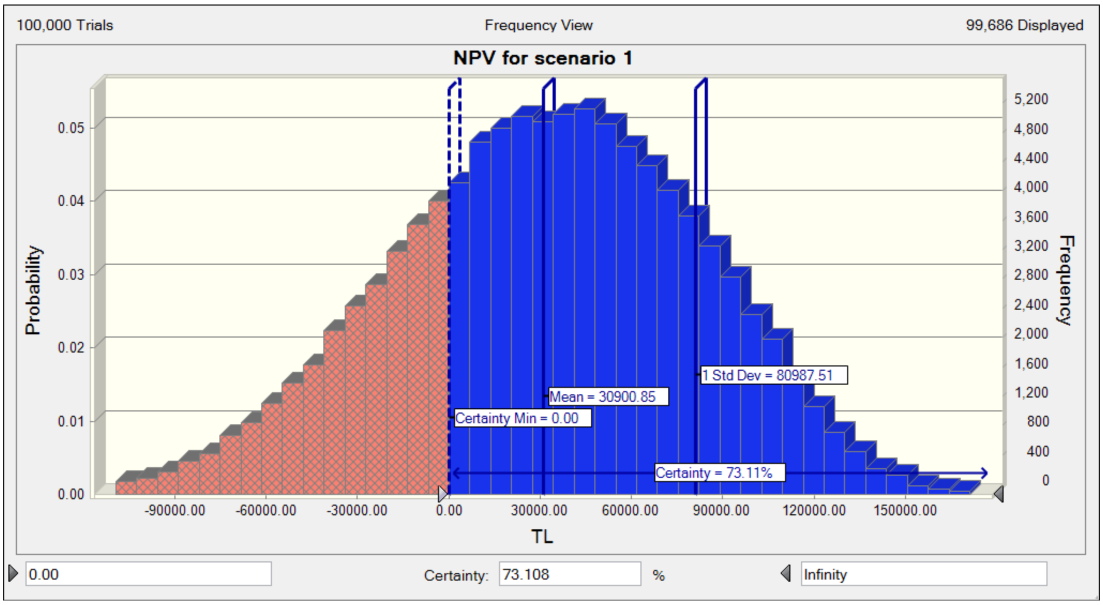


Figure 5.1: Risk analysis result for NPV probability distribution scenario 1

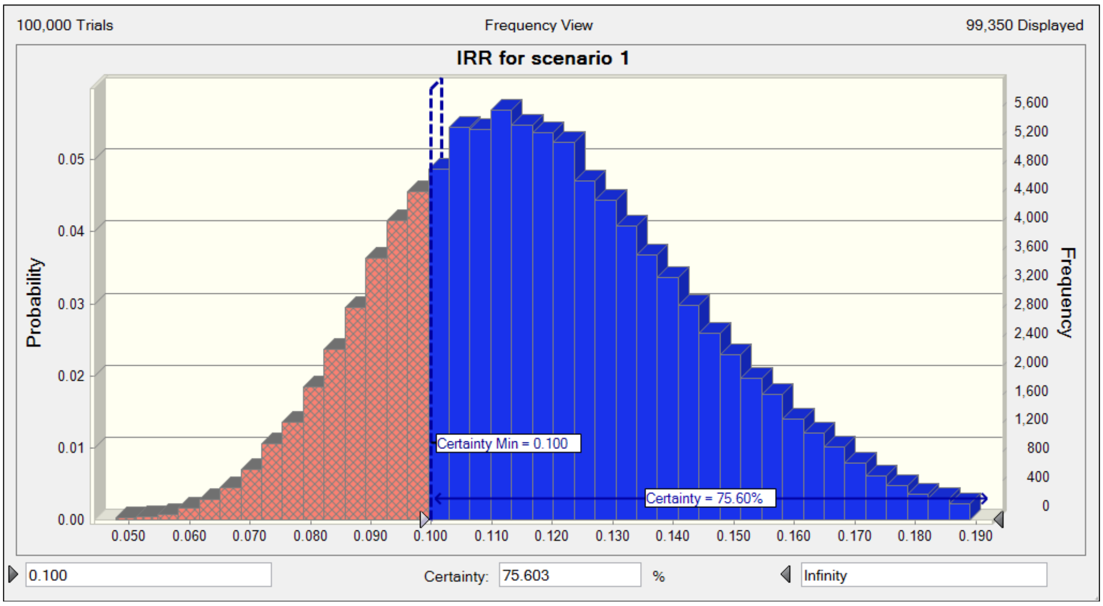


Figure 5.2: Risk analysis result for IRR probability distribution scenario 1

As far as the scenario 2 concerns as best scenario among other in financial appraisal based on deterministic value, risk analysis is also approved that with mean value of 147,542 TL and 55,556 TL standard deviation in NPV yield from scenario 2 it is the profitable scenario among others, where it most of the time generates IRR of 15.9% which is above 10% real discount rate and with just 2.2% of standard deviation. The statistical result of scenario 2 for NPV and IRR is presented in Table 5.5. From the result it is evident that in terms of NPV for scenario 2 the calculated mean value after considering all the parameterized risk is 147,542 TL with standard deviation just above 66,556 TL and for IRR 15.9% for mean value with standard deviation of 2.2%. Also the maximum possible profitability of scenario 2 evaluated to be 385050.1 TL within the specified period which generates the highest possible income among other alternatives and also the maximum possible loss of this scenario is estimated 53,343 TL which is the least among other alternatives. The probability distribution of both NPV and IRR for scenario 1 is presented in below Figures 5.3 and 5.4 which indicates there is more than 99% chance that scenario 1 create positive NPV and for IRR the chance of generating IRR above 10% which is considered real discount rate is 100%.

Table 5.5: Risk analysis statistical result for scenario 2

Forecast: NPV for scenario 2		Forecast: IRR for scenario 2	
Statistic	Forecast values	Statistic	Forecast values
Trials	100,000	Trials	100,000
Base Case	169,864	Base Case	0.17
Mean	147,542	Mean	0.15
Median	151,821	Median	0.15
Mode	'---	Mode	'---
Standard Deviation	66,556	Standard Deviation	0.02
Variance	4429791177	Variance	0
Skewness	-0.17	Skewness	0.39
Kurtosis	2.43	Kurtosis	2.69
Coeff. of Variability	0.45	Coeff. of Variability	0.13
Minimum	-53,343	Minimum	0.10
Maximum	385,050	Maximum	0.25
Mean Std. Error	210.47	Mean Std. Error	0

From the graphs it is clear that more than 99% of the time scenario 2 generates positive NPV within 25 years of investment and almost in the entire process of investigation the internal rate of return is above the 10% real discount rate that was determined for project.

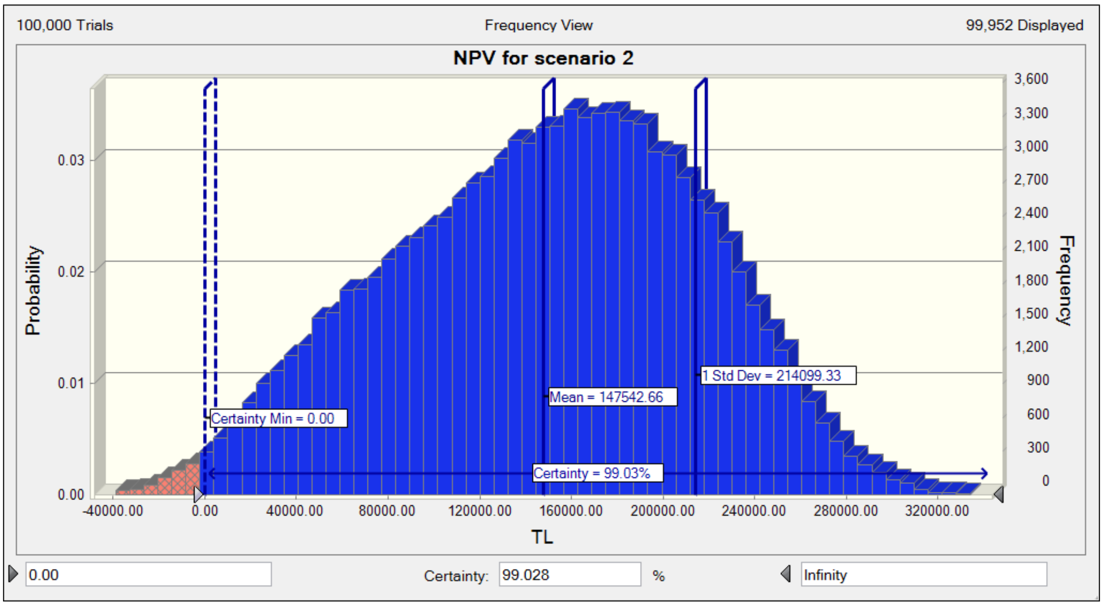


Figure 5.3: Risk analysis result for NPV probability distribution scenario 2

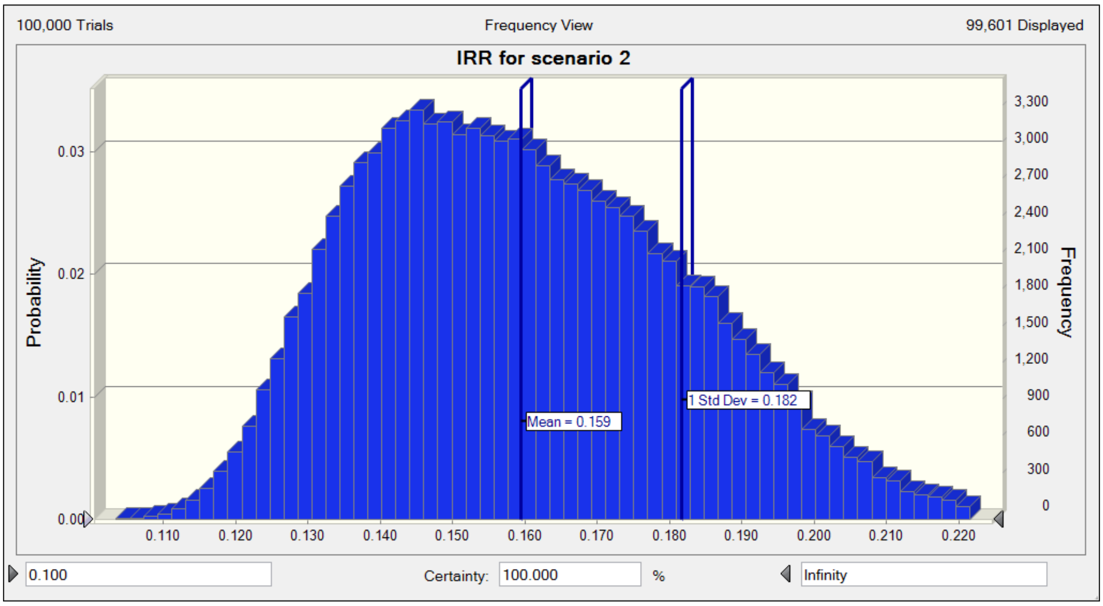


Figure 5.4: Risk analysis result for IRR probability distribution scenario 1

Among all the scenarios but scenario 3 and 4 seems to be not worthy of investment due to their negative NPV and less than 10% IRR therefore for scenario 4 which is the combination of all the scenarios the notion of do it all or do nothing is incorrect. The result for both statistics and probability graph for both the scenario 3 and 4 are presented in Table 5.6 and 5.7 below which indicated that implementing those projects could just cause huge lost in short and long run.

Table 5.6: Risk analysis statistical result for scenario 3

Forecast: NPV for scenario 3		Forecast: IRR for scenario 3	
Statistic	Forecast values	Statistic	Forecast values
Trials	100,000	Trials	100,000
Base Case	-103,238	Base Case	0.0005
Mean	-118,661	Mean	-0.0063
Median	-118,656	Median	-0.0068
Mode	'---	Mode	'---
Standard Deviation	20,451	Standard Deviation	0.0089
Variance	418247487	Variance	0.0001
Skewness	-0.01	Skewness	0.16
Kurtosis	2.11	Kurtosis	2.29
Coeff. of Variability	-0.17	Coeff. of Variability	-1.41
Minimum	-171,746	Minimum	-0.03
Maximum	-63,930	Maximum	0.02
Mean Std. Error	64.67	Mean Std. Error	0

Table 5.7: Risk analysis statistical result for scenario 4

Forecast: NPV for scenario 4		Forecast: IRR for scenario 4	
Statistic	Forecast values	Statistic	Forecast values
Trials	100,000	Trials	100,000
Base Case	-255,153	Base Case	0.04
Mean	-314,365	Mean	0.03
Median	-311,774	Median	0.03
Mode	'---	Mode	'---
Standard Deviation	65,432	Standard Deviation	0.0066
Variance	4281409807	Variance	0
Skewness	-0.15	Skewness	0.19
Kurtosis	2.61	Kurtosis	2.79
Coeff. of Variability	-0.20	Coeff. of Variability	0.18
Minimum	-542,389	Minimum	0.01
Maximum	-108,952	Maximum	0.06
Mean Std. Error	206.92	Mean Std. Error	0

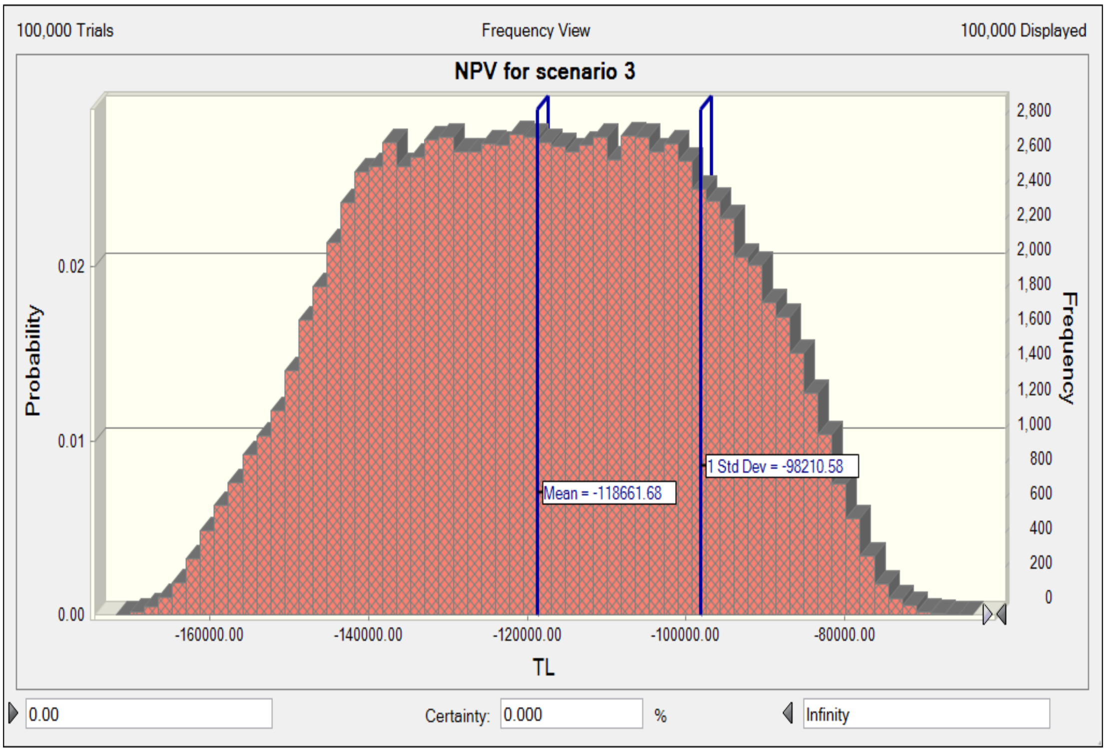


Figure 5.5: Risk analysis result for NPV probability distribution scenario 3

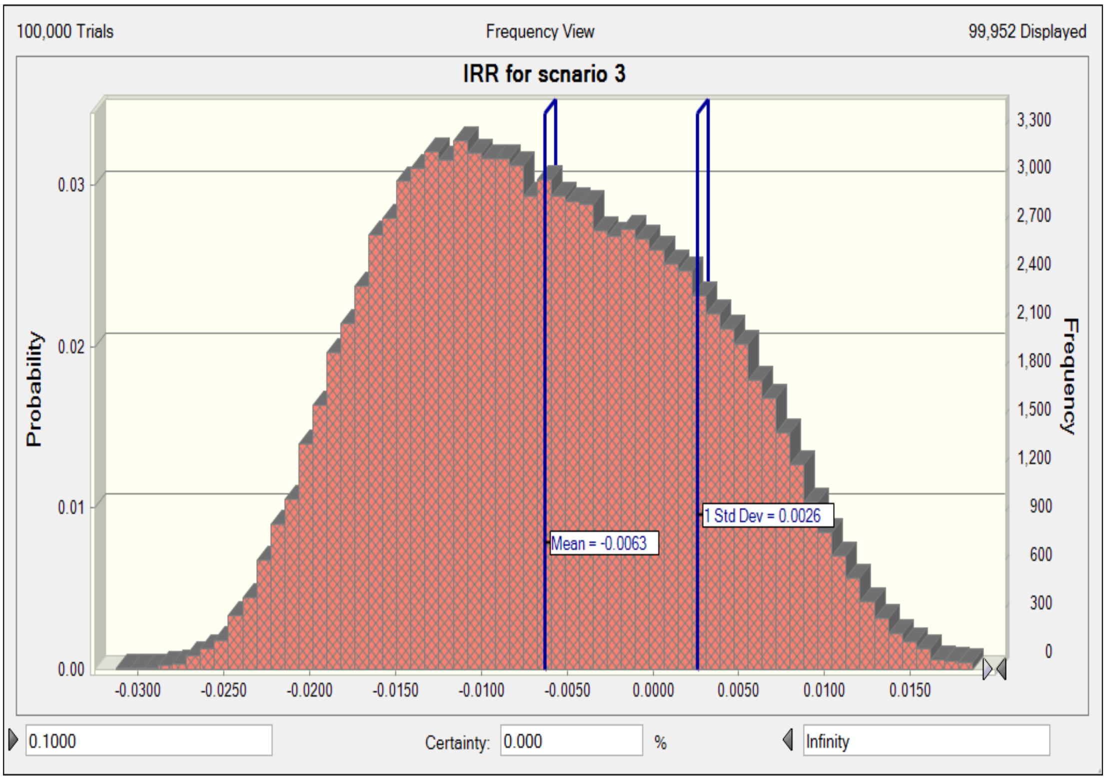


Figure 5.6: Risk analysis result for IRR probability distribution scenario 3

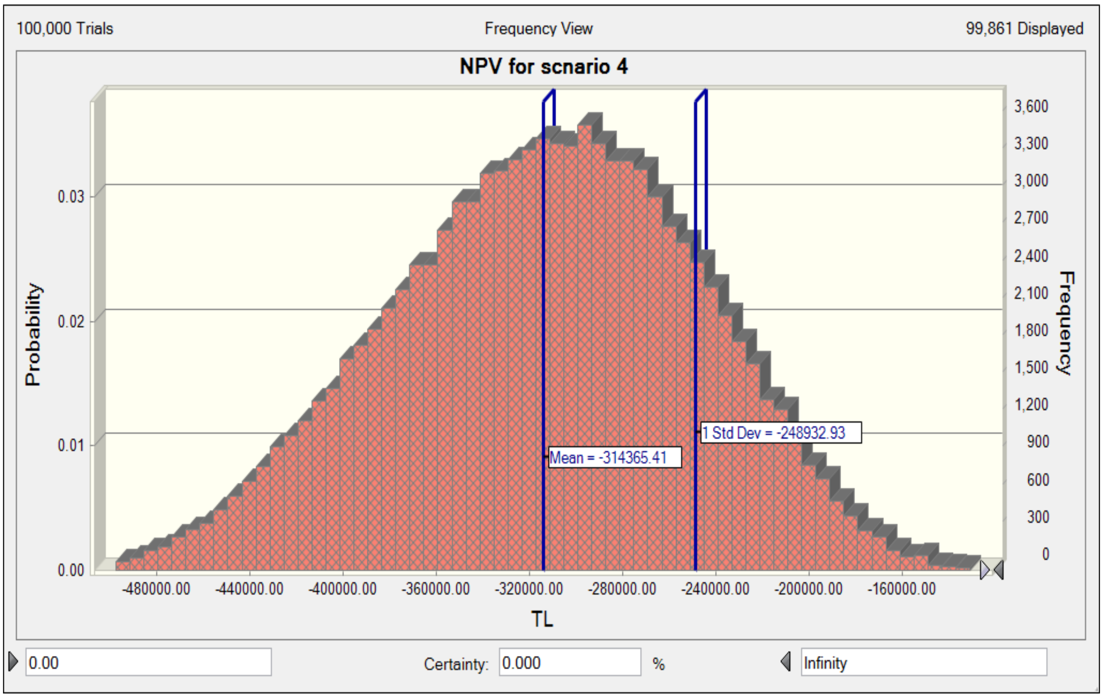


Figure 5.7: Risk analysis result for NPV probability distribution scenario 4

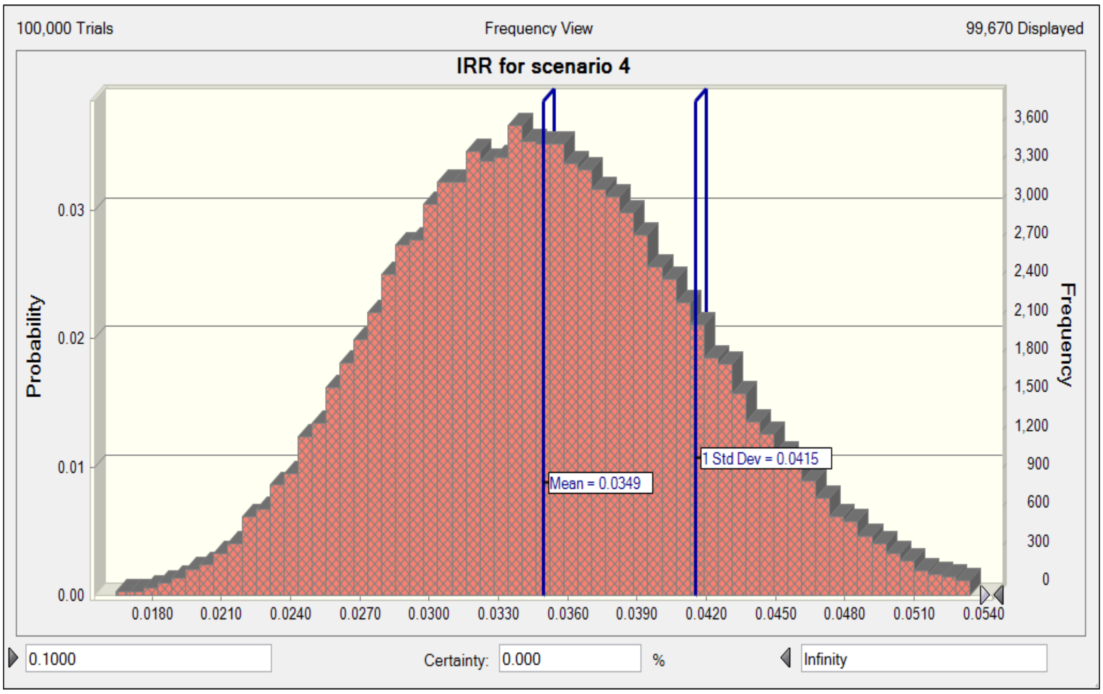


Figure 5.8: Risk analysis result for IRR probability distribution scenario 4

In conclusion for the purpose of better comprehension and comparison of all the scenarios together superimposing graphs are generated by risk analysis software for both the NPV and IRR criterion.

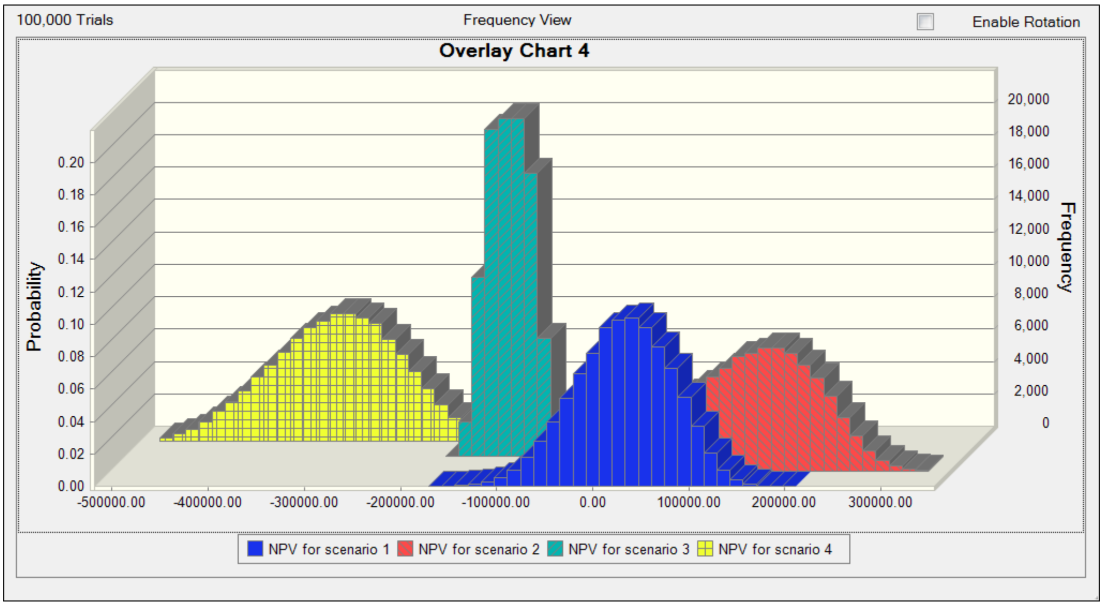


Figure 5.9: Risk analysis result for NPV probability distribution all scenarios

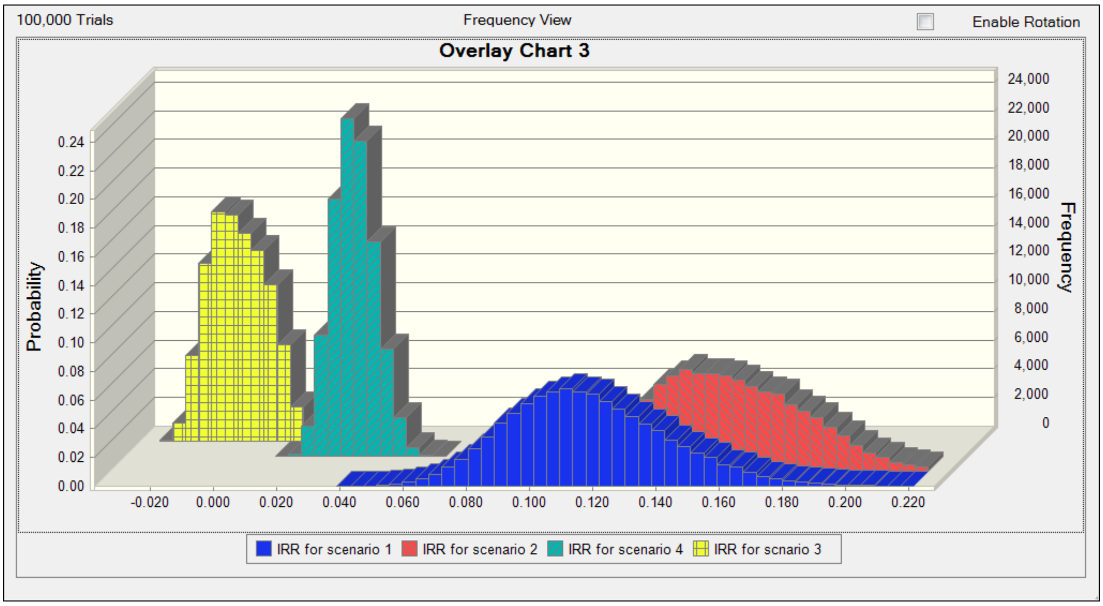


Figure 5.10: Risk analysis result for IRR probability distribution all scenarios

From the overlay graph in Figure 5.9 and 5.10 is also clear that the highest return from both NPV and IRR criterions are generated by scenario 2. Although in terms of IRR scenario 1 estimated to generate up to 22% which is almost similar to scenario 2 but still due to spread of extracted distribution generating higher amount of IRR is most likely by scenario 2.

Chapter 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusion

Being responsible for more than 40% of global energy consumption, prioritized buildings as one of the determining subject to reduce energy demand at global scale. Recently all the governments around the world facing with strange paradox in terms of homologating sufficient funds to promote retrofitting scenarios in existing buildings due to lack of financial liquidity to supply such robust incentives. Moreover, the current political and economic crisis as a result of political and financial instability in the region became another cause to demotivate governments for taking initiative in this area. However, such examination on existing public and private buildings to investigate financial merit of implementing energy retrofitting expected to accentuate clearer picture of advantages of investment in this area for both public and private investors and authorities. During this assessment through technical and financial evaluation of the case study the aforementioned answers to three critical questions from introduction chapter have been addressed as follow:

Question 1: Does EMU's Civil engineering department have potential to adopt retrofitting measures from energy conservation point of view? Since implementing scenario 1 and 2 and 4 could generate significant energy saving it seems that the existing building carries huge potential in terms of implementing identified retrofitting measure.

Question 2: What are the efficient retrofitting alternatives which could be utilized for the case study by considering associated circumstances to reduce energy consumption? From the study it is realized that adopting insulation's alternatives such as roof insulation or window's glazing replacement in arid climate of the region assumed to be a beneficial alternative as a retrofitting scenario.it is also notable that although a combination of different scenarios may lead to decrease the energy consumption of the building but it is not necessarily the prime option from financial return point of view.

Question 3: Shall investors invest in building retrofitting? If yes to what extent the investment is justifiable? during financial analysis on retrofitting option it is concluded that out of four different retrofitting scenarios two of them (scenario 1 and 2) are feasible alternative for investors to invest in, where scenario 2 proved to be not only financially beneficial but also feasible and according to the result from risk analysis the range of investment at its maximum should not be exceeding 3,685,941 TL which is the present worth of operational cost at its most in base case scenario to generate positive return as a result.

Apart from demonstration of financial benefit and introduction of retrofitting options in existing public buildings the core conclusion of this study despite huge constraint in terms of time and data resources was to encourage governmental planning in evaluating the possibilities of proposing financial incentives to promote energy conservation measures such as active and passive measure in both public and private sectors.

6.2 Future Work

The proposed future study on the subject could be comprised of introducing recent applicable active and passive measures as retrofitting scenarios which are compatible with region's climate and accordingly investigating the affordability of those scenarios from both technical and financial point of view. Consideration of calculating of monthly breakdown of actual electricity and LPG consumption in existing building from provided bill based on the volume of each area instead of meter square of each area is also proposed to be investigated in future studies. It is also have to be mention that, since lack of governmental incentive is one of the influential factors in discouraging investor to fund in such projects, analysis of energy retrofitting in building along with calculation of CO2 reduction as result of implementing energy conservation measures from government's point of view could be beneficial to prove financial feasibility of such incentives for government as well as for investors.

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