

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**AN APPROACH FOR COST OPTIMUM ENERGY
EFFICIENT RETROFIT OF PRIMARY SCHOOL
BUILDINGS IN TURKEY**

M.Sc. THESIS

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Department of Architecture

Environmental Control and Construction Technologies Program

JANUARY 2015

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**TÜRKİYE'DE İLKÖĞRETİM OKULU BINALARIN MALİYETİ
OPTİMUM ENERJİ ETKİN İYİLEŞTİRMESİ İÇİN BİR
YAKLAŞIM**

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To my spouse and parents,

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ABBREVIATIONS

BEP-TR	: National Building Energy Performance Calculation Methodology of Turkey
BPIE	: Buildings Performance Institute Europe
DDZ	: Degree Day Zone
EPBD	: Energy Performance of Buildings Directive
EU	: European Union
IEA	: International Energy Agency
MEB	: Milli Eğitim Bakanlığı (Ministry of Education)
MS	: Member States
RB	: Reference Building
TS	: Turkish Standard
WEO	: World Energy Outlook

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AN APPROACH FOR COST OPTIMUM ENERGY EFFICIENT RETROFIT OF PRIMARY SCHOOL BUILDINGS IN TURKEY

SUMMARY

Large portion of the building stock in EU and Turkey was built before prosper of energy efficiency issue in building construction, hence; consume a huge amount of energy that can be preserved. On the other hands, demolition of an existing building and construction of a new energy efficient building requires huge amount of budget and is irrational. Most well-known regulation in this field is an EU Legislation, “Directive on Energy Performance of Buildings” (EPBD). The directive asserts the necessity to increase energy-efficiency for new and existing buildings; together with Recast-EPBD identifies 2020 targets related with reduction in greenhouse gas emissions, nearly zero-energy buildings and cost-optimal levels of minimum energy performance requirements for existing and new buildings. Thereupon the importance of energy efficient retrofit of existing buildings is an inevitable issue in current situation. Schools alone are responsible for 15% of the total energy consumption in contrary to other commercial buildings, for decreasing energy consumption of this type of buildings, energy demand of buildings must be minimized and energy efficiency should be increased. Overall, it seems renovation of existing buildings with higher energy efficiency and minimum cost can be a logical step for current barriers.

This research’s main aim is to recognize a systematic approach for energy-efficient retrofit of school buildings in order to acquire the optimum level of retrofit action with the aid of dynamic simulation tools, and comparing different circumstances and economical variations during desired period.

In order to reach this paper’s goals, one of the existing typical schools building in Turkey, which is located in Istanbul, take to account as a reference building. This existed reference building’ energy audits and primary energy consumption calculated with the aid of a dynamic simulation tool, Energy plus. Thereafter, proper energy efficiency measures applied to the envelope, mechanical system, and lighting system and different packages are prepared by combination measures. After all, packages’ energy consumptions are calculated and global cost of each package estimated according to standard EN15459. In order to reach optimum cost level, the payback

period and sensitivity analysis done for each package together with related comparison.

TÜRKİYE'DE İLKÖĞRETİM OKULU BINALARININ MALİYETİ OPTİMUM ENERJİ ETKİN İYİLEŞTİRİLMESİ İÇİN BİR YAKLAŞIM

ÖZET

70'li yılların petrol krizinden sonra, enerji gündemin en önemli konularından biri olmuştur. Gelişmiş ve gelişmekte olan ülkeler, enerji ihtiyaçlarını başka ülkelerden temin etmekteydi ve bu nedenle petrol krizinin etkisi oldukça büyük oldu. Öte yandan, uzun vadede, fosil yakıtların yanması atmosferdeki karbon dioksit miktarını arttırmaktadır ve bu halen büyük bir endişe konusudur. Ayrıca, dünyada hızla artan enerji tüketimi, enerji tedariki, enerji kaynaklarının tükenmesi ve tüm bunların ağır çevresel etkileri (ozon tabakasının incelmesi, küresel ısınma, iklim değişikliği, vb.) de bu konudaki endişeleri arttırmaktadır. Uluslararası Enerji Ajansı enerji tüketimi trendlerini yayınlamaktadır. Son 20 yılda, sırasıyla birincil enerji ve karbondioksit (CO₂) emisyonu % 49 ve %43, ve aynı zamanda sırasıyla %2 ve %1,8 ortalama yıllık artış ile, büyümektedir.

Tüm endüstrileşmiş ülkelerde, enerji tüketiminin üçte biri inşaat sektöründen kaynaklanmaktadır. Ayrıca Avrupa'da toplam CO₂ emisyonlarının %36 ve enerji tüketiminden %40'ı binalardan kaynaklanmaktadır. Bu kullanım miktarı, coğrafi konum, iklim ve tüketim şekillerine göre değişebilmektedir, ancak Uluslararası Enerji Ajansı'nın 2009 yılı verilerine göre dünyadaki elektriğin neredeyse yüzde 60'ı konut ve ticari binalarda tüketilmektedir.

Avrupa Birliği (AB) ve Türkiye'de yapı stoğunun büyük bir kısmı binalarda enerji verimliliği konuları gündeme gelmeden önce inşa edilmiştir. Dolayısıyla; yapı stoğunda büyük miktarda enerji tasarruf potansiyelinin var olduğu kabul edilmektedir. Diğer taraftan, mevcut bir binanın yıkılması ve enerji verimli yeni bir bina inşaatı büyük miktarda bütçe gerektirmektedir ve bu çözüm gerek ekoloji gerek maliyet açısından makul görünmemektedir. Binalarda enerji performansını değerlendirmek ve arttırmak amacıyla, 2002 yılında Avrupa Birliği (AB) tarafından Binalarda Enerji Performansı Direktifi (EPBD) yayımlanmıştır. Bu direktif 'de her bir üye ülke kendi iklimsel, ekonomi, sosyal vb. koşullarını göz önünde bulundurarak, yeni ve mevcut binalarda, yasal mevzuat ile tanımlanmış olan minimum enerji performans gereksinimlerinin sağlanması ve binaların enerji performansının hesaplanması için ulusal yöntemlerin geliştirilmesi ve bu yöntem ile tüm binaların sertifikalandırılması zorundadır. EPBD kapsamında, Avrupa Birliği üyesi ve aday ülkeler kendi yasal mevzuatlarını geliştirmiş ve sertifikalandırma amacıyla kullanılacak olan ulusal bina enerji performansı hesap yöntemlerini oluşturmuştur. Bu kapsamda, yeni binaların enerji etkin bir şekilde yapılması ile birlikte, mevcut binaların enerji etkin iyileştirilmesi kaçınılmaz bir konu haline gelmiştir.

2007 yılında Enerji Verimliliği Kanunu ve 2008 yılında Binalarda Enerji Performansı Yönetmeliği'ni yürürlüğe girmek ile birlikte, Türkiye, Avrupa Birliği'ne aday bir ülke olarak, EPBD gereksinimleri çerçevesinde gerekli yasal düzenlemeleri gerçekleştirmiştir. Bu gelişmelere paralel olarak, Binalarda Enerji Performansı Yönetmeliği gereğince EN standartları ile tanımlanmış olan basit saatlik metoda uygun şekilde, bina enerji performansı ulusal hesap metodu (Bep-Tr), Türkiye koşullarına uygun olarak geliştirilmiştir.

2010 yılında EPBD, yeni gerekliliklere göre revize edilmiş ve EPBD-Recast adı ile yayımlanmıştır. Bu yenilemede mevcut direktifin zorunlu kıldığı yükümlülüklerle

açıklık getirilmekle birlikte, yeni terimler ve hedefler ortaya konmuştur. Optimum maliyet düzeyi ve yaklaşık sıfır enerji binalar tanıtımı bu direktifte yapılmaktadır. Ayrıca 20-20-20 hedefi ortaya konulmakla birlikte 2020 yılında; sera gazı salımının 1990 yılı düzeyinin %20 altına olması, Avrupa Birliği'nin enerji tüketiminin %20 azaltılması, kullanılan enerjinin %20'sinin yenilenebilir kaynaklardan sağlanması ve tüm binaların neredeyse sıfır enerjili olması hedeflenmektedir. Bu direktifte, minimum enerji performans ve enerji etkin güçlendirme gereksinimlerine ilişkin optimum maliyet düzeyinin hesaplanması ve bu hesaplamanın ulusal bina enerji performansı hesap metodlarına entegre edilmesi tüm üye ülkeler için zorunlu kılınmıştır.

Avrupa Birliğine üye ülkeler, yeni direktifin getirdiği zorunluluklar üzerine, enerji performans gereksinimlerine uygun değerleri bulmak ve maliyet düzeyleri ile ilgili çalışmalarını sürdürmektedirler. Tüketilen enerjinin yaklaşık %80'ini ithal eden Türkiye için de maliyet etkin enerji verimliliği büyük öneme sahiptir. İlgili yasal prosedür Türkiye de henüz oluşturulmuş olmasa bile bu konuda çalışmalar sürdürülmektedir. 2013 yılında başlayan ve 2015 yılında bitirilmesi hedeflenen bir TÜBİTAK projesinde Türkiye de konut binaları için referans binaların belirlenmesi ve onların enerji etkin güçlendirilmesinde kullanılan maliyet optimum düzeyinin belirlenmesi yapılmaktadır.

Okullar, ticari binalar içinde toplam enerji tüketiminin % 15'inden sorumludur, bu tip binaların enerji tüketimini azaltmak için binaların enerji ihtiyacı azaltılmalıdır ve enerji verimliliği artırılmalıdır. Genel olarak, mevcut binaların enerji etkin yenilenmesi, minimum maliyet hedefine ulaşma yönünde mantıklı bir adım olacaktır. Türkiye Milli Eğitim Bakanlığı istatistiklerine göre, 2013-2014 öğretim yılında 83.204 okul binası mevcutmuş. Bu akademik yıl boyunca, yaklaşık 17,5 milyon öğrenci okullarda okumuş ve 911 bin öğretmen çalıştı. Bu istatistikler, Türkiye'nin nüfusunun neredeyse dörtte birinin zamanlarının çoğunu okullarda geçirdiğini göstermektedir. Bu bağlamda, okul binalarının uygun iç mekan koşullarında ve yüksek enerji performansına sahip olmaları büyük önem taşımaktadır. Türk nüfusunun çoğunlukla gençlerden oluştuğunu göz önüne alındığında bu konu oldukça önemlidir.

Başka bir açıdan bakıldığında, mevcut eğitim binalarının yüksek enerji tüketimi ve devlet okullarının bütçe eksikliği Türkiye'nin eğitim binalarının işletmesindeki temel sıkıntılarındandır. Ayrıca, enerji tasarruflu yeni okul binalarının inşa edilmesi, enerji tüketiminin azaltılması açısından makul bir yaklaşım değildir ve üstelik, her yapının ortalama ömrü yaklaşık 60-80 yıldır.

Sonuç olarak, okul binalarının yenilenmesi önemli ölçüde enerji korunumu sağlarken, çevresel ve ekonomik faydaları da beraberinde getirecektir.; Ayrıca, sera gazı (SG) emisyonlarını, çevresel etkileri ve enerji maliyetlerini azaltacak, iç mekan kalitesini arttıracak ve hasta bina sendromunu (SBS) engelleyecektir., Bu yolla, öğrenci performansı artırılarak, eğitim imkanları da geliştirilebilecektir.

Bu projede, enerji verimli yenileme yoluyla ilköğretim binalarında enerji tasarrufu hedeflenmektedir ve bu hedefe ulaşmaya yönelik olarak gerçekleştirilen örnek çalışma için, bir mevcut okul binası, Türkiye'deki tipik projelere bakılarak seçilmiştir. Farklı enerji verimliliği ölçütleri bu bina üzerinde analiz edilmiştir. Bu önlemler, çeşitli ulusal ve uluslararası standartlara uygun olacak şekilde belirlenmiştir. Çalışmada ortaya konulan maliyet hesapları Binalarda Enerji Performansı Direktifi (EPBD)'nin önerdiği şekilde yapılmıştır.

İlk olarak, Türkiye'de mevcut ve tipik bir ilköğretim binası referans bina olarak seçilmiştir. Bu referans bina İstanbul'da bulunmaktadır, ancak Milli Eğitim Bakanlığı'nın MEB.2004-53 numaralı tip ilköğretim okulu projesini temsil etmektedir. Dolayısıyla, bu tip binalar Türkiye'nin farklı iklim bölgelerinde de

mevcuttur. Bu arařtırmada, iki farklı iklim bölgesinden birer řehir seçilmiřtir. Bunlardan biri ılımlı-nemli iklim bölgesinde yer alan İstanbul'dur ve diğeri soğuk iklim bölgesinde yer alan Erzurum'dur. Referans binanın enerji performansı, Design Builder ve Energy Plus detaylı dinamik simülasyon araçları yardımı ile hesaplanmıştır. Bu çalışma, enerji tasarrufu amacıyla düzenlenen optimize edilmiş çözüm paketleri ile en düşük toplam maliyeti sağlamak mümkün olduğu hipotez üzere dayanmaktadır. Maliyet optimum enerji verimlilik seviyesine ulaşmak için, bina kabuğunda, aydınlatma sistemlerinde ve mekanik sistemlerinde çeşitli iyileştirmeler analiz edilmiştir. Bu tezin bir diğer önemli aşaması, iyileştirme paketlerinin maliyetlerinin Çevre ve Şehircilik Bakanlığı birim fiyatlarına göre hesaplanmasıdır. Maliyet hesaplamaları 2013 yılı birim fiyatlarına göre yapılmıştır. İyileştirme paketlerinin ekonomik değerlendirmesi EPBD 2010 Revize direktifine uygun olarak yapılmıştır. EPBD'de belirtildiği gibi hesaplama süresi konut dışı binalar için 20 yıldır.

Finansal veriler 2013 yılı, Türkiye Cumhuriyet Merkez Bankası'ndan elde edilen verilere göre kabul edilmiştir. Buna göre, Türkiye'nin enflasyon oranı %7,5 ve Merkez Bankası'nın güncel istatistiklerine göre Türkiye'nin iskonto oranı % 5,5 olduğu varsayılmıştır. Ayrıca, Euro(€)/Türk Lirası (TL) dönüşümleri için kur 2,9 alınmıştır. TEDAŞ (Türk Elektrik Dağıtım Şirketi) verilerine göre elektrik birim fiyatı, 0,3465 TL / kWh ve Doğal gaz birim fiyatı İGDAŞ'a (İstanbul Gaz Dağıtım Sanayi ve Ticaret Anonim Şirketi) göre 0.105 TL / kWh olarak hesaba katılmıştır.

Optimum enerji verimliliği seviyesinin belirlenmesi için farklı iyileştirme paketleri, basit geri ödeme süresi ve duyarlılık analizi ile, farklı iskonto oranı ile ve daha kısa (10 yıl) ve uzun (30 yıl) hesaplama dönemleri için minimum maliyet açısından analiz edilmiştir.

Buna ek olarak, bu arařtırmada farklı iklimin etkisini görmek adına, aynı binanın soğuk iklim bölgesini temsilen Erzurum'da bulunduğu kabul edilerek benzer analizler yapılmıştır. Böylece, her iki iklim bölgesi için sonuçları karşılařtırmalı olarak değerlendirme imkanı olmuřtur. Genel olarak, analiz edilmiş olan iyileştirme paketleri İstanbul'da bulunan bu referans bina için, elektrik tüketiminin doğalgaz tüketiminden neredeyse iki kat fazla olduğu görülmektedir. Bunun nedeni binadaki yüksek aydınlatma ve soğutma ihtiyacıdır. Aksine, soğuk iklim bölgesinde bulunan Erzurum'da referans bina için analiz edilmiş olan çoğu iyileştirme paketi için doğalgaz tüketimi elektrik tüketiminden daha yüksek çıkmaktadır.

1. INTRODUCTION

By retrospect to 70's decade oil crisis, energy becomes one of the major topics in agendas of developed and developing countries, which provide their energy needs from others [1]. In the long term, fossil fuel burning affects the carbon dioxide content of the atmosphere and this is presently a subject of great concern.

Moreover, rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts (ozone layer depletion, global warming, climate change, etc.). According to International Energy Agency has represented data on energy consumption trends. During the last two decades, primary energy has grown by 49% and CO₂ emissions by 43%, with an average annual increase of 2% and 1.8% respectively [2].

Certainly, reducing emissions of greenhouse gases and other pollutants, decreasing energy consumption and providing security of energy supply are main global targets against environmental problems. Beside environmental problems, world economy also requires energy savings since economic load of energy use is one of the major actors of the global economy. Due to ever-increasing demand for fossil fuels brings ever-increasing energy prices, world is forced to use less energy [3]. Energy saving potential of buildings sector is considerable, due to buildings use noticeable amount of world's sources, consume great amount of energy and responsible from nearly 1/3 of CO₂ emissions.

1.1 Energy Consumption of Buildings

All over the industrialized world, the building sector accounts for more than 1/3 of the global energy consumption. Focus on the European situation it is responsible for about 40% of the total energy use for 36% of CO₂ emissions. These data could not be neglected because they directly involve the share of global greenhouse emissions with all its negative impacts on the environment. According to International Energy Agency -2009, nearly 60 per cent of the world's electricity is consumed in residential and

commercial buildings, although this usage varies widely according to geographical location, climate and consumption patterns [3].

Over the past years, Turkey has experienced considerable growth in energy demand among the Organization for Economic Cooperation and Development (OECD) countries. According to the International Energy Agency (IEA), energy use will continue to grow at an annual rate of about 4.5% from 2015 to 2030, approximately doubling over the next decade while it is expected that electricity demand growth at an even faster pace. Although Turkey is planning large investments in natural gas, electricity and nuclear energy infrastructure, the government seeks to reduce the country's dependence on imported natural gas, which is almost all of consumption [4].

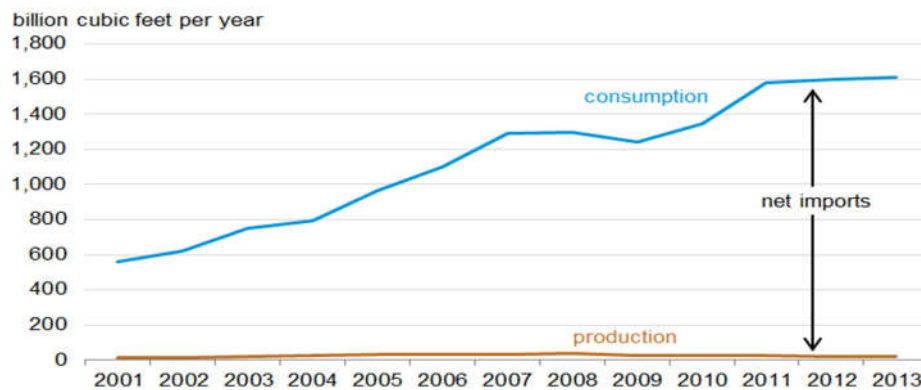


Figure 1.1: Turkey natural gas consumption and production between 2001 and 2013 [4].

About 40% of whole energy consumption in Turkey belongs to building sector while it has a large saving potential, hence improvement of building energy performance seems inevitable.

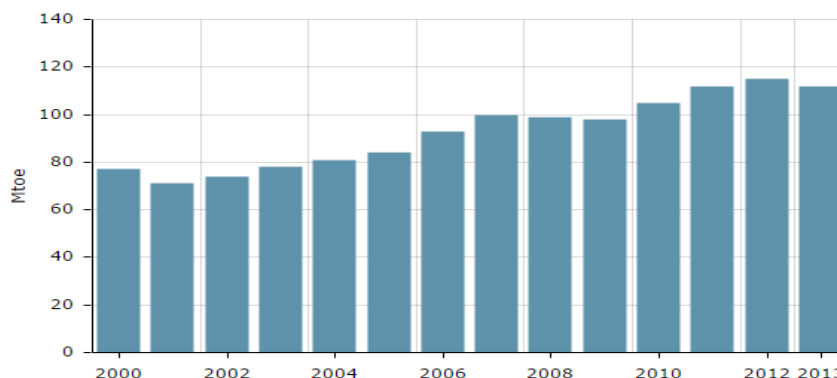


Figure 1.2: Turkey primary energy consumption [5].

In Turkey as many European countries, school buildings share many similar design, operation and maintenance features while it should be different because of different construction, climate and operation (especially operation time) features. They also often have high-energy consumption resulting with the need of energy efficient retrofit. Despite the climatic differences throughout Turkey, all school buildings are designed primarily to comply with winter conditions while it is obvious that indoor climate has special influence of student performance and productivity.

1.2 Energy Efficiency in Buildings

Energy efficiency policies and programs starting dates by EU comebacks to oil crises within 1973 [6]. Due to importance of this issue especially in buildings, European commission states that “Improving the energy performance of buildings is a cost-effective way of fighting against climate change and improving energy security, while also creating job opportunities, particularly in the building sector.”[7].

Energy Efficiency Directive EED is a one the major force directive of the European that established in 2002/91/EC. This directive main target until 2020 is 20% less energy consumption and CO₂ emissions of buildings, 20% reduction in Greenhouse gases and 20% more saving energy [8].

Energy efficient building design means requiring the minimum amount of energy for heating, cooling, equipment and lighting that is required to maintain comfort conditions in building. The energy efficient buildings must adjust their self by utilizing natural resources of lighting, heating, cooling or by avoiding from them if they make no benefit for building environment [9].

However, existing building is the main problem to achieve the objectives. According to Building Performance Institute Europe (BPIE) in the 2011 report, in order to achievement renovating all buildings until 2050 and energy saving in the EU, annual refurbishment rates should exceed from around 1% today to 2.5% Depending on the rate of uptake of higher refurbishment, rates BPIE distinguishes between three different scenarios [10] .

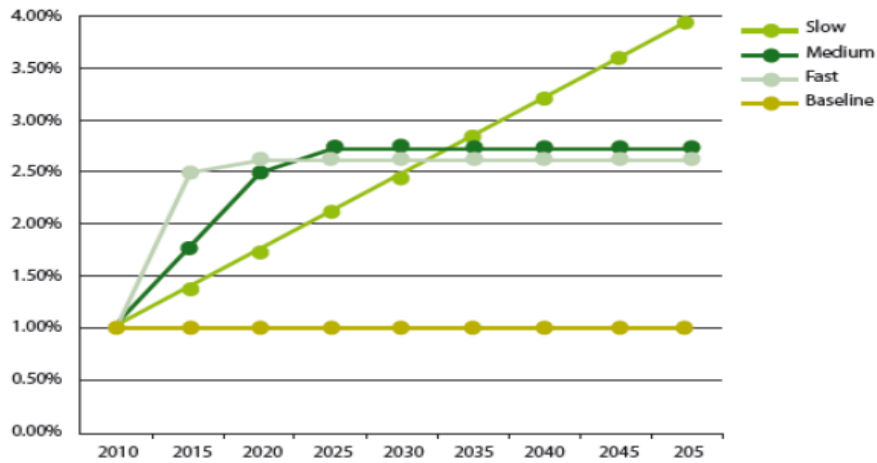


Figure 1.3: EU building stock baseline and three accelerated refurbishment rates scenarios due to achieve refurbishment until 2050 [10].

1.3 Importance of School Buildings' Energy Efficiency

Educational buildings are the foundation of every country while they consume a large portion of the nation's non-industrial energy needs; they are responsible for 15% of the total energy consumption [11]. Notwithstanding of this fact, educational building charges to lack of budget in comparison to other typical buildings. Furthermore, energy technologies have been entered in building's industry after 80's decade whereas buildings life span are almost 60-80 years; Construction of energy efficient new schools need huge amount of money and most existing school buildings.

Consequently, Energy efficiency is a critical issue for school buildings. The benefit of energy efficient school to environment is not only reducing CO₂ emissions but also improving comfort levels for occupants. Due to achievement objectives and improve the energy and environmental quality of school buildings, important international programs to are actually carried out in the world.

The green school project, it is an American program developed from the Alliance to save energy, which aims at improving the energy and environmental efficiency of existing school buildings [12]. *Teenergy Schools - High Energy Efficiency Schools in Mediterranean Area* is another funded project by EU that include 4 countries, Italy, Greece, Cyprus and Spain. The project aims at improving secondary existing schools energy efficiency, through the implementation of a common Strategy based on the three typical climatic models that characterize the Mediterranean area: coast, mountain and plain [13].

“IEA ECBCS Annex 36 - Retrofitting of Educational Buildings – REDUCE” is an IEA project in Buildings and Communities Programme (EBC, formerly ECBCS) that includes 10 different countries and is aimed to provide tools and guidelines for decision makers and designers to improve the learning and teaching environment of educational facilities through energy-efficient retrofitting. Through this project activities, a web-based software tool (the Energy Concept Adviser) is developed in order to give advice on energy-efficient retrofit measures to decision makers [14, 15].

Another new established Intelligent Energy - Europe programme project is *“50/50 European Network of Education Centers spreads across Europe”* (EURONET 50/50 MAX) that start in 2013 with 1.590.479,00 € budget and is aimed to implement a methodology that helps local authorities to learn about energy and to save it, mainly through behavioral changes [16].

Energy smart schools, it is a program of the USA Department of Energy and its Rebuild America program which mainly aims at offering school training workshops, publications, recognition, direct technical assistance, financing options, in order to improve school buildings energy efficiency [17]. *PEB Exchange Programme on Educational Building* is another program, which are applied in order to reach Energy-Efficient Renovation of Educational Buildings and establishing low energy schools Building. *The Advanced Energy Retrofit Guide for K-12 Schools* is one of retrofit guides commissioned by the U.S. Department of Energy (DOE). This guide to building energy retrofits offers practical methodologies, diverse case studies, and objective evaluations of the most promising retrofit measures for K-12 schools. By combining modeled energy savings and estimated costs, this guide presents cost-effectiveness metrics for individual EEMs and for recommended packages of EEMs.

According to statistics from the ministry of National Education of Turkey, 83,204 school buildings were existed in 2013-2014 academic year. During this academic year, about 17.5 million students studied and more than 911 thousand of teachers worked in schools [18]. These statistics indicate that almost one fourth of Turkey's population spends majority of their time in schools. In this context, school buildings have great importance of having proper indoor environmental quality and being high-energy performance buildings. This aspect will be more important when considering that Turkish population consists from mostly young people.

Consequently, refurbishment of school building can produce substantial energy, environmental, and economic benefits, including; Reduce greenhouse gas (GHG) emissions and other environmental impacts, Reduce energy costs, Increase economic benefits through job creation and market development, Improve indoor environmental quality and prevent from sick building syndrome (SBS), Improve student performance, Enhance educational opportunities and even Increase attendance.

1.4 Aim of Thesis

By a glimpse to last decades, with considerable lack of fossil and non-renewable energy in the world, using renewable energy is more important and required in our buildings. This energy type is not only reduced amount of energy costing in building but also reduced greenhouse gases emissions. It seems that retrofitting of building is a reasonable act for increasing energy efficiency of building and achieving optimum needed in a building due to the high cost of construction.

Similar to all other countries, in Turkey, primary school buildings have great importance in energy efficiency from not only exact energy consumption but also human behavior and attitude point of view. As every activity has a considerable impact on teenagers' behavior when they become mature, it is important to create retrofit action in school buildings to improve awareness among societies in the future. Thus, improving energy efficiency of school buildings supplies beneficial effect in current and future energy consumption worldwide. From other point of view, refurbishment in school not only provide thermal comfort for occupants but also lead to improving students' performance and boosting teacher moral and retention.

Overall, this research aim is to demonstrate a systematic approach for optimization of an energy-efficient retrofit strategy for school buildings. In addition, another aim is to acquire optimum energy retrofit with aid of simulation with dynamic tools, and calculate minimum level of energy cost with different simulated models of schools. By concluding this research, a method will be proposed to reduce the amount of energy consumed for new and existed building in two different climate.

2. OVERVIEW OF BUILDINGS' ENERGY PERFORMANCE STUDIES

2.1 Building Energy Performance Legislations and Standards

With the energy performance method, a total requirement for the building is set based on the supply of energy or the resulting environmental impact, for instance in form of CO₂ emissions. This method requires a comprehensive study for calculating the energy performance level of a building, with standard values for climate and different types of buildings.

Energy performance standards give optimal solutions for constructors or designers to reduce energy consumption within the frame. For instance, if efficient boilers or air conditioners are more cost effective than improved insulation, the constructors can choose this alternative to improve performance. Similarly, it will be possible to substitute more expensive solutions in the building envelope with efficient renewable energy systems or heat recovery. Therefore, legislative limitations and standards about building energy consumptions are also on the agenda including renovation of existing buildings and energy efficient design for new buildings. In the following part, legislative processes in EU and Turkey will be presented.

2.1.1 International Legislations and Standards

In 1993, European Council published Directive 93/76/EEC, which requires to limit carbon dioxide emissions by improving energy efficiency. The directive refers;

“Energy certification of buildings, the billing of heating, air-conditioning and hot water costs on the basis of actual consumption, third-party financing for energy efficiency investments in the public sector, thermal insulation of new buildings, and regular inspection of boilers” [19].

In 1997, Kyoto Protocol, an international agreement, was adopted by United Nations Framework Convention on Climate Change (UNFCCC), with the aim of reducing greenhouse gas emissions. With this agreement, 5% carbon reduction against 1990 levels is required [20]. Kyoto Protocol entered into force in 2005 and binding for also European Union countries.

European Parliament and Council reported that, buildings sector reached some benefits with the Directive 93/76/EEC, however the sector has a great unrealized potential for

energy savings and a complementary legislation is necessary. Besides, energy efficiency measures needed to comply with Kyoto Protocol. Thus, on January 2003 Energy Performance of Buildings Directive 2002/91/EC (EPBD) came into force to have more concrete actions in buildings sector [21]. EPBD aims to set minimum energy performance standards for new and existing buildings in different categories.

In 2010, European Parliament and Council enacted Directive 2010/31/EU (recast EPBD) to make the provisions of Directive 2002/91/EC more clear and strength. Recast EPBD identifies 2020 targets related with reduction in greenhouse gas emissions, nearly zero-energy buildings and cost-optimal levels of minimum energy performance requirements [22].

The Energy Efficiency Directive, approved in 2012, was the legislative result of the EEP that was published in March 2011. The new directive repeals the Cogeneration Directive (2004/8/EC) and the Energy End-Use Efficiency and Energy Services Directive (2006/32/EC). The EED is ambitious. It is meant to fill the gap between existing framework Directives and national/international measures on energy efficiency and the 2020 EU target for energy savings. It covers all sectors except transport, and includes, for the first time in an “energy efficiency” directive, measures for supply side efficiency [23].

There are many standards related to energy performance of buildings. EN standard 15459 indicates a methodology to calculate global cost in buildings’ design and retrofit process. [EN 15459, 2008, Energy performance of buildings - Economic evaluation procedure for energy systems in buildings] A German standard, provide a methodology to calculate the net, final and primary energy demand for energy system of buildings. [DIN 18599 Energy efficiency of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting] While an EN standard indicated a method to calculate energy consumption for heating and cooling system. [EN ISO 13790, 2008: Energy Performance of Buildings – Calculation of Energy Use for Space Heating and Cooling] Energy requirements for lighting system illustrated in BS EN 15193. [BS EN 15193, 2007, Energy performance of buildings - Energy requirements for lighting] Different indoor environment criteria for design and calculation of energy performance of buildings is illustrated in EN 15251. [EN 15251, 2007, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air

quality, thermal environment, lighting and acoustics] Methods of expressing energy performance of building for certification purpose indicated in EN 15217. [EN 15217, 2006, Energy performance of buildings – Methods for expressing energy performance and for energy certification of buildings]

2.1.1.1 Energy Performance of Buildings Directive (EPBD)

Energy Performance of Buildings Directive (EPBD) is the main legal tool of European Union that aims to improve energy performance of buildings and provide efficient use of energy in buildings sector.

Main requirements of EPBD are, provision of minimum energy performance requirements in new and existing buildings by enhancing individual national laws and regulations, adaptation of national methodologies for calculating energy performance level of buildings, mandatory certification of all buildings using the national methodology and regular inspection of boilers and air-conditioning systems [21].

With EPBD, Member States are obliged to set their building energy performance calculation methodologies at national or regional level. For these methodologies, a general framework is defined in Annex of the Directive. According to the Annex, the methodology shall include at least,

- Thermal characteristics of the building (shell and internal partitions, etc.).
- These characteristics may also include air-tightness;
- Heating installation and hot water supply, including their insulation characteristics;
- Air-conditioning installation;
- Ventilation;
- Built-in lighting installation (mainly the non-residential sector);
- Position and orientation of buildings, including outdoor climate;
- Passive solar systems and solar protection;
- Natural ventilation;

Indoor climatic conditions, including the designed indoor climate.

In calculations of space heating and cooling energy demand, European standard namely EN 13790 “Energy performance of buildings – Calculation of energy use for space heating and cooling”, supports essential requirements of EPBD. As stated in EN 13790, the standard gives calculation methods for assessment of the annual energy use for space heating and cooling of a residential or a non-residential building [24].

Most remarkable obligation through EPBD is the mandatory certification of the buildings using the national building energy performance level calculation methodologies. EPBD requires MS to ensure availability of energy performance certificate to the prospective buyer or tenant when buildings are constructed, sold or rented out.

EPBD had been in force since 2003 and implemented in most of the European countries with different approaches. Then, in 2008 according to necessities, a recast procedure took place for EPBD and with the final agreement, recast EPBD came into force in July 2010.

2.1.1.2 Recast EPBD

European Commission indicates the aim of the recast of EPBD as “to clarify and simplify certain provisions, to extend the scope of the directive, to strengthen some of its provisions so that their impact is more effective, and to provide for the leading role of the public sector” [25].

Among clarifications and simplifications of provisions, obligations related with nearly zero-energy buildings and calculation of cost-optimal levels of minimum energy performance requirements are the main renewals of recast EPBD. This directive introduces 2020 targets as, reducing overall greenhouse gas emissions by at least 20% below 1990 levels, reducing by 20% European Union’s total energy consumption, providing 20% share of energy from renewable sources and ensuring all new buildings are nearly zero-energy buildings. Besides, EU Member States shall ensure, after 2018 all new public buildings are nearly zero-energy buildings.

According to the recast EPBD, nearly zero energy building means, a building with a very high-energy performance level. This buildings are required nearly zero or very low amount of energy which is mostly met by renewable energy sources [22].

Additionally, Article 5, “Calculation of cost-optimal levels of minimum energy performance requirements”, appeared with recast EPBD and obliges those cost-optimal levels of minimum energy performance requirements shall be calculated by using comparative methodology framework, which should be established by the European Commission [22]. Through Annex III, principals of methodology for identifying cost-optimal levels of energy performance requirements is defined in detail complying with Article 5. Methodology for calculating cost optimal levels of minimum energy performance requirements is explained in detail in Chapter 3.

2.1.1.3 Energy Efficiency Directive (EED)

The Energy Efficiency Directive (EED) entered into force on 4 December 2012 and repeals the Cogeneration Directive (2004/8/EC) and the Energy End-Use Efficiency and Energy Services Directive (2006/32/EC).

The EED is as close as the EU comes to an EU-wide energy efficiency strategy anchored by legislation. It is a framework directive which sets overarching objectives and targets to be achieved by a coherent and mutually reinforcing set of measures covering virtually all aspects of the energy system: from supply, transformation, transmission and distribution to consumption. Member States (MSs) must transpose the EED into national law by 5 June 2014 within their own legal, social, environmental and economic culture.

The European Union has three climate and energy targets to be reached before 2020: a 20% reduction in greenhouse gas emissions, 20% of energy derived from renewables and a 20% increase in energy efficiency. If these 2020 targets are not met, a sustainable, secure and affordable energy system will be exceedingly difficult and expensive to achieve [8].

2.1.2 National Legislation and Standards

In parallel with the events in EU, Turkey, as a candidate country, enacted Energy Efficiency Law and Building Energy Performance Regulation in accordance with EPBD and related standards. Before the Directive, Turkey had a mandatory standard TS 825 which regulates required heating energy of buildings.

However, the most important legislation in energy performance of building in Turkey is Bep-Tr that provide a national methodology to calculate energy performance of buildings, the most important [26].

Besides, effective standard related to energy consumption in buildings is TS-825 standard which is insulation standard for buildings [27]. The methodology that used in standard is heating insulation method. This standard divide Turkey to five degree-day zones and recommend different building's component characteristics for each of them. However, energy related calculations except heating energy demand are not included in this mandatory standard for buildings in Turkey.

Turkish Building Energy Performance Regulation came into force in December 2008 by Ministry of Public Works and Settlement to meet requirements of Energy Efficiency Law and revised in 2010. Aim of the regulation is explained as, to set calculation procedures of building energy use considering climatic conditions, internal requirements and cost optimality, to classify buildings according to primary energy and CO₂ emissions, to set minimum energy performance requirements for major renovations of existing buildings, to evaluate feasibility of renewable energy sources, to provide inspection of heating and cooling systems, to limit greenhouse gas emissions, to determine building energy performance measures and to protect environment [28].

For classification of buildings according to primary energy amounts, an energy certification procedure laid down as stated in EPBD. In order to meet requirements of Building Energy Performance Regulation, national building energy performance calculation method, Bep-Tr, was published in 2010. The method has the simulation tool that represents the methodology of the calculation that provides building energy certificates showing energy performance levels.

2.2 The Parameters Affecting Building Energy Efficiency

Energy efficient building design means requiring the minimum amount of energy for heating, cooling, equipment and lighting that is required to maintain comfort conditions in building. The energy efficient buildings must adjust their self by utilizing natural resources of lighting, heating, cooling or by avoiding from them if they make no benefit for building environment. Energy efficient design parameters comprise

location of building, site of building, orientation of building, shape of building and building envelope.

2.2.1 Location of the Site

Location of the building determine the micro-climate conditions which has very important role in building energy efficiency, as it is important for learning, climatic values like sun radiation, air temperature, air circulation, humidity which effect energy costs [29].

2.2.2 Location of Building in the Site

2.2.2 Location of Building in the Site is one of the most important design parameters, which effects sun radiation amount, air circulation velocity around the buildings and distance between the buildings. For this reason site of the building in area should be determined to benefit and defend from the renewable energy resources like sun and wind [29].

2.2.3 Orientation of Building

Orientation of building is important parameter, which affects the ratio of the solar radiation gain of building sides, consequently total solar radiation gain of building. In addition, side of buildings effect wind amount, consequently, effect natural ventilation possibility and heat loss amount by convection and air lack. For this reason according to the necessities of that region, buildings must be oriented for avoid of or benefit from the sun and wind according to the conditions [29].

2.2.4 Shape of Building

Shape of building is important in areas that have different climate conditions. In cold climate regions compact forms should be used which minimize the heat loss part. In hot-dry climate regions compact forms and courtyards should be used which minimize heat gain and helps to provide shaded and cool living spaces. In hot-humid climate region long and thin forms whose long side oriented to the direction of prevailing wind makes possible maximum cross ventilation. In mild climates, compact forms, which are flexible more than the forms used in cold climate regions, should be used [29].

2.2.5 Building Envelope

Building envelope, which is composed of opaque and transparent components, acts as external covers with environment so all of the heat gains and heat losses happen through envelope. This skin of building performs the role of a filter between indoor and outdoor conditions, to control the intake or outtake of air, and light.

Although heat losses in buildings may vary according to the architecture and state of the building project, generally, heat losses of a multi-story building is based on 40% of exterior walls, 30% of windows, 7% of the roof, 6% of basement slab and 17% of air leaks. For single story buildings heat losses are based on 25% of exterior walls, 20% of windows, 22% of the roof, 20% of basement slab and 13% of air leaks [30].

There are two ways to lower the heat transfer rate through the building envelope. The first is to raise the thermal resistance, or decreasing U value, in the building envelope components considering also heat storage capacity of materials at the same time , possibly by increasing the length (or depth) of insulation or choosing insulation with a lower thermal conductivity. The second is to lower the temperature difference between the indoor and outdoor environment, a more difficult challenge to overcome if occupant comfort is considered. Lowering the heat transfer rate of the building envelope will allow the mechanical systems to use less energy when heating and cooling the building, thus making the building more energy efficient [31].

Overall and regarding everything to be considered, energy efficient refurbishment is one the main strategy in order and reaching to main target Energy Efficiency of building. Besides, it needs less investment cost in contrast to rebuilding new ones.

2.3 Energy Efficient Renovation Strategies on Building Envelope

Energy efficiency is a way of managing and restraining the growth in energy consumption. In addition, energy efficiency is one the most important issue due to numerous existed building, which are not efficient. Demolishes all existed buildings for construction new types is not logical approach in terms of operation cost and shortage of time. The rate of this type of reconstruction is not more than 1.5% per year [32]. It is clear fact that Turkey has required energy almost 80% of required energy in Turkey is imported from other countries hence; energy efficiency is important issue [33].

One significant thing is that tendency must be to design building systems, which use minimum energy. Initial solution is using passive systems, and then active systems must be added to get more performance. If only active systems are added to building after construction, without taking any consideration of energy efficient design parameters during the design and construction period, it will not be true assuming that building as a real energy efficient building. For a building passive renovation, interventions usually involve; roof, windows, walls and ground floor.

2.3.1 Wall's energy efficient renovation strategies

It is clear fact that, a building's exterior walls are its public face and as the most heat losses and gains are happened in wall components, so the most effective way to reduce the amount of energy consumed for heating or cooling of the building. High levels of insulation, with a minimum of thermal bridging and air leakage paths are key components in improving the thermal performance of a building envelope. From heating energy point of view, without the right combination of these factors, simply adding more insulation may extenuate thermal discontinuities within the building envelope. To be cost effective the degree of retrofit should be carefully considered [30].

Even though there are various technologies except insulation application , which could applied to external walls, the significant aspect being more cost effective and having more efficient. Among energy efficient renovation approaches, which could applied to the walls are including:

- Adding solar walls in appropriate orientation,
- Improve energy related properties of Wall System,
- Improve daylight Amount and Prevent From Glare,
- Photovoltaic panel application,
- Changing transparency ratio,
- Condensation control,
- Color [32, 34].

2.3.2 Roof's energy efficient renovation strategies

The roof is usually second the largest area of a building has exposed envelope surface; as a result, the roof experiences the most hours of direct sun exposure. Therefore, if the roof is deficient, it can have a considerable impact on overall energy consumption. Post insulation of roofs can be an economical way of placing additional insulation in one of the main elements of the building. Besides, some others methods can be used for retrofitting roof are including:

- Green roof application ,
- Color of the roof ,
- Dark colors at the cold climate zones ,
- Light colors at the warm climate zones ,
- Use of renewable energy sources by roof integrated systems ,
- Photovoltaic panels,
- Thin-film photovoltaic roofing materials ,
- Solar collectors [30].

2.3.3 Fenestration system's energy efficient renovation strategies

Windows as transparent elements on envelope are the least insulating part of the thermal envelope with a heat loss coefficient, a U-value, typically 4-10 times higher than other thermal elements. From other point of view, in spite of having higher heat loss coefficient rather than thermal envelope elements, at the same time windows allow solar energy to pass through into the building. In refurbishment, it requires a balance between two different properties. Research and development into window design has concentrated on new super insulated glazing, improved insulation of frame construction and increased G-value. Furthermore, other factors for determining the choice of window used include orientation, shading conditions, thermal mass of the building, climate zone of building and internal heat load. Assessment and calculation, in terms of its energy characteristics, will be required to achieve the optimum choice of window.

- Add exterior window films ,
- Replace windows ,
- Air-infiltration prevention,

- Add exterior window shading and light shelves ,
- Testing with different glasses,
- Renovation of the Frame,
- Multi layered glass application ,
- Filling gas between the layers of glass as an insulation material.

In addition, heat loss through doors can be prevented by draught sealing and also by thermal insulation. In school buildings, main entrances should always be lobbied to prevent large heat losses due to the frequent movement of students in and out [30].

3. BUILDING ENERGY PERFORMANCE AND COST OPTIMAL CALCULATION METHODOLOGY

3.1 Energy Performance Calculation Methodology for Energy Certification

Most of the European Union countries has been developed their national calculation methodologies for building energy performance certification according to EPBD obligations. Main legislative tool, which guides for establishing a calculation methodology for building heating and cooling energy need is EN ISO 13790 standard.

EN ISO 13790 standard introduces three different methodologies for calculating heating and cooling energy use of buildings. These methodologies are:

- Simple hourly method
- Monthly/seasonal method
- Detailed dynamic method

Simple hourly method is a semi dynamic method and provides to calculate heating and cooling energy together during the same calculation period in accordance with heating and cooling set point temperatures.

Monthly/seasonal method, is a method based on monthly/seasonal calculation periods. In this method, heating and cooling period of the whole year are determined based on months or seasons. As stated in EN ISO 13790 this method, “gives correct results on an annual basis, but the results for individual months close to the beginning and the end of the heating and cooling season can have large relative errors.” [21].

Detailed dynamic methods are based on calculations with short time steps. This method is capable of taking parameters as stored heat and mass of the building into account. There are many different methods of dynamic calculation with several complexity levels. Calculating building energy performance using dynamic method.

In European Countries, selection of the national building energy performance calculation methodology ranges between methodologies defined in EN ISO 13790 According to specifications and requirements, each country made the proper selection of methodology.

Due to northern countries, scarcely need cooling energy, mostly monthly/seasonal methods are used in these countries. However, studies on these methodologies are continuing in Europe in order to overcome disadvantages for intermediate seasons. A few European country endeavor to use detailed dynamic methods with dynamic simulation tools. However, these tools are complex and a few user can run them accurately, also inspection is a problem for dynamic simulation tools.

3.2 Cost Optimal Energy Efficiency Calculation Methodology

The cost-optimal methodology is a tool that allows EU Member States to create a legal framework for raising their minimum energy performance requirement levels ensuring that all economically rational measures are taken into account.

On 19th of April, the European Commission published guidelines (accompanying Commission Delegated Regulation No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU) on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

According to the EPBD recast, Member States (MS) must “assure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels.” MS must also “take the necessary measures to ensure that minimum energy performance requirements are set for building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are replaced or retrofitted, with a view to achieving cost optimal.

The cost-optimal level is defined as “the energy performance level which leads to the lowest cost during the estimated economic lifecycle.” MS will determine this level by taking into account a range of costs including investments, maintenance, operating costs and energy savings. The economic lifecycle is defined in the Cost-Optimal Delegated Regulation of the Commission [22].

MS are requested to report to the Commission all input data and assumptions used for these calculations as well as the results of the calculations from two perspectives: the macroeconomic level (societal level) or the financial level (private investor).

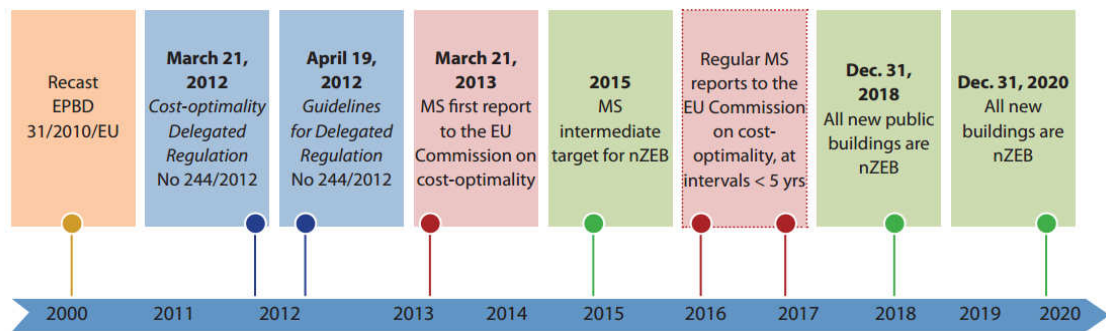


Figure 3.1: Implementation timeline for cost-optimality and nearly Zero-Energy Buildings 'requirements of EPBD.

This picture describes steps from 2000 to 2020 the evolution of the energy policy in the European context in order to increase the number of the nearly-zero energy buildings in which energy efficiency measures are defined by the cost-optimal method. This method comes out from the Global Cost that is the way of calculation defined in the European Standard EN 15459-2007 about energy performance of building, with the title "Economical Evaluation Procedure for Energy System in Buildings".

The Regulation sets the cost-optimal methodology according to six main steps:

1. Establishment of reference buildings;
2. Identification of energy efficiency measure, measures based on renewable energy sources and/or packages and variants of such measures for each reference building;
3. Calculation of the primary energy consumption resulting from the application of such measures and packages of measures to a reference building;
4. Calculation of the Global Cost in terms of net present value for each reference building;
5. Undertaking a sensitivity analysis for cost input data including energy prices;
6. Derivation of cost optimal levels of energy performance for each reference building.

These steps, according to which the whole research is been structured, will be summarily analyzed in the following paragraphs in order to let the lector to be aware of the main topics and concepts which lie behind the cost-optimal approach.

3.2.1 Establishment of Reference Building

According to Annex III of EPBD Recast, reference buildings (RBs) are “buildings characterized by and representative of their functionality and geographical location, including indoor and outdoor climate conditions” [35]. Basically, they symbolize the most typical building geometry and systems, its typical energy performance level (for both building envelope and system) according to the typical function and structure by which the building stock can be divided. Hence, reference buildings represent an average of a pre-determined building stock in a certain EU Member State [36].

The Regulation requires Member states to establish at least one RB for new buildings and at least two RBs for existing building, according to the following building categories:

- Single-family buildings;
- Apartment blocks and multi-family buildings;
- Office buildings.

Consequently, each Member States should establish in total at least 9 reference buildings. All data needed for this purpose are usually taken from official statistics at national or regional level and they can concern 4 “sub-sets”:

- The “form” (type, size and geometry) of the building;
- The envelope features (construction technologies and materials) with their thermo physical properties;
- The HVAC (Heating Ventilation Air Conditioning) systems and system based on renewable energy source (RES);
- All those operational parameters that affect the usage of the building itself.

“Once collected the data within the 4 sub-sets, in order to create RBs, the process of gathering all data together is a crucial task. It is important to understand the typology of available data depending on the sources used. It is possible to collect data from statistical analyses or to base RBs on experts’ assumptions.” [37].

Directive 2010/31/EU points out three methodologies to classify reference buildings as:

- *Example reference buildings*, which result from the collection of information from experiences, handbooks, standards or experts’ inquire. This method is adopted when no statistical data are available and the result is the most probable building of a group, within a selected location and age;
- *Real reference buildings*, derived from a large amount of information on the building stock that allows choosing a real existing building, with average features, that is the closest to statistical data.
- *Theoretical reference buildings*, which are made of the most common used material and systems as a summation of various features of real buildings. It will not represent a real building itself but just a statistical composite of building features.

It is possible to use just one of the three methodologies for all models of RBs or apply them differently to each model of the same building, results will depend on the different level and quality of data considered as starting assumptions of the classification [37].

Guidelines to EPBD Recast also suggests the use of already existing catalogues and databases of reference buildings, together with works carried out under the Intelligent Energy Europe program, such as TABULA and ASIEPI Project.

- TABULA Project is a typology approach for building stock energy assessment and it has been pursued by 13 countries. The project concerns the residential building stock and is targeted to establish a set of typical buildings in terms of construction period or building size [38].

- ASIEPI Project gathers a set of reference buildings to be used in energy performance calculation studies. It involves twelve European countries and concentrates on the single-family house typology [39].

3.2.2 Identification of Energy Efficiency Measures (EEM)

Article 4 of EPBD Recast requires Member States to set minimum energy performance requirements for all elements, susceptible to be replaced or retrofitted, which have a significant impact on the energy performance of the whole building, taking into account general indoor climate conditions, local conditions, the function and the age of the building. Consequently, the identification of energy efficiency measures (EEMs) to analyze is driven by the minimum energy performance requirements set at national level. For new constructions, Article 6 of Directive 2010/31/EU expressly require evaluating “the technical feasibility of high-efficiency alternative systems” such as cogeneration, district heating/cooling based on renewable energy source, heat pumps. About existing buildings, Member States shall ensure that all major renovation will lead to an increase in the energy performance of the building in order to meet minimum requirements, taking into account the feasibility of high-efficiency alternative systems as for new constructions.

According to the Regulation No 244/2012 Member States should:

- Identify measures suitable in the specific local, economic and climatic context;
- Considers the use of renewable energy source in defining measures/packages/variants;
- Include measures/packages/variants necessary to meet the minimum energy performance requirements for nearly zero energy buildings;
- Exclude EEMs which are certainly far from cost-optimal levels;
- Choose measures/packages/variants compatible with air quality and indoor comfort levels according to CEN standard 15251 on indoor air quality.

The interaction between different measures has to be taken into account when combining packages/variants, in order to achieve meaningful combinations and exploit synergy effects that lead to better results in terms of cost-optimality.

“The more packages/variants are used (and variations of the measures included in the assessed package), the more accurate the calculated optimum of the achievable performance will be.” [40].

3.2.3 Calculation of Primary Energy Consumption (EP)

As ratified by EPBD Recast “‘energy performance of a building’ means that calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting” [35]. According to Annex I of EU Regulation N. 244/2012 the 'direction' of the calculation should be from the needs to the source (i.e. from the building's energy needs to the primary net energy).

The Regulation recommends following several steps toward energy performance calculation:

1. Calculation of net thermal energy needs;
2. Subtraction from net thermal energy needs of the thermal energy from RES generated and used on-site;
3. Calculation of the energy uses for each end-use (heating, cooling, ventilation, lighting) and for each energy carrier;
4. Subtraction from electricity use of the electricity from RES;
5. Calculation of the delivered energy for each energy carrier (fuel, electricity);
6. Calculation of the primary energy associated with the delivered energy;
7. Calculation of primary energy associated with energy exported to the market;
8. Calculation of primary energy as the difference between delivered energy and energy generated by RES.

Figure 3.2 summarizes the procedure for the derivation of the net primary energy of reference buildings suggested by EPBD.

The calculation methodology depending on national legislations, the boundaries of the system and the timing of calculation steps (months, hours, etc.) have to be established at the beginning of the procedure. In addition, energy needs for hot water, energy use for lighting and that used for ventilation shall be determined according to respective EN standards. In respect of the energy needs for heating and cooling, the energy balance of the building and its systems are the basis of the procedure and follow the steps of standard EN ISO 13790.

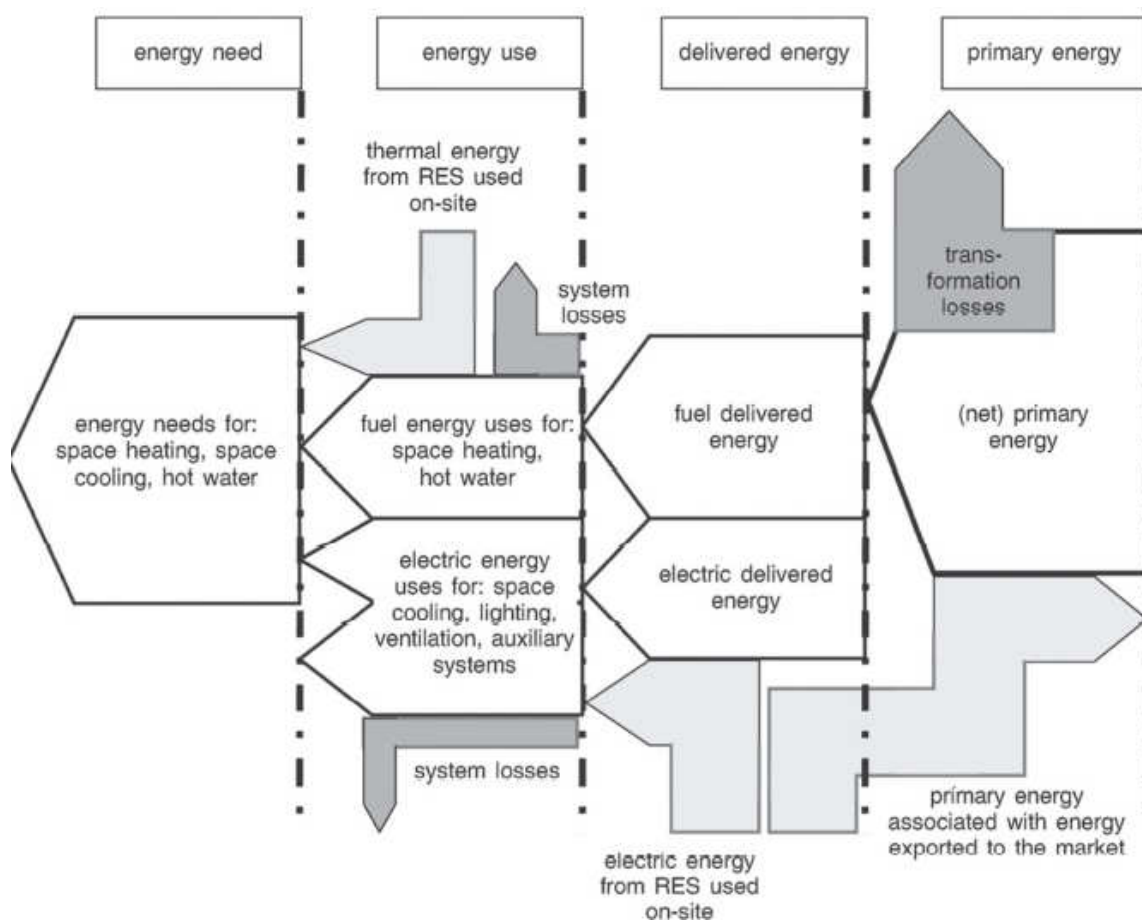


Figure 3.2: Scheme of primary energy calculation from EPBD guideline.

The calculation can be done according to two different approaches:

- The holistic approach that considers the effect of all heat gains associated with a building and its technical systems, which influence the energy needs for heating and cooling.

- The simplified approach, which multiplies recoverable thermal system losses by a fixed factor and subtracts this recovered heat from the thermal loss of each technical building system considered.

Although CEN standards or national energy performance calculation methods could be used as reference for calculating energy use for space heating/cooling, hot water and energy generation from RES, the detailed dynamic simulation method should be preferred to achieve reliable results.

3.2.4 Calculation of Global Cost

3.2.4.1 General Principles for Cost Calculation

Initially the cost optimal analysis is started by calculation of global cost, which has different perspective. According to EPBD recast, the cost-optimal methodology is addressed to national authorities for developing generally applicable regulation at national level. Among the multitude of cost optimal levels for every single building/investor combination of needs, Member States can base their calculation on three different perspectives: [40].

- The “societal macro-economic perspective” that includes societal benefits as climate changes and CO₂ emissions costs, ignoring national taxes and subsidies;
- The “individual end user perspective” that takes into account cost and benefits, taxes and subsidies from occupant’s point of view;
- The “idealized end user micro-economic perspective” that assesses a typical end user definition (avoiding differences among different end-user perceptions) and ignores markets barriers.

This research adopts the individual perspective by computing all costs sustained by end users/investors during the calculation period. The latter is relevant in order to analyses the variation of global cost according to the relationship between investment costs and annual costs.

The Regulation No 244/2012 suggests keeping a calculation period of 30 years for residential buildings and a period of 20 years for commercial buildings, which represents the average period that occurs between two set of renovation actions [41].

Standard EN 15459 defines global cost as the “sum of the present value of all costs (referred to the starting year) including investment costs. At the end of the calculation period, the deconstruction costs or the residual value of the components should be taken into account to determine final costs” [42].

3.2.4.2 Cost Categories

Overall, there are five different types of costs to be examined:

- Initial investment cost, which includes all costs (design, purchases, installation and commissioning process) incurred up to the point when the building or its renovated components are delivered to the customer;
- Running cost that comprises “annual maintenance costs, operational costs, energy costs and added costs”;
- Energy cost is the annual cost due to the total energy demand of the building including fixed quotas, peaks charges and national taxes;
- Replacement cost depending on the lifespan of building elements which can necessitate to be replaced during the calculation period;
- Disposal cost, hence costs for deconstruction at the end of life of a building (including deconstruction, removal, transport and recycling of building elements).

For the calculation at macroeconomic level, Member States shall in addition establish the cost of greenhouse gas emissions. These shall reflect the quantified, monetized and discounted operational costs of CO₂ resulting from the greenhouse gas emissions in tones of CO₂ equivalent over the calculation period.

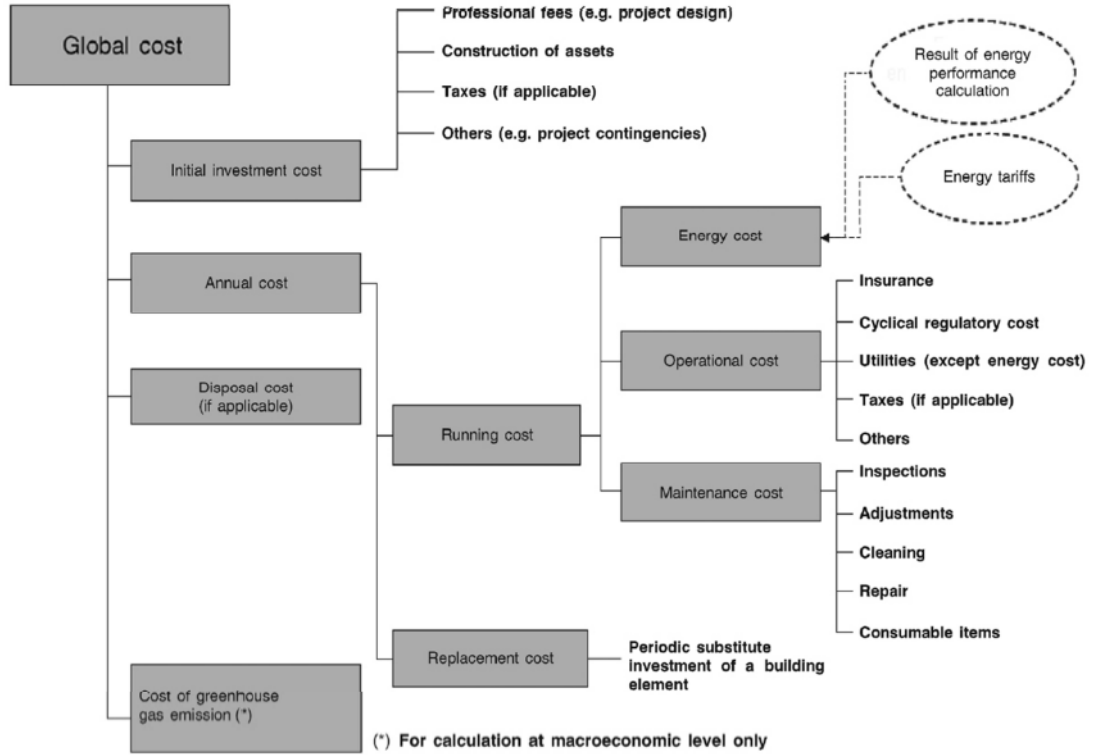


Figure 3.3: Cost categorization according to the methodology established be EN 15459.

3.2.4.3 Calculation of Global Costs for a Financial Calculation

When determining the global cost of a measure/package/variant for the financial calculation, the relevant prices to be taken into account are the prices paid by the customer including all applicable taxes including VAT and charges. Ideally, the subsidies available for different variants/packages/measures are to be included into the calculation, but Member States can choose to leave subsidies aside, ensuring however that in that case both subsidies and support schemes for technologies, but also possibly existing subsidies for energy prices are taken out; [42].

Global costs for buildings and building elements shall be calculated by summing the different types of costs and applying to these the discount rate by means of a discount factor to express them in terms of value in the starting year, plus the discounted residual value as follows:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right]$$

where:

- τ means the calculation period
- $C_g(\tau)$ means global cost (referred to starting year $\tau 0$) over the calculation period
- C_I means initial investment costs for measure or set of measures j
- $C_{a,i}(j)$ means annual cost during year i for measure or set of measures j
- $V_{f,\tau}(j)$ means residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year $\tau 0$).
- $R_d(i)$ means discount factor for year i based on discount rate r to be calculated as:
where p means the number of years from the starting period and r means the real discount rate.

$$R_d(p) = \left(\frac{1}{1 + r/100} \right)^p$$

When determining the global cost at macroeconomic level of a measure/package/variant, in addition to the cost categories listed under 4.1, a new cost category cost of greenhouse gas emissions is to be included so that the adjusted global cost methodology reads as:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j)R_d(i) + C_{c,i}(j)) - V_{f,\tau}(j) \right]$$

3.2.5 Undertaking a Sensitivity Analysis

“Sensitivity analysis is standard practice in ex-ante assessments when outcomes depend on assumptions on key parameters of which the future development can have a significant impact on the final result. The Regulation requires Member States to perform at least a sensitivity analysis on different price scenarios for all energy carriers of relevance in a national context, plus at least two scenarios each for the discount rates to be used for the macroeconomic and financial cost optimum calculations”.

The purpose of sensitivity analysis is to identify the most important parameters of a cost optimal calculation. The regulation also requires Member States to perform a sensitivity analysis on the energy price development scenarios for all energy carriers used to a significant extent in buildings in their national context [40].

3.2.6 Derivation of Cost Optimal Levels

According to Directive 2010/31/EU “cost-optimal level means the energy performance level which leads to the lowest cost during the estimated economic lifecycle” where the lowest cost corresponds to the global cost and the lifecycle depends on Member States assessments and on the typology of building considered.

Consequently, the cost-optimal level is obtained by comparing the global cost and the correspondent primary energy, both calculated for each measure/packages/variants. Results of this comparison can be reported on a graph that describes primary energy use [$\text{kWh/m}^2 \text{ year}$] on the x-axis and global costs on the y-axis [$\text{€}/\text{m}^2$]. From the number of combination of measures assessed, a specific cost curve can be drawn following the lower border of the area marked by the data points of different variants, as show in the following sample graph:

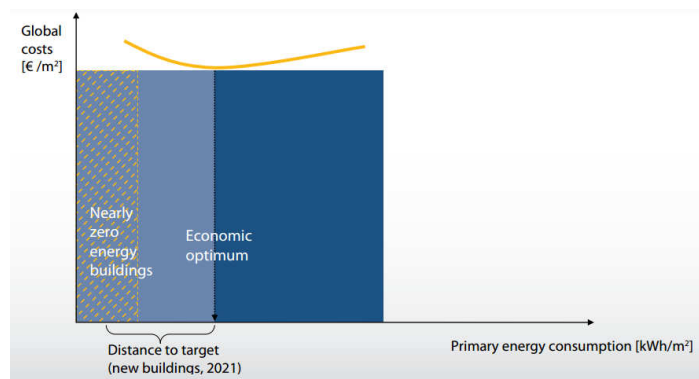


Figure 3.4: Determination cost optimal level from curve.

In this way, a cost-optimal range is defined as the average of lower global cost solutions. The lowest point of the curve gives the “economic optimum” (cost-optimal level of minimum energy performance requirements). In cases where the outcome of the cost-optimal calculations gives the same global costs for different levels of energy performance, Member States are encouraged to use the requirements resulting in lower use of primary energy as the basis for comparison with the existing minimum energy performance requirements. The following diagram represents summarizes the necessary steps to be followed when implementing cost-optimality at national level [43].

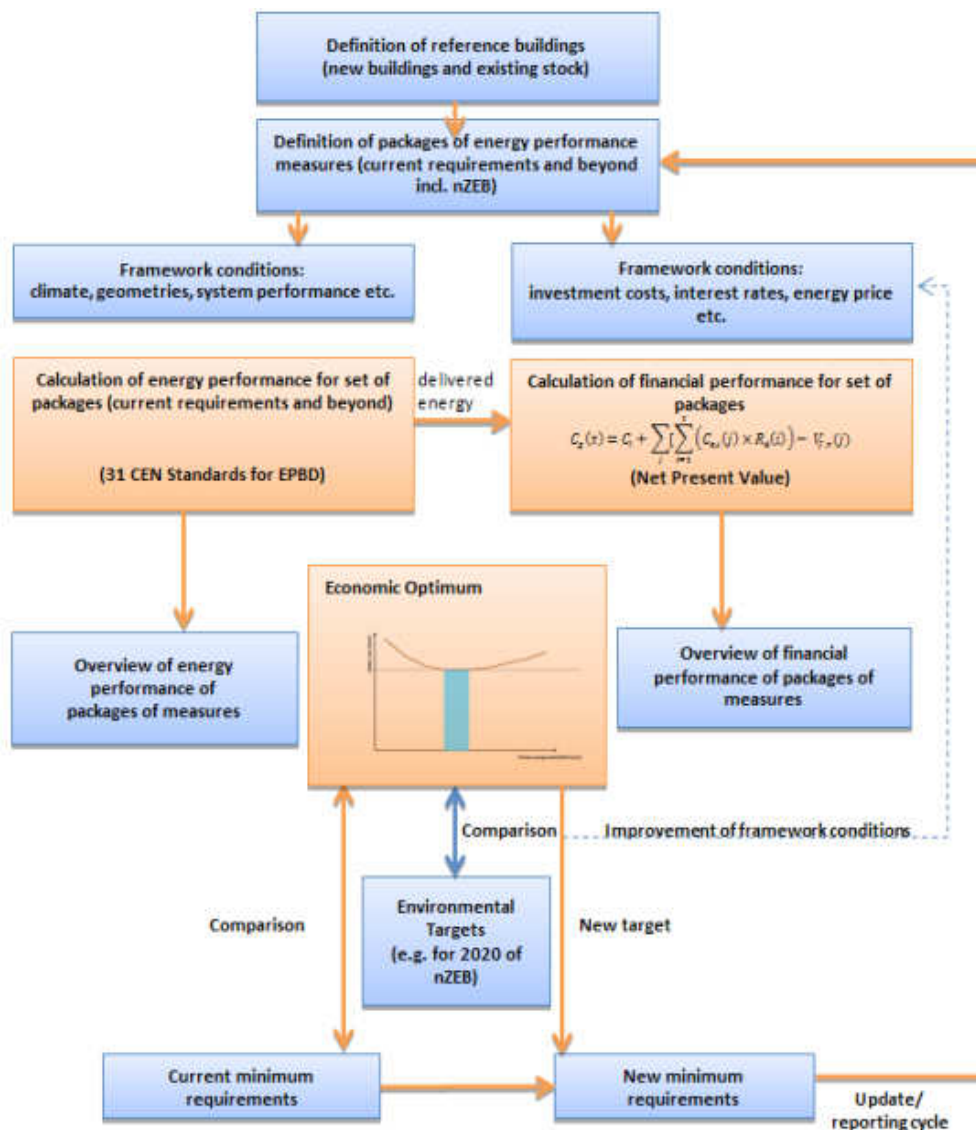


Figure 3.5: Implementation steps of cost-optimal methodology.

4. DETERMINATION OF COST OPTIMAL LEVEL FOR ENERGY EFFICIENT RETROFIT OF A CASE STUDY PRIMARY SCHOOL BUILDING IN ISTANBUL AND ERZURUM

4.1 Climate Zones in Turkey

According to a research that is made for to classify climate regions in Turkey through the climatic datas, which are taken from the 35 different center, Turkey has been separated 7 different climate regions by Ümran Emin Çölaşan. In the following studies made by Lütü Zeren, it is assumed that there are five climate zones in Turkey [44]. These are mild-humid climate zone, hot-humid climate zone, hot-dry climate zone, mild-dry climate zone and cold climate zone as it is seen in figure 4.1.



Figure 4.1: Distribution of Turkey's Climate Zones [44].

However, In Turkey there are four thermal zones according to the insulation application, which are based on heating degree-days. Each zones require different building envelope properties. The limited U value of building envelope in different degree-day zones shown in table 4.1 [27].

Table 4.1: The limit U values in different degree-day zones [27].

	U exterior wall (W/m ² K)	U ceiling (W/m ² K)	U ground floor (W/m ² K)	U windows (W/m ² K)
1. DDZ	0.66	0.43	0.66	1.8
2. DDZ	0.57	0.38	0.57	1.8
3. DDZ	0.48	0.28	0.43	1.8
4. DDZ	0.38	0.23	0.38	1.8
5. DDZ	0.36	0.21	0.36	1.8

In this research, Istanbul and Erzurum are selected, which are located in two different climates zone and various degree-day zones according to TS825-2013. The characteristic of each representative are as following;

4.1.1 Mild-humid Climate Zone (Istanbul)

This city is effective by Sea of Marmara and Black Sea simultaneously. Istanbul is the characteristic city for this climate zone. According to Köppen-Geiger classification, Istanbul is in Cfa region and has a humid subtropical climate that is mild with no dry season, constantly moist. Summers are hot and muggy with thunderstorms. Winters are mild with precipitation. Seasonality is moderate. The average monthly relative humidity in Istanbul is more than 70% as shown in Table 4.2. Based on TS825-2013, Istanbul is the representative city for second climate zone [45, 46, 27].

Table 4.2: Distribution of average relative humidity in Istanbul [27].

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
IST	79	76	75	74	74	70	71	74	75	80	79	80

4.1.2 Cold Climate Zone (Erzurum)

This climate zone is effective in East Anatolia region. Erzurum is the characteristic city for this climate zone. According to Köppen-Geiger classification, Erzurum is in Dfb region and has a humid continental climate with severe winters, no dry season, warm summers and strong seasonality. The average monthly relative humidity in Erzurum is more than 51% as shown in Table 4.3. Based on TS825-2013, Erzurum is the representative city for fifth climate zone [45, 46, 27].

Table 4.3: Distribution of average relative humidity in Erzurum [27].

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
ERZ	78	77	75	67	63	59	54	51	54	66	75	79

4.2 Definition of Type Primary School Building

In Turkey, there are specified typical projects that are design for primary school building by each Special Provincial Administration (İl Özel İdaresi) with approval from Turkey's Ministry of Education (T.C Milli Eğitim Bakanlığı) . To be illustrate,

there are seven typical projects for primary school in Istanbul, which are designed by Istanbul Special Provincial Administration and (İstanbul İl Özel İdaresi). These typical projects are constructed in most regions of Istanbul. Table 4.4 shows typical projects for primary school buildings in Istanbul. As each typical project is representing a number of new and existing school buildings in Istanbul, each of them can be selected as a reference building for school buildings depends on the capacity and number of classrooms [47].

Table 4.4: List of typical projects for primary school that implemented by Istanbul Special Provincial Administration [47].

No	Name of project	Capacity (student)	Number of floors	Areas
1	MEB.2000-41	240 Students	5	635 m ²
2	10025R-480	480 Students	5	863 m ²
3	10025R-720	72 Students	5	1121 m ²
4	MEB.2000-42	720 Students	5	1.285 m ²
5	MEB.2004-53	1200 Students	5	1.541 m ²
6	RAGIP AKIN	B.B Private Project	5	789 m ²
7	RIFAT YALMAN	B.B Private Project	7	533 m ²

4.3 Determination of Case Building as Reference Building

Considering the number of building located in a climate region, calculations of cost optimal levels of minimum energy performance requirements for each building is almost impossible. Defining reference buildings is the initial requirement for performing calculations. The main aim of establishing a reference building is to identify a representative building that reflects most typical measures for building geometry and systems, energy performance for both building envelope and systems, function and cost structure of building stock and represents climatic conditions and geographic location.

As argued in chapter 3 about definition reference building according to EPBD recast, up to now there is not established reference building for non-residential buildings in Turkey. However, for definition of residential reference building there have been initiated a research. In Turkey, reference buildings have defined in existing with the purpose of energy certification. However, aim of this methodology and reference building description do not serve to cost optimality calculations. The aim of the Bep-Tr reference building was to set a base building, which provides opportunity for comparison between proposed and baseline design for building energy performance level considering minimum energy performance requirements at national level. In this research project, the largest typical school project (MEB.2004-53) is selected as a case study reference building as it is constructed in different regions of Istanbul and representing a number of existing buildings. Sample of existing building constructed according to MEB.2004-53 typical projects are indicated in table 4.5. Besides, some of pictures of primary school buildings in Istanbul that are constructed in terms of MEB.2004-53 typical project are represented in figure 4.2.

Table 4.5: List of some typical projects for primary school that constructed in Istanbul terms of MEB 2004-53 typical [47].

NO	Regions in Istanbul	Name of Primary School
1	Bağcılar	Bağcılar İlçesi İlköğretim Okulu
2	Kağıthane	C.Şamikoğlu-Namık Kemal İ.Ö.O.
3	Eyüp Alibeyköy	Eyüp Alibeyköy Çırçır Mahallesi İ.Ö.O.
4	Beylikdüzü	İstanbul Beylikdüzü Marmara Mahallesi İ.Ö.O.
5	Gaziosmanpaşa	Gaziosmanpaşa İlçesi, Yeni Mahalle 3110 Parsele İ.Ö.O.
6	Sultanbeyli	Sultanbeyli İlçesi, Hamidiye Mah. İ.Ö.O.
7	Pendik	Pendik, Fuat Köprülü İ.Ö.O.
8	Arnavutköy	Arnavutköy Yavuz Selim Mah. İ.Ö.O.
9	Esenler	Esenler Davutpaşa Mah. Ayvalıdere İ.Ö.O.
10	Pendik	Pendik İlçesi, Kurtköy Mahallesi İ.Ö.O
11	Sancaktepe	Sancaktepe İlçesi Sefa Yenidoğan Mahallesi İ.Ö.O
12	Ümraniye	Ümraniye Yukarı Dudullu Mehmet Akif Ersoy Mahallesi İ.Ö.O



Gaziosmanpaşa İlçesi, Yeni Mahalle
3110 Parsele İlköğretim Okulu



Sancaktepe İlçesi Sefa Yenidogan
Mahallesi İ.Ö.O



Sultanbeyli İlçesi, Hamidiye Mah.
İ.Ö.O.



Pendik, Fuat Köprülü İ.Ö.O.



C.Şamikoğlu İlköğretim Okulu



Esenler Davutpaşa Mah. Ayvalıdere
İ.Ö.O.

Figure 4.2: Sample of school building constructed based on MEB2004-53.

Consequently, existed case building which is selected for investigation is assumed to be the reference building. It is considered that reference building has situated in the same climate with the same orientation and geometry with the proposed building. Number of floors and area of reference building are equal to the actual building. Also in reference building; all surface areas, transparency ratios, set point temperatures, usage schedules and all spaces and functions are assumed same as with the proposed building.

In order to consider the reference building in another climate zones of Turkey except Istanbul, which is located in mild humid climate zone, building physical properties are kept same for all other climate zones. However, project thermo physical properties like insulation thickness is changed.

4.3.1 Description of Reference Building

In this study, C.Şamikoğlu-Namık Kemal İ.Ö.O is one of the seven specified typical project, which is name MEB.2004-53.This project is constructed in Istanbul Kağıthane. This project capacity is 1200 students. The situation of this building is shown in figure 4.3. This school has five stories that is including basement floor, ground floor and 3 typical floors. Building has 22m height and 1685 m² floor area; 40 classrooms are existed in this building. Situation of reference building in site, first floor and typical floor plans of the building are shown at figure 4.4 and figure 4.5.



Figure 4.3: Location of reference building in site Plan.

In essence, this reference building is calculated for a full year in two different climate zones; Istanbul and Erzurum, which are representing Turkey's moderate-humid and cold climate zones. The majority of existed building, which are constructed before 1990, are without thermal insulation. Hence, all physical and thermo physical properties are supposed same of RB in Istanbul and Erzurum and it's assumed that for both reference buildings in Istanbul and Erzurum are without thermal insulation. In this chapter, reference building for Istanbul and Erzurum description and improvement scenarios have been presented in this chapter. All package results and analysis have been illustrated in chapter 5.



Figure 4.4: Reference building's geometry.

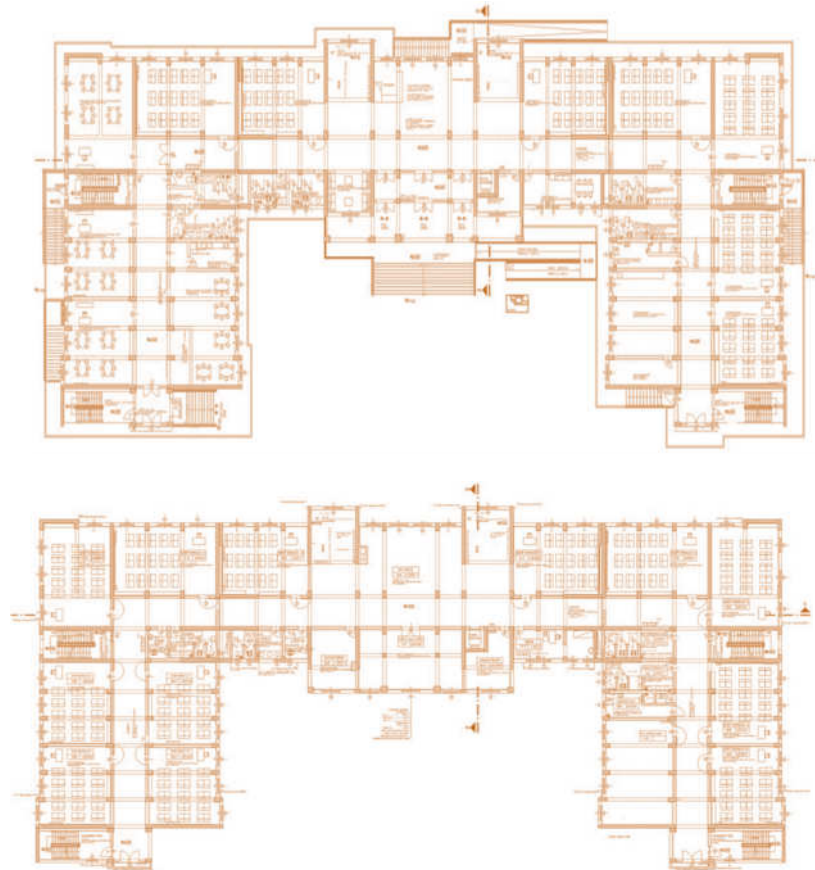


Figure 4.5: Ground and typical floor plan of primary school.

Building physical properties information such location, orientation and etc. have been shown in table 4.6. Figure 4.6 shows axonometric views that is simulated by Design Builder software. This primary school was occupied by Students, academic and administrative staff in weekdays between 08:00 am and 17:00 pm. School occupancy schedule is indicated by figure 4.7.

Table 4.6: Reference building information.

Physical properties of building		
▪ Location	Istanbul	Erzurum
	41°03_53.96__ latitude	40°99_35.97__ latitude
	28°58_15.44__ longitude	39°74_96.18__ longitude
▪ Orientation	315° (CW normal angle of north facade)	
▪ Environment	Open land, no shading element and structure in the close environment, landscape, etc.	
▪ Floor area (m ²)	1685	
▪ Floor height (m)	3.30	
▪ Facade surface area (m ²)	3570.5	
▪ Roof area (m ²)	1852.45	
▪ Glazing area (m ²)	660.5	
▪ Glazing ratio (%)	18.5	
▪ Number of storey	5 (basement+ground+3 typical floors)	

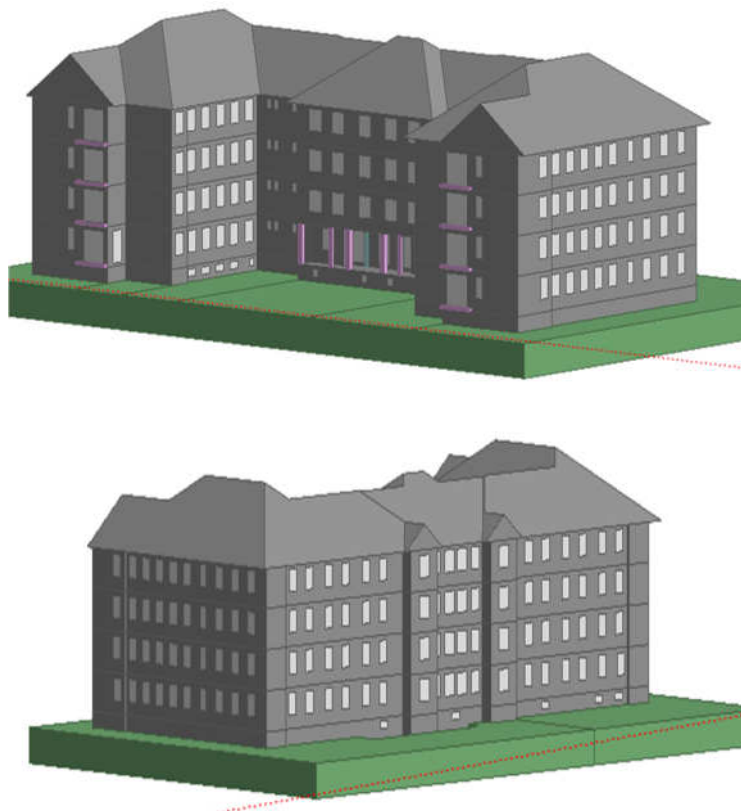


Figure 4.6: Axonometric views of reference building.

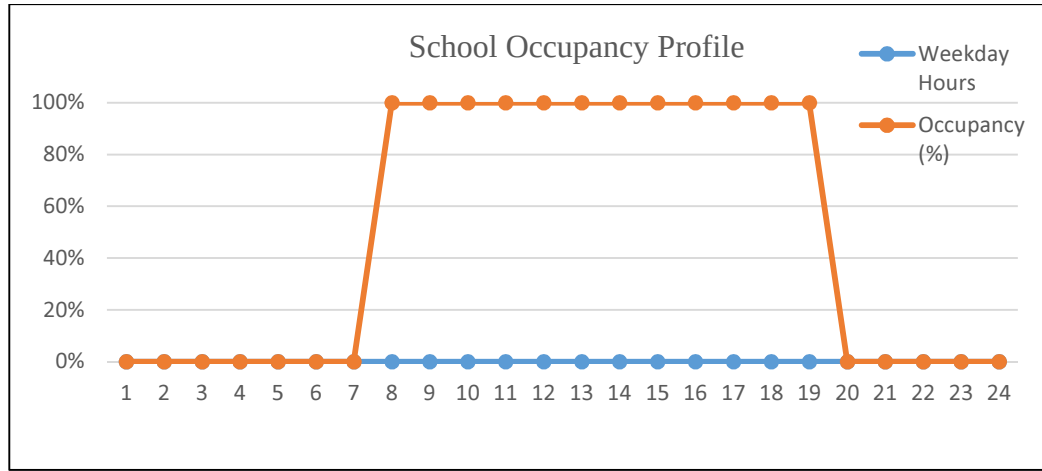


Figure 4.7: School occupancy profile.

According to TS 825 (2013), limited u vale of exterior walls in Istanbul and Erzurum degree-day zone are given in table 4.1. In this project, it is considered that reference building does not have any thermal insulation hence the amount of U vale of exterior wall of this school is 1.93 ($\text{W/m}^2 \text{ K}$) which is more than limited U value. The building has a reinforced concrete structure with filled in brick walls.

In addition, there are two types of internal portions, first one is bricked walls and the next one is shear walls, which made different zones in floors. Thermal characteristics of opaque building envelope components indicated in Table 4.7 and Table 4.8.

Table 4.7: Thermo physical property of exterior walls.

Envelope Components	Thickness (m)	Conductivity (W/m.K)	Density (kg/m ³)	Specific heat J/(kg·K)	U-value (W/m ² K)	Limit U-value TS 825 (W/m ² K)
Exterior walls						
Plaster (EXT)	0.03	0.5	1300	1000		
Hollow Brick	0.29	0.72	1920	840	1.93	> 0.57
Gypsum Plaster	0.025	0.4	1000	1000		

Table 4.8: Thermo physical properties of Interior wall.

Envelope components	Thickness (m)	Conductivity (W/m.K)	Density (kg/m3)	U-value (W/m ² K)
Interior walls				
Plaster	0.03	0.4	1000	
Hollow Brick	0.19	0.72	1920	1.713
Plaster	0.03	0.4	1000	

The total glazing surface area of this school is 596.83 m² and transparency ratio is 18.5 %. Glazing components of this school consist of aluminum frames. Total solar transmission (SHGC) of this type glazing and U value are 0.81 and 6.121 (W/m² K) respectively. As stated in Turkish standards, the limited u vales of windows for all degree-day zone is 1.8 (W/m² K).Table 4.9 shows thermo physical properties of transparent components in reference building.

Table 4.9: Thermo physical properties of Glazing.

Envelope Components	Thickness (m)	U-value (W/m ² K)	(SHGC)	Light transmission	Limit U-value TS 825 (W/m ² K)
Windows					
Single glazing	0.006	6.121	0.81	0.881	< 1.8

The building roof consists of two parts; first part is pitched roof, which is unoccupied, and the second one laid under the pitched roof. The material is used in outermost are clay tile roofing, membrane and rafters. The thermal insulation is not implemented on the inner flat roof. Roof surface area of this building is 1852.45 m². Besides, the floor area of this type building is 1685 m². Internal floors cover with granite tiles; ground floor finishing materials is ceramic tiles. The ground floor of building considered that there is not any insulated layers. Hence, the U value of ground floor is 2.733(W/m² K) and more than limit U values. Thermo physical characteristic of ceiling and ground floor represented in table 4.10 and table 4.11.

Table 4.10: Thermo Physical properties of ceiling.

Envelope Components	Thickness (m)	Conductivity (W/m.K)	Density (kg/m ³)	Specific heat J/(kg·K)	U-value (W/m ² K)	Limit U-value TS 825 (W/m ² K)
Flat roof						
Screed+ Epoxy	0.04	1.35	1800	1000		
Reinforced Concert	0.15	2.5	2400	1000	2.53	> 0.38
Gypsum plastering	0.025	0.4	1000	1000		

Table 4.11: Thermo Physical properties of ground floor.

Envelope Components	Thickness (m)	Conductivity (W/m.K)	Density (kg/m ³)	Specific heat J/(kg·K)	U-value (W/m ² K)	Limit U-value TS 825 (W/m ² K)
Ground floor						
Ceramic tile	0.01	1.3	2300	840		
Screed	0.04	1.35	1800	1000	1.79	
Lean concrete	0.15	0.55	2000	1000		>0.57
Compacted Ground	0.15					

Occupancy time for primary schools in Turkey, which is represented in figure 4.8, is including fall semester and spring semester. The school open at fall semester from 15 September until 31 January and at spring semester 15 February until 15 June.

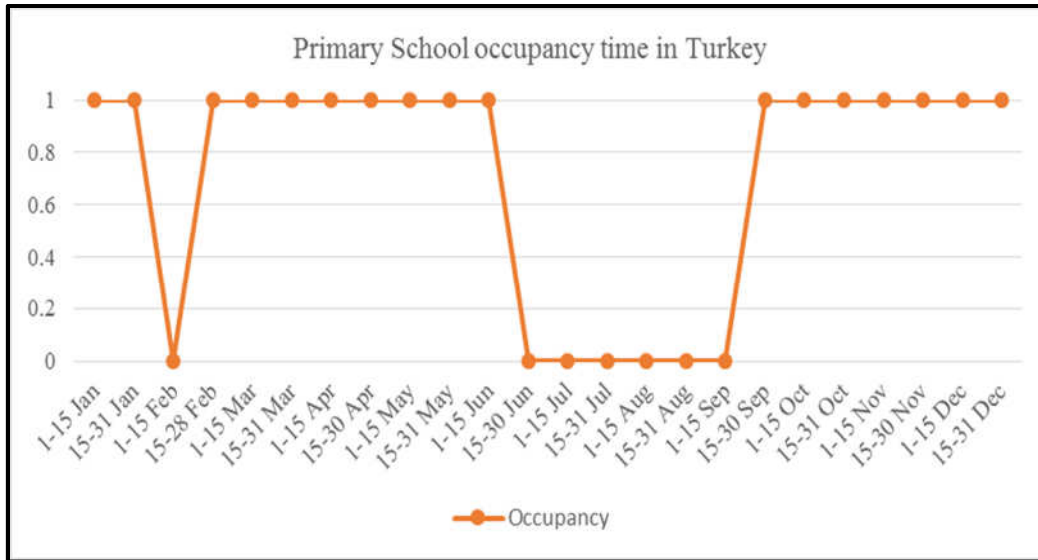


Figure 4.8: Primary School occupancy time in Turkey.

One of the important issue in school is related to thermal comfort. In order to reaching comfort range temperatures in schools according to, internal ambient temperatures of most spaces in the building assumed as 20° C which is recommended by TSE 825 and MMO. While, all toilets, stocks, stairs and corridors are assumed at 18 °C. For dressing room and administrative rooms heating are supposed 26°C and 21°C according to MMO. Other space as recommendation by TS 825 such as classrooms, library or laboratories heating thermostat is 20°C. Building interior temperature in winter period in occupied times should be 20 °C and in unoccupied times should be 7 °C and for other periods, building interior temperature in occupied times should be 24 ° C and in unoccupied times should be 32 ° C as mentioned ASHRAE/IESNA Standard 100-2006. Therefore, Central heating system is used to acclimatize the indoor environment and to maintain indoor air temperature. Comfort range temperatures for schools are 20°C and 24°C, for storage spaces and weekends 7°C and 32 °C circulation spaces and toilets are 19 °C and 26 °C respectively, for heating and cooling periods. Approximate discrepancies of $\pm 2^{\circ}\text{C}$ are observed in monitored indoor temperature data.

In this Reference building, there are 100 zone while 62 zones of this variant zone are applied heating and cooling systems. Figure 4.9 shows buildings different zone that is located in floors. In addition, it is assumed building toilets and dressing rooms do not have any cooling systems. In addition, an average outdoor temperature considered for 12 months of a year.

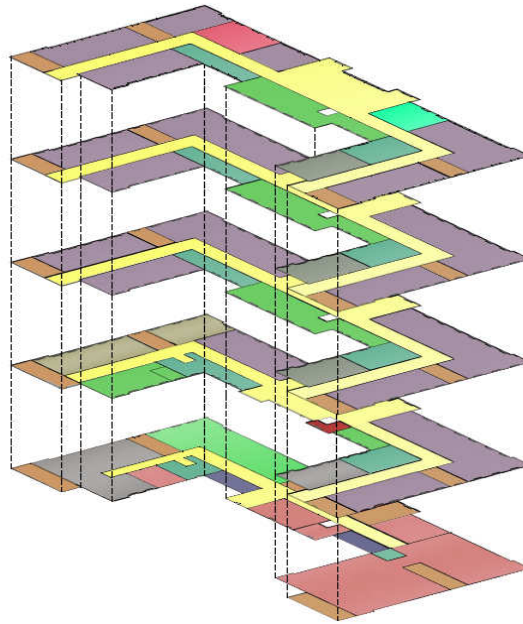


Figure 4.9: Reference building various thermal zones in floors.

Heating system of systems used in November until May also it has been worked for 5 days from 7 am until 18 pm. In holidays and rest of days (unoccupied times of school), building interior temperatures should be 7 ° C .The coldest time in winter period is from 1-31 January, which its clear heating consumption exceeded in this month. Cooling system used in May and June. As comfort temperature in spring period is 24 ° C It has been worked for 5 days from 7am until 18 pm and also, it has reached to 32 ° C the rest of days and holidays and also, The hottest times in spring semester is from 15 may until 15 June. HVAC schedule in primary school in year are shown by figure 4.10.

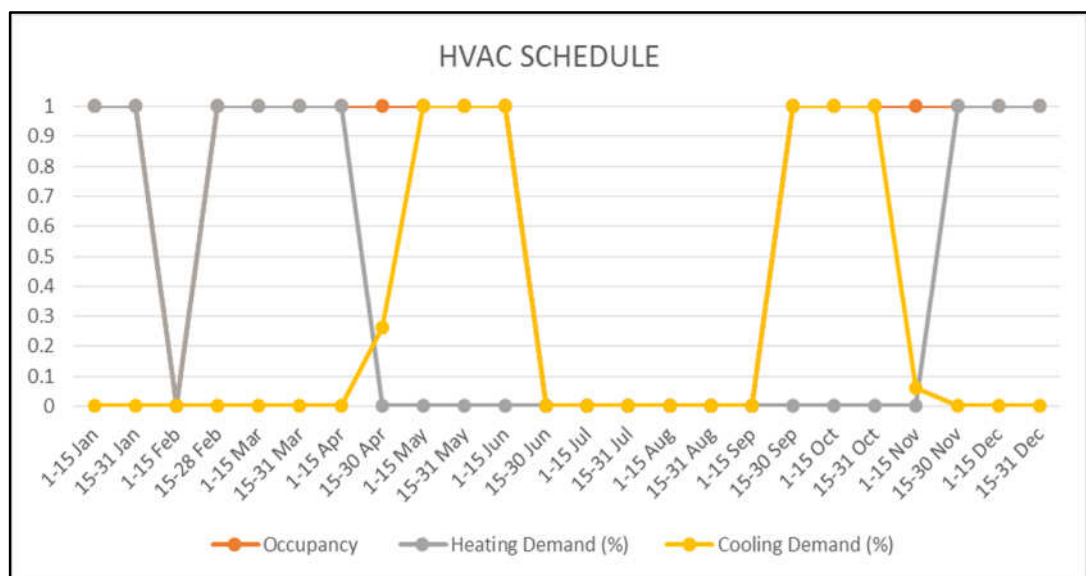


Figure 4.10: HVAC schedule in primary school in a year.

In order to define cooling demand in Istanbul RB, it's considered building's cooling thermostat doesn't work to find demand which their temperatures in thermal zones are more than 24 ° C, then after acquired appropriate dates which is started in spring semester from 27 April until 15 June and for fall semester it's begin from 15 September until 1 November . However, cooling demand for Erzurum climate is 22 May-15 June and 19 Sep-13 Oct.

According to ASHRAE Standard 62.1-2013, Minimum Ventilation Rates in classrooms is 10 cfm/person and for other spaces of educational building as stated by ASHRAE standard are considered in this research. It is supposed by opening windows in break times, classrooms and other spaces of primary school ventilated, as there is not any mechanical ventilation. Figure 4.10 illustrates natural ventilation schedule, which have applied in RB. Besides, recommended range for relative humidity is between 30%-60%. Infiltration rate for reference building is considered 0.5 1/h (air change per hour) for all perimeter zones. Figure 4.11 shows Natural ventilation schedule in reference building.

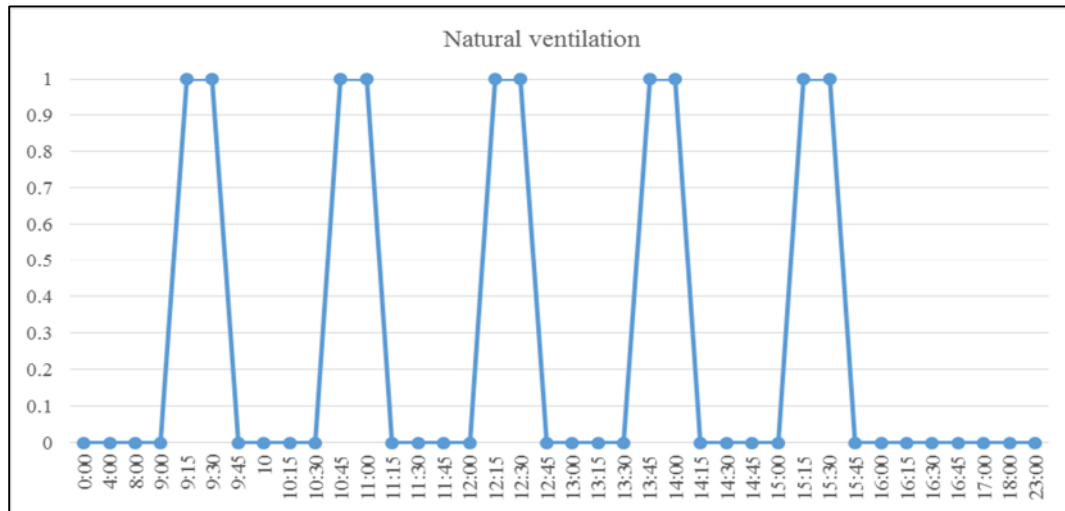


Figure 4.11: Natural ventilation schedule in reference building.

Generally, the main source of internal heat gain in all buildings are lighting, people and equipment. In this building, lighting system of reference building is assumed 50% fluorescent, 50% incandescent which is started from 08:00 until 17:00. In addition, there is not any lighting control in building classrooms so the lighting systems. It has supposed that half of Stair lighting and 75% of WC are on from 08:00 until 17:00. Artificial lighting density for educational building was taken as 12.9 W/m² according to EN 12464.

Furthermore, the lighting system of reference building is assumed as direct lighting. In addition, light reflectance of the surfaces are, $\rho_{\text{wall}} = 50\%$, $\rho_{\text{ceiling}} = 70\%$. In this research, reference building due to the lack of schools budgets, it's considered that required illuminance level is provided by 50% of the fluorescent, 50% incandescent lamps.

Furthermore, the population density at this school is almost 0.55 for every meter square. The amount of heat gains for electrical appliance, which are taken from ASHRAE 90.1-2007, are shown in table 4. 12.

Table 4.12: Internal heat gain amounts in various zones.

Data source	Occupancy		Electric equipment	Artificial lighting		
	ASHRAE 90.1-2007		RB (50%Inc-50%Flou)			
Zone type	Total Areas m²	w/person	Appliance – Watts		Numbers /Total w	Total w/ m²
Classrooms	2496.45	100	Computer (80 w)		-	21.7
Administrations	353.55	105	printer	(100 w)	1100	41
Toilets	515.04	105	copier	(500 w)	-	9.8
Corridors & stairs	2778	105	projector (2000 w)		-	15.4
Gyms	394.3	300	server	(60w)	-	21
Multi-purpose hall	204.2	100			2000	51.8
Library	73.2	100			210	42
Laboratory, compute room, Technical room	343	100			8100	28
store, shelter, archive	879.5	100			-	10
Dressing room	43	100			-	16.8

In this project, some properties of reference building in Bep-Tr calculation methodology have been used to reach minimum energy performance and cost level. Mechanical systems of Bep-Tr reference building is central heating system using hot water circulation and standard and atmospheric burner boiler is natural gas, which working temperature is 90/70°C. Domestic hot water consumption was assumed as 60 liter/person day. Radiators are located under the window of the external wall. For Domestic Hot water system is considered central system with natural gas boiler, which is a standard and atmospheric burner boiler. Cooling system of reference building is Fan Coil system with air-cooling and on/off controlled [28].

In this research, the defined parameters that used in reference building have been indicated in table 4.13.

Table 4.13: Parameter of reference building.

Parameters	Values
Occupancy time	Weekdays 08:00-17:00 Fall semester =15 September until 31 January Spring semester=15 February until 15 June
Heating Setpoint	Winter period Occupied times should be 20 °C Unoccupied times should be 7 °C
Cooling Setpoint	Other periods Occupied times should be 24 ° C Unoccupied times should be 32 ° C
HVAC Schedule	Weekdays 07:00-18:00
Heating System Generator	Hot water boiler
Cooling System Generator	Chiller with 1,5 COP
Ventilation systems	Natural ventilation
Lighting system	Weekdays 08:00-17:00 50% fluorescent, 50% incandescent

4.4 Definition of Energy Efficiency Measures for Reference Building

In order to reach cost optimum level, at first step according to EPBD Guidelines as argued in Chapter 3 identification of retrofit actions that can be applied on the reference building in order to improve its energy performance level. As, energy efficiency measures are independent and one system can affect the energy performance of the other, it recommended by commission staff to assess packages of measures in order to reach results of synergy effects of meaningful combinations. In this study, selected energy efficiency measures are applied to the reference building, which is named to Reference Building. Since it is not possible to include all energy efficiency measures; for this RB, most typical measures usually applied to school buildings are preferred.

Within this stage, retrofit actions can be gathered in three main categories:

[E]-Envelope: improvement of envelope insulation level;

[L]-Lighting: actions to manage solar gains and day-lighting;

[S]-HVAC Systems: increase of the efficiency of HVAC systems;

4.4.1 [E] Envelope Scenarios

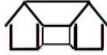
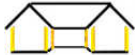
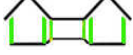
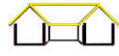
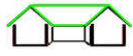
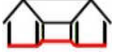
Measures on the envelope involve external walls, ground floor, roof and windows. According with the structure of opaque components potential solutions to improve their insulation level consist in adding insulation panels on the outside layer of the external wall [E1], roof [E3] and in the demolition of the ground floor to create a new insulation layer [E2]. Insulation thickness and U-values are determined in conformity to national insulation level requirements. Minimum U value, which is compulsory, by TS825 is represented in different degree-day zone in table 4.1.

In this study, in order to refurbishment of envelope of building thermal insulation levels have been applied in reference buildings of these two climate. First level is of this measures is related to TS825 standard minimum requirement's U values on envelope. Other steps U values are higher than minimum requirement.

Moreover, Reference building is considered without any thermal insulation. The only difference between is Istanbul and Erzurum reference buildings is U value amounts on envelope measure. Table 4.14 and 4.15 represent that Energy efficiency measures referred to the building envelope of the reference building of Istanbul and Erzurum

respectively. Figure 4.12 and 4.13 illustrate the location of thermal insulation in envelope of reference building. However, thickness of thermal insulation are according to different levels that are indicated in table 4.14 and table 4.15. Furthermore, different U-values and thickness of thermal insulation of RB's envelope in Istanbul and Erzurum are shown by table 4.14 and 4.15.

Table 4.14: Energy efficiency measures referred to the building envelope of the reference building in Istanbul.

EEM	Unit	RB	First level	Second level	Third level
<i>Wall insulation (on external surface)</i>	W/m ² K	No thermal insulation	E1-1 EPS = 0.04 m	E1-2 EPS = 0.055 m	E1-3 EPS = 0.09 m
E1 Conductivity= 0.035 W/mK Density= 30kg/m ²					
Area = 22675.2 m ²	[m ²]	U 1.93 W/m ² K	U 0.57 W/m ² K	U 0.45 W/m ² K	U 0.3 W/m ² K
<i>Roof insulation</i>	W/m ² K	No thermal insulation	E2-1 EPS = 0.075 m	E2-2 EPS = 0.10 m	E2-3 EPS = 0.16 m
E2 Conductivity= 0.035 W/m.K Density= 30kg/m ²					
Area = 2030 m ²	[m ²]	U 2.53 W/m ² K	U 0.38 W/m ² K	U 0.3 W/m ² K	U 0.2 W/m ² K
<i>Basement floor insulation</i>	W/m ² K	No thermal insulation	E3-1 EPS = 0.038 m	E3-2 EPS = 0.05 m	E3-3 EPS = 0.07 m
E3 Conductivity= 0.035 W/m.K Density= 30kg/m ²					
Area = 1685 m ²	[m ²]	U 1.79 W/m ² K	U 0.57 W/m ² K	U 0.5 W/m ² K	U 0.4 W/m ² K

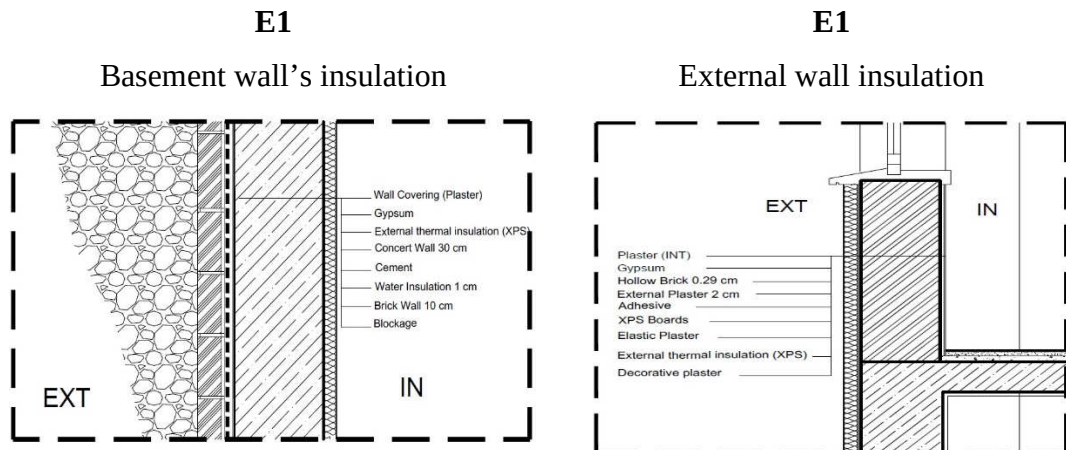


Figure 4.12: Detail of Energy efficient measures in the external walls.

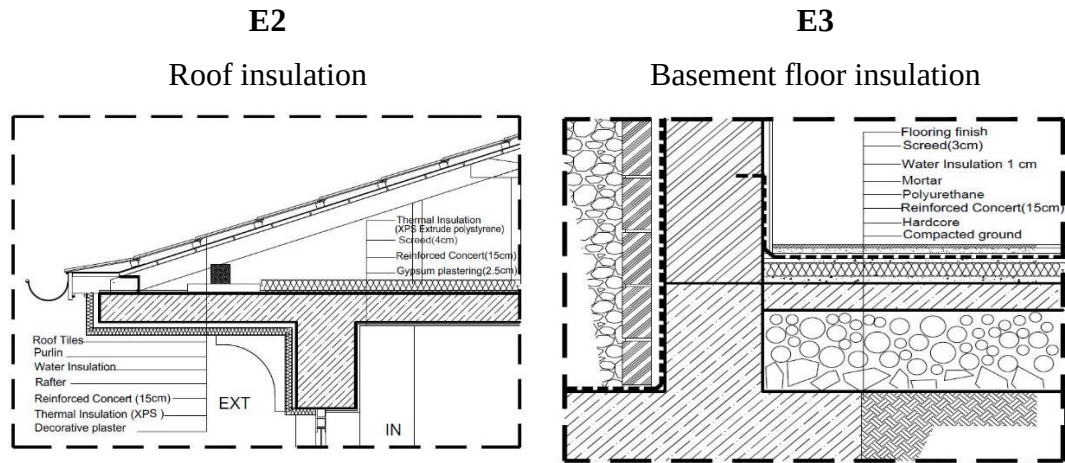


Figure 4.13: Detail of Energy efficient measures in the roof and basement floor.

Table 4.15: Energy efficiency measures referred to the building envelope of the reference building in Erzurum.

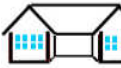
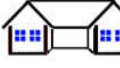
EEM	Unit	RB	First level	Second level	Third level
<i>Wall insulation (on external surface)</i>	W/m ² K	No thermal insulation	E1-1 EPS = 0.065 m	E1-2 EPS = 0.10 m	E1-3 EPS = 0.15 m
E1 Conductivity= 0.035W/m.K Density= 30kg/m ²					
Area = 22675.2 m ²	[m ²]	U 1.93 W/m ² K	U 0.36 W/m ² K	U 0.29 W/m ² K	U 0.20 W/m ² K
<i>Roof insulation</i>	W/m ² K	No thermal insulation	E2-1 EPS = 0.12 m	E2-2 EPS = 0.20 m	E2-3 EPS = 0.28 m
E2 Conductivity= 0.035W/m.K Density= 30kg/m ²					
Area = 2030 m ²	[m ²]	U 2.53 W/m ² K	U 0.21 W/m ² K	U 0.16 W/m ² K	U 0.11 W/m ² K
<i>Basement floor insulation</i>	W/m ² K	No thermal insulation	E3-1 EPS = 0.065 m	E3-2 EPS = 0.10 m	E3-3 EPS = 0.15 m
E3 Conductivity= 0.035W/m.K Density= 30kg/m ²					
Area = 1685 m ²	[m ²]	U 1.79 W/m ² K	U 0.36 W/m ² K	U 0.3 W/m ² K	U 0.2 W/m ² K

Retrofit actions on the transparent components [E4] lie in the replacement of all windows and frames with the purpose to decrease their thermal conductivity and their transparency to solar radiations responsible of summer overheating. First level renovation on glazing part is initiated with adding extra glazing and argon gas between

to glass parts. Energy efficiency measures referred to the building envelope on transparent part of the reference building are represented in table 4.16.

First level amount is minimum amount U value for transparent components, which is compulsory for all climate zone. This U value is same for climates, which is 1.8 W/m²K according to TS 825 2013. Second level include changing windows with double low-e glazing and last level is gathering triple glazing 1.1 W/m²K. Besides, in all levels all of frames of windows are changed to UPVC.

Table 4.16: Energy efficiency measures referred to the building envelope on transparent part of the reference building.

EEM	Unit	RB	First level	Second level	Third level
E4	Windows	Sgl clr 6mm	E4-1 Dbl glass	E4-2 Dbl low-e U	E4-3 Trp low-e
	W/m ² K				
	U-value glazing	U 5.77 W/m ² k	U 1.8 W/m ² K	1.49 W/m ² k	U 1.1 W/m ² K
	SHGC	0.81	0.704	0.568	0.524
	Light transmission	0.881	0.781	0.745	0.677
	Glass thickness	mm	6mm	6+13+6	6+13+3+13+6
	Type of frame	Aluminum	UPVC	UPVC	UPVC
	U-value frame	W/m ² K	U 4.7 W/m ² k	U 1.8 W/m ² k	U 1.8 W/m ² k

4.4.2 [L] Lighting Scenarios

Lighting systems has a very high energy saving potential in educational building. Daylighting is difficult for applications in practice (limited by building geometry and the lighting performance of the windows). If possible, architects and engineers should use more daylighting measures, such as changing light tubes and window reflective shading or other element depends on the situation of the project.

Indeed, lighting retrofit is a simple way to make building's energy system more efficient. Over time, these energy savings can be significant enough to not only pay for the equipment, but may produce a return on investment. Lighting retrofits not only

improve the quality of light, but also result in less heat gain, and results in reducing HVAC run times.

In this project, at first step [L1] lamp type changed in two different levels .It is supposed reference building artificial lightings are 50% fluorescent and 50% incandescent. Hence, at first level for improving lighting systems, it is considered the number of lamp type changed to 70% fluorescent and 30% incandescent like RB illuminance level in Bep Tr calculation methodology [28].

As it's clear in table 4.17, at second level in order to improve the energy performance of the building, all building's lamp types are assumed 100% fluorescent. In order to calculate average illumination level for different space of school lumen method has been used. Table 4.18 shows lighting requirements for various zones, which are taken from EN 12464 and reference building and two levels improvements for space in terms of w/m^2 are calculated by lumen methods.

Table 4.17: Energy efficiency measures referred to the lighting of reference building.

EEM	Unit	RB	Bep-Tr level	Improved level
L	L.1 Lamp type	50% fluorescent, 50% incandescent 	70% fluorescent, 30% incandescent 	100% fluorescent 
	L.2 Lighting control	There is no lighting control in reference building. 	Continuous/Off Control The lights switch off completely when the minimum dimming point is reached 	

Furthermore, second step [L2] is installing of a dimming day-lighting control system that the lights switch off completely when the minimum dimming point is reached. Dimming control varies the light output over a wide range according to natural light level and offers two main advantages: firstly it automatically compensate the expected 30% drop in lighting output to guarantee a constant light level over time and secondly day-lighting controls can be adjusted to give the desired light level to meet the lighting needs of each area.

Table 4.18: Artificial lighting power density in different zones.

Zone type	Lighting requirements Level (lx)	RB Total w/ m ²	First level Total w/ m ²	Second level Total w/ m ²
Classroom	300	21.7	15	7.5
Administration	500	41	30	14
Toilets	100	9.8	7	3
Corridors	100	15.4	11	5.5
Gyms	300	21	15.5	7.5
Multi-purpose hall	500	51.8	37	13.5
Library	500	42	30	13
Laboratory, computer room, Technical room	300	28	15	8
Store, Shelter , Archive	100	10	7	3
Dressing room	200	16.8	12	6

4.4.3 [S] Mechanical Systems Scenarios

Another set of measures that this essay attempts to investigate refers to the renovation and implementation of heating and cooling systems.

Among the actions to improve the efficiency of the heating system one of the most common is the substitution of the existing boiler with a condensing boiler.

These systems are able to achieve high efficiency (greater than 90%) by using the waste heat in the flue gases to pre-heat the cold water entering the boiler.

In this research, nominal efficiency of existing boiler is 0.85COP, which is changed to 0.90 COP and 0.95 COP at two levels with substitution to condensing boiler. [S1.1-S1.2]

Second renovation measures is changing Cool generator to higher efficient ones. [S2] Cooling generator system of RB is chiller with 1.5 COP efficiency, which is substituted to new chiller with 2.5 COP and 4.0 COP at 2 levels.

The third step of Renovation HVAC System is installation of radiant floor on reference buildings. The radiant floor system is made up of thermal conductor slats and flexible polyethylene pipes, assembled on pre-formed polystyrene insulation panels, which fulfil the whole floor area increasing the radiant surface and supporting the natural

ascensions of heat from the bottom of the thermal zone upwards. When the heat is distributed by the whole floor area, the temperature of the water circulating through the plant can be much lower than that required in normal systems.

Hydronic radiant floor systems pump heated water from a boiler through tubing laid in a pattern under the floor. In some systems, controlling the flow of hot water through each tubing loop by using zoning valves or pumps.

Table 4.19 summarize HVAC systems that have been used in this project as energy efficiency measurements.

Table 4.19: Energy efficiency measures referred to the mechanical system of reference building.

EEM		Nominal Efficiency [W/W]		Description
	Heating generator (BOILER)	-	0.8	
RB	Cool generator (CHILLER)	1.5 COP	-	
	Fan coil	63 unit		
S1	S.1.1 Condensing boiler		-	Hot water boiler
	S.1.2 Condensing boiler		-	
S2	S.2.1 Chiller 1		2.5 COP	Electrical chiller
	S.2.2 Chiller 2		4 COP	
S3	Radiant floor (heating)			HVAC terminal units
	Radiant floor (heating & cooling)			

4.5 Definition of the Possible Improvement Scenarios

In this section, all energy efficiency measures are combined with own measures in order to comparison energy performance and global cost of each package.

Consequently, there are various identified packages are created which are made up Single EEM and Packages of EEMs belonging to the same category.

These packages are presented in figure 4.14 which are consist of four main categories

1. Combination of single EEM on envelope [E];
2. Combination of envelope measures with each other [E];
3. Combination of lighting systems with each other [L];
4. Combination of single EEM on Mechanical systems and with each other [S].

After definition of EEMs packages and single EEMs, all possible measures in envelope, lighting and HVAC are combined with each other for preparing final packages. Figure 4.15 shows possible renovation packages, which are applied in RB,'s in order to reach optimum cost level.

Finally, all energy efficiency measures global cost and primary energy consumption are calculated to reach optimum cost level.

Packages	ENVELOPE
E1-1	
E1-2	
E1-3	
E2-2	
E2-2	
E2-3	
E3-1	
E3-2	
E3-3	
E4	
E5	
E6	

Packages	ENVELOPE
E1-1-1	
E2-2-2	
E3-3-3	
E7-1	
E8-2	
E9-3	

Packages	LIGHTING
L1	
L2	
L3	
L4	
L5	

Packages	HVAC
S1	
S2	
S3	
S4	
S5	
S6	
S7	
S8	
S9	
S10	
S11	
S12	
S13	
S14	

Figure 4.14: Single Energy Efficiency Measures.

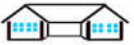
Packages	ENVELOPE		LIGHTING		HVAC	
P1						
P2						
P3						
P4						
P5						
P6						
P7						
P8						
P9						
P10						
P11						
P12						
P13						
P14						
P15						
P16						
P17						
P18						
P19						
P20						
P21						
P22						
P23						
P24						
P25						
P26						
P27						
P28						
P29						
P30						
P31						

Figure 4.15: Definition of renovation packages.

4.6 Calculation of the Primary Energy Consumption

As it was mentioned in chapter 3, the third step of the cost-optimal methodology concern the calculation of the energy performance level of the reference building after the application of measures/packages/variants targeted to improve its energy efficiency. To facilitate the comparison between different energy sources, a conversion factor is assigned to non-fossil fuel sources, which relates electricity generated to a nominal primary energy. Conversion factors are for natural gas 1 and for electricity 2.36 in Turkey. Primary energy for a building is the energy used to produce the energy delivered to the building. It is calculated from the delivered and exported amounts of energy carriers, using primary energy conversion factors. Primary energy includes non-renewable energy and renewable energy. All results related to package primary energy consumption of RB, energy efficiency measures and final packages have been analyzed in chapter 5.

In order to be able to analyze the reference building as precisely as possible, software for energy performance calculations are used in this research. There are two different calculation methods for energy calculation in buildings. One of them is simple method and the second one is dynamic method. The dynamic method is more reliable than simple one while is more time consuming and grinding. Recently, dynamic simulation software such as EnergyPlus, which is suggested by EPBD Recast, and DesignBuilder are becoming most adorable software for building's energy assessors.

DesignBuilder has a user-friendly modeling environment while working in virtual environment. Hence, in this project, for modeling of reference building DesignBuilder software has been used. In addition, in order to make modeling process and define materials and all simulation part have been done by energy plus 8.1 software. EnergyPlus is one of the most competitive and accurate programs used nowadays and is one of the most utilized in the scientific field. The 8.1 version of this software is used in this thesis study. It is recognized and used namely by the U.S. Department of Energy (DOE), as a building energy simulation tool for modeling and calculating building heating, cooling, lighting, ventilating, and other energy flows. The interaction between the users and the 3D interface of DesignBuilder illustrated in the figure 4.16.

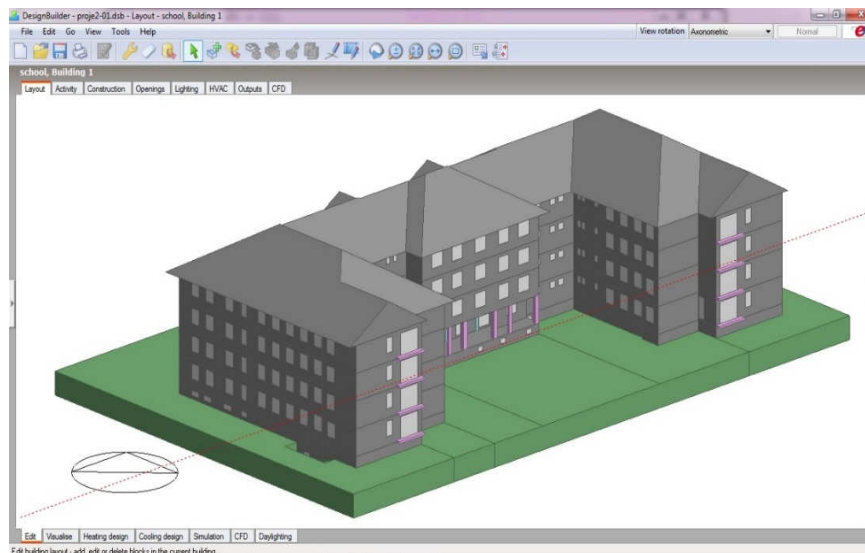


Figure 4.16: Design Builder interface.

4.7 Calculation of Global Cost

The main significant part of the cost-optimal analysis is represented by the global cost calculation procedure. Global cost means the sum of the present value of the initial investment costs, sum of running costs, and replacement costs (referred to the starting year), as well as disposal costs if applicable. For the calculation at macroeconomic level, an additional cost category cost of greenhouse gas emissions is introduced; In order to calculation global cost, five different types of costs should be examined which are including:

1. Initial investment cost
2. Running cost
3. Energy cost
4. Replacement cost
5. Disposal cost

All these steps are described specify in chapter 3 which is related to calculation global cost according to EPBD recast.

First it should be defined the cost calculation perspective. In this research “individual end user perspective” that takes into account cost and benefits, taxes and subsidies from occupants.

4.7.1 Gathering Financial Data

The calculation period is set up at 20 years, according to the Regulation advice financial data gathered at Central Bank of Turkey, which these statics are related to 2013 financial data. Inflation rate of Turkey in 2013 is 7.5% and discount rate of Turkey according to recent statics of central bank is 5.5%. Moreover, exchange rate for conversion of Turkish Lira (TL) to Euro (€) is 2.9.

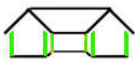
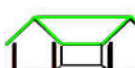
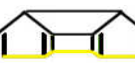
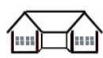
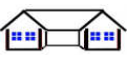
In concerning the sensitivity analyses, a shorter (10 years) and longer (30 years) calculation periods will be performed to evaluate the results changes. In addition, other discount rates are calculated in order to evaluation of results. All these results are illustrated in sensitivity analysis.

4.7.2 Cost Regarding Components and Systems (Investment Cost)

This step consists in the collection of data about renovated components and replaced/improved systems.

All energy efficiency measures, which are described previously, have been analyzed in terms of materials and man power needed to realize them in order to figure out the initial investment cost that the investor should sustain. The calculation is performed taking into account only costs due to the refurbishment/replacement of the component/system. Cost data are taken from Price List of environment and Urbanism ministry Istanbul updated to 2013 [48]. Furthermore a collection of real costs has been achieved by a direct confront with product producers and companies in order to verify the reliability of some extrapolated data. In below tables all EEMs initial cost which are used for refurbishments Envelope, Lighting and Mechanical systems are summarized in Table 4.20, 4.21, and 4.22.

Table 4.20: Initial investment costs of EEMs on Envelope for Istanbul climate.

E-Envelope					
Energy efficiency measures			Unite price	Quantit y	Initial Investment cost
Envelope					
E1 External wall	E1-1 EPS =0.04 m		14 TL		332,812.50 ₺
	E1-2 EPS =0.055 m		15 TL	22675.18 m ²	355,487.70 ₺
	E1-3 EPS =0.09 m		20 TL		468,863.60 ₺
E2 Upper floor	E2-1 EPS =0.075 m		18 TL		38,588.00 ₺
	E2-2 EPS =0.10 m		21 TL	2030 m ²	44,678.00 ₺
	E2-3 EPS =0.16 m		27.5 TL		57,873.00 ₺
E3 Lower floor	E3-1 EPS =0.038 m		13 TL		37,981.80 ₺
	E3-2 EPS =0.05 m		14.75 TL	1685 m ²	40,930.55 ₺
	E3-3 EPS =0.07 m		17 TL		44,721.80 ₺
Windows & Frame					
E4 Window	E4-1 U 2.51 W/m ² K		33 TL/m ² - 25 TL /m ² Frame		24,392.61 ₺
	E4-2 1.49 W/m ² k		41 TL/m ² - 25 TL/m ² Frame	284 Win & 4 Doors	29,002.77 ₺
	E4-3 U 1.1 W/m ² K		70 TL/m ² - 25 TL/m ² Frame		45,714.60 ₺

In all Initial investment costs are including labor costs plus new components

Initial cost of windows are including labor cost of add new windows and frame +destroying windows +new windows& frames

Table 4.21: Initial investment costs of EEM on Lighting for Istanbul and Erzurum climate zones.

	EEM		Control of lighting		cost	Description
			M	A	[TL]	
L1	Daylight control		Automatic		7,350.00 ₺	There is no lighting control in reference building.
L2	L2.1 70% FLOURCENT & 30% incandescent		-		32,349.00 ₺	Reference building lamp types are 50% fluorescent and
	L2.2 100% FLOURCENT		-		19,320.00 ₺	50% incandescent

Table 4.22: Initial investment costs of EEM on Mechanical systems for Istanbul and Erzurum climate zones.

EEM		Nominal Efficiency [W/W]		Cost	Description
		-	-	[TL]	
Reference building with fan coil unit					
RB	Heating generator (BOILER)		0.8	12,957.30 ₺	Existing System
	Cool generator (CHILLER)	1.5 COP		11,260.50 ₺	
	Fan coil	63 unit *410 TL		28,902.00 ₺	
Heat generator for space heating					
S1	S.1.1 Condensing boiler		0.9	47,900.00 ₺	Hot water boiler
	S.1.2 Condensing boiler		0.95	55,000.00 ₺	
Cool generator for space cooling					
S2	S.2.1 Chiller 1		2.5 COP	75,250.00 ₺	Electrical chiller
	S.2.2 Chiller 2		4.0 COP	92,250.00 ₺	
Heating and Cooling generator for space heating					
S3	Radiant Floor heating			285,090.00 ₺	Total floor are conditioned
	Radiant Floor heating & cooling		-	398,190.00 ₺	

4.7.3 Replacement Cost

Replacement cost is a periodic cost that is relative to each measure and depends on the relevance between the lifespan of the system/component to be replaced and the calculation period assumed during the analysis. Every time the first is lower than the latter, the cost of replacing the building system/component enters the global cost calculation as a cost to actualize to the starting year. On the contrary, if the system/component considered has a lifecycle that is equal or superior to calculation period there are no extra costs due to its replacement. In both references the final value of the system/component has to be calculated from the remaining lifetime of the last replacement, assuming linear depreciation over its lifespan. Lifespans of systems and components are assumed according to Annex “A” of EN 15459 [42].

4.7.4 Running Cost

Other periodic costs that have to be considered are the running costs, which comprise: operational costs (for energy operators of the building); maintenance and repairs costs (including staff inspections, consumable items or annual contract for cleaning the building); added costs, insurance and taxes related to energy systems. In order to simplify the calculation procedure, this research takes into account only the running costs related to HVAC systems, which are usually the most significant on the total value.

It's important to underline that every time a measure/package provides for the maintenance of some or all existing systems (boiler, chiller and fan coils), the replacement cost, residual value and running costs of these systems have to be considered as part of the global cost. To exemplify, boiler and chiller's running cost are 2% for each one and for fan coil system is 6%.

4.7.5 Energy Cost

Energy costs are made up of two parts: one is related to the amount of energy needed by the building and on the type of end user and his range of annual consumption; the second part is a fixed quota that depends on the typology of contract submitted with the energy distribution company.

Electricity unit price, which is taken from TEDAŞ (Turkish Electricity Distribution Company), is 0.3465 TL/kWh and Natural gas unit price is 0.105 TL/kWh according to İGDAŞ (Istanbul Gas Distribution Industry and Trade Incorporated Company). Furthermore these tariffs have included national and regional taxes 0.18. All final package energy cost are summarized in Appendix Table A.3. All the tariffs are related to 2014 price which are taken from related website [49, 50].

4.7.6 Residual Cost

Final value by the end of the calculation period is determined by summing up the final value of all systems and components.

The final value of a specific system or component is calculated from the remaining lifetime (by the end of the calculation period) of the last replacement of the system or component, assuming linear depreciation over its lifespan. The final value is determined as remaining lifetime divided by lifespan and multiplied with the last replacement cost and referred to the starting year by the appropriate discount rate. Figure 4.17 illustrates the calculation process for one unit component or system [42].

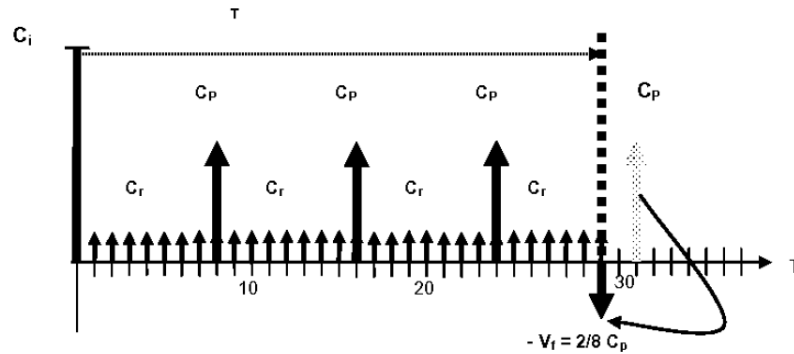


Figure 4.17: Calculation process of final value for one component or system.

$$V_{f,\tau}(j) = V_0(j) \times (1 + R_p / 100)^{n_{\tau}(j) \times \tau_n(j)} \times \left[\frac{(n_{\tau}(j) + 1) \times \tau_n(j) - \tau}{\tau_n(j)} \right] \times R_d(\tau)$$

In this study, most components and systems which compose retrofit actions have a lifespan that is longer than the calculation period that follows a short-term investment perspective (20 years) according to what the Regulation indicates for commercial buildings. Hence, disposal costs are considered and replacement costs occur when the four-pipe fan coils system, fluorescent and incandescent lightings whose lifecycle are 15 years, are maintained, while for all the components/systems which have a lifespan

over 20 years the relative residual value has been calculated and subtracted from final global cost.

4.7.7 Global Cost

According to the EN15459 standard, “the different types of costs (initial investment costs, periodic and replacement costs, running costs) as well as the final value are converted to global cost (i.e. referred to the starting year) by applying the appropriate present value factor (or discount rate). The total global cost is determined by summing up the global costs of initial investment costs, periodic and replacement costs, annual costs and energy costs and subtracting global cost of the final value ” [42].

The function of the total global cost for the financial calculation is reported below:

$$C_G(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right]$$

Where:

- $C_G(\tau)$ = total global cost;
- C_I = initial investment cost of the measure/package of measure considered;
- $C_{a,i}(j)$ = annual cost of year “i” for component “j” (including running costs and periodic or replacement costs);
- $R_d(i)$ = discount rate for year “i”;
- $V_{f,\tau}(j)$ = final value of component “j” at the end of the calculation period (referred to the starting year τ_0) [42].

Furthermore, all calculation procedure of global cost for all renovation packages, which have comprised all initial investment cost for individual packages, energy cost, residual cost, maintenance cost and running cost, are shown in table A.3.

4.8 Calculation of Simple Payback Period

The length of time required to recover the cost of an investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions.

4.9 Undertaking Sensitivity Analysis

The Regulation No 244/2012 specifies, “For the sensitivity analysis on the discount rate for the macroeconomic calculation, one of the discount rates shall be set at 3 % expressed in real terms. Member States have to determine the most appropriate discount rate for each calculation once the sensitivity assessment is performed. This is the one to be used for the cost optimal calculation.” The discount rate represents the interest rate charged to commercial banks and other depository institutions for loans received from Bank’s discount window. It depends on the real interest rate RR and the year of the calculation:

The sensitivity analysis allows assessing how results may change according to variation of assumptions and key parameters, on which the cost-optimal calculation is based. With this purpose results for the Istanbul reference building are evaluated after the variation of two main parameters:

- The calculation period (10 years – 30 years);
- The discount rate (3% - 4% - 5% - 6%).

5. RESULTS

As in chapter 3 and 4 argued, all of the Calculations are made based on main steps of the method given in recast EPBD, related regulation and standards. Initially, energy use of base situation of the reference building and different scenarios are examined.

End use consumptions and primary energy amounts including heating, cooling and lighting electricity are calculated for each scenario. In reference building, heating energy is met with natural gas, while cooling and lighting energy is met with electricity. The primary school building is analyzed in two different cities: Istanbul as the city in Mild-humid Climate Zone and Erzurum as the city in cold climate zone.

In this chapter, all results related to Istanbul and Erzurum reference buildings and renovation packages in different climate zones are compared.

5.1 Comparison of Istanbul and Erzurum's Reference Buildings

All parameter of reference building in Istanbul and Erzurum are same, such as Occupancy time, heating and cooling Set point, HVAC Schedule, Heating and cooling System Generators, Ventilation systems and Lighting system, but as before argued thermal insulation, which are applied on envelope, are different.

Figure 5.1 presents regarding two reference buildings' end uses in terms of kWh/m² year, which have same physical and thermo physical, in Erzurum and Istanbul. Not surprisingly, Erzurum as before discussed about that is located in cold climate zone so natural gas consumption of RB in this climate 174.02 kWh/m² year. While, natural gas consumption of RB in Istanbul with same properties of boiler is 68.02 kWh/m² year. End use cooling for RB in Istanbul is 39.42 kWh/m² year but Erzurum RB's end use for cooling is 8.2 kWh/m² year. Lighting end use for these two reference buildings are same as well as other equipment. To sum up, Erzurum RB end use consumption is related to natural gas and the only consumption of electricity is related to lighting and equipment. Conversely, heating and cooling consumption by Istanbul RB is almost equal due to locating in mild-humid Climate Zone.

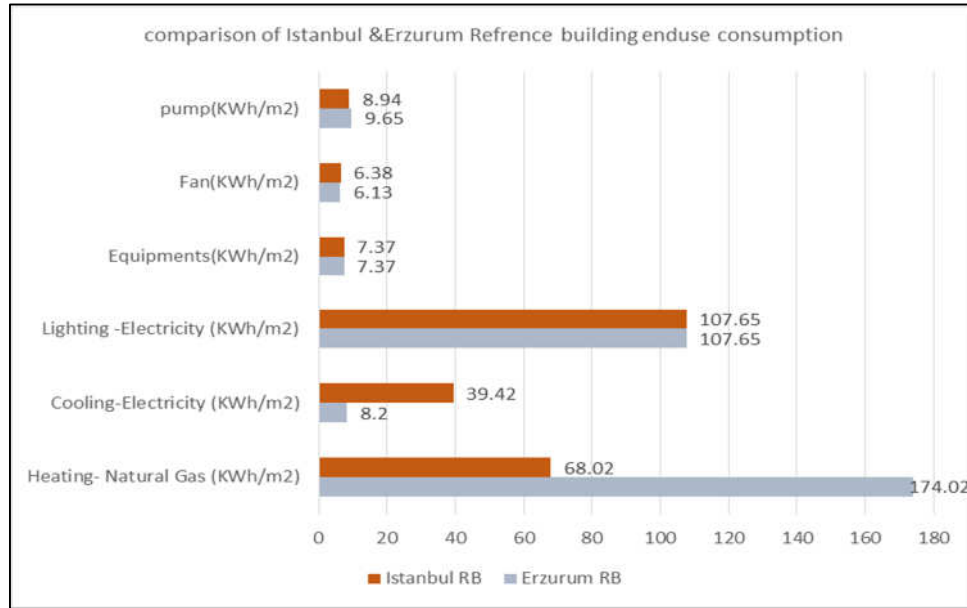


Figure 5.1: Comparison between Istanbul and Erzurum RB's end use consumption.

Reference building End use components consumptions of Istanbul and Erzurum climates are shown as percentage in figure 5.2. In Istanbul's RB the most end use consumption is allocated to Lighting with 45%, the second and third most end users are heating and cooling with 29% and 16% respectively. The least end use component consumption are fans, pumps and equipment, which are used in this school reference building, amount of energy consumption are 14% at totally. While, in Erzurum's RB the most end use consumption is allocated to Heating with 56%, the second most end users is lighting with 34% consumption. The least end use component consumption are cooling, fans, pumps and equipment with 10% at totally.

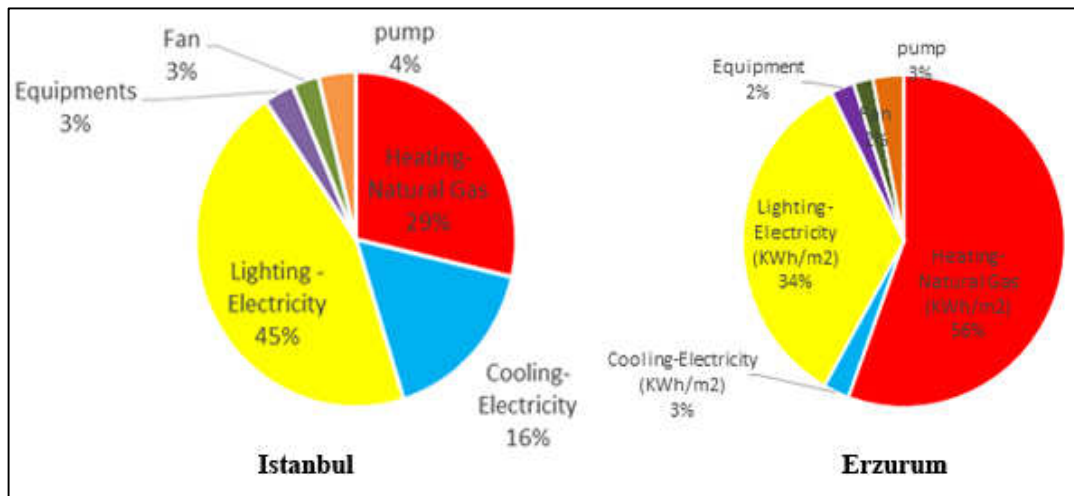


Figure 5.2: Comparison of Istanbul and Erzurum's Reference building End use consumptions in terms of percentage.

5.2 Comparison of Reference Building's Energy Consumption with Occupancy and Without Occupancy

In this research, in order to find impact of heat gain from occupancy, it is considered RB does not have any occupancy in Istanbul and Erzurum cites. By comparison of the RB in two different situation. It could understand that building primary energy consumption has been exceeded. In Istanbul's RB with occupancy Primary energy consumption is 128.40 kWh/m² year but in without occupancy primary energy consumption has reached to 137.19 kWh/m² year. Consequently, building occupants (heat gain) are influenced on primary consumption of building. By glimpse to end uses of RB it's clear that natural gas consumption has been increased from 42.5 kWh/m² year to 57.93 kWh/m² year while electric consumption have reduced from 36.40 kWh/m² year to 32.09 kWh/m² year. The reason for minimizing electric consumption is absence of occupants.

Furthermore, in Erzurum's RB primary energy consumption has increased from 178.92 kWh/m² year to 182.18 kWh/m² year in without occupancy situation. Although, natural gas consumption has increased by 18 per cent, electric consumption has decreased from 29.74 kWh/m² year to 27.96 kWh/m² year. Figure 5.3 and 5.4 show total primary energy consumption and end uses with occupancy and without occupancy's RB in Istanbul and Erzurum.

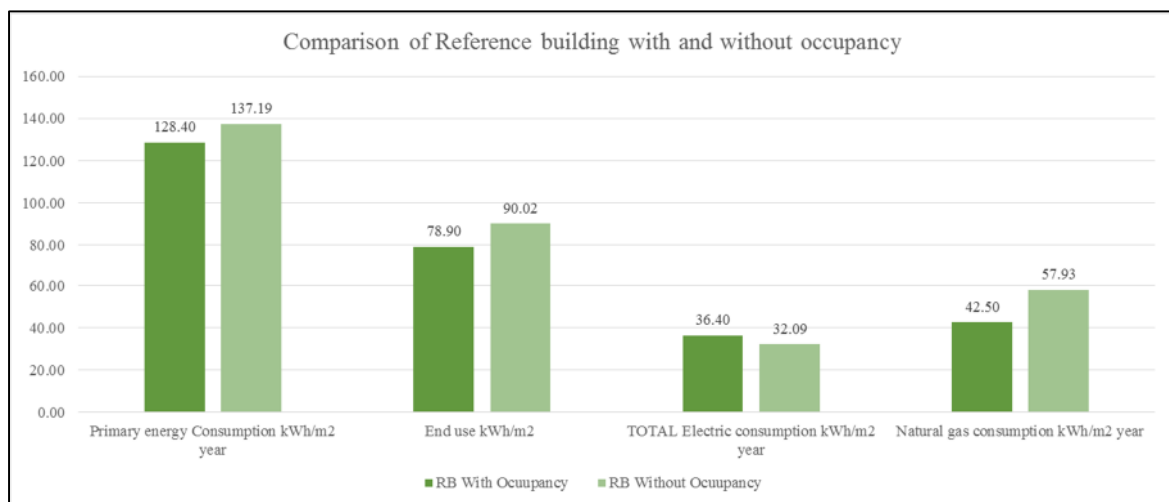


Figure 5.3: Comparison of Istanbul reference building's consumption with and without occupancy.

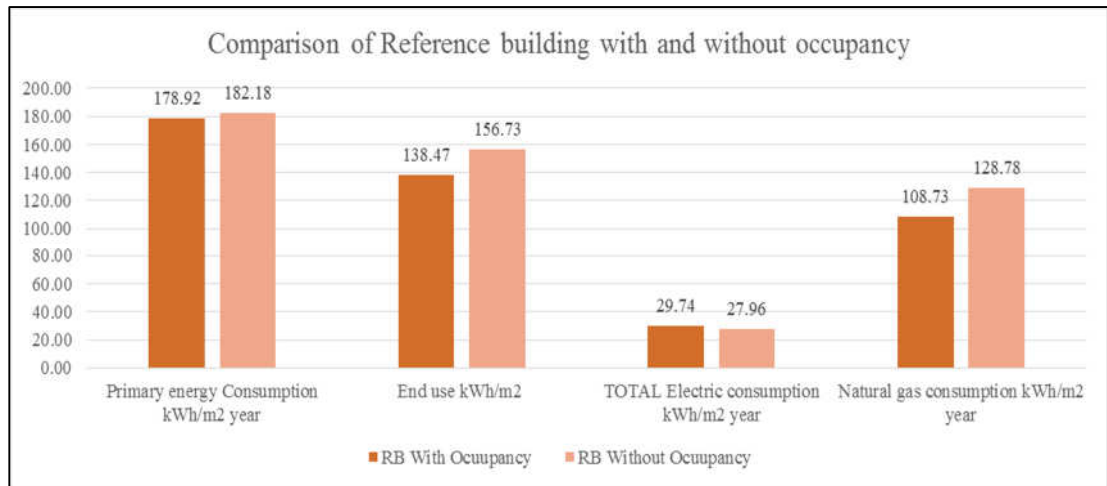


Figure 5.4: Comparison of Erzurum reference building's consumption with and without occupancy.

5.3 Comparison of Reference Building's End Use and Defined Packages in Istanbul and Erzurum Climates Separately

Figure 5.5 illustrates Istanbul Reference building and final packages' end uses which are including Heating ,cooling, lighting ,equipment, fans and pumps. RB total end use is 237.78 kWh/m². Among renovation packages, P16 has dramatic decrease by 76 per cent to 65.14 kWh/m² and the second most reduction of is related to P21 with 70.41 kWh/m². By specific view to this package, amount of Heating by Natural Gas is 39.19 KWh/m² and Cooling consumption by Electricity is 2.68 KWh/m². Lighting end use consumption by P16 is by Electricity 14.13 KWh/m² and other equipment consumption at totally 9.14 KWh/m². In addition, among Reference building and final packages, it's clear that packages which are composed of lighting control and 100% fluorescent have dramatic reduction on electricity. As already mentioned that electricity cost is expensive to natural gas and in all calculation of end uses conversion factor for electricity and natural gas are 2.36 and 1 respectively.

However, Figure 5.6 illustrates Erzurum Reference building and final packages' end uses which are including Heating ,cooling, lighting ,equipment, fans and pumps. RB total end use is 313.02 kWh/m². Among renovation packages, P16 has noticeable decrease by 72 per cent to 87.52 kWh/m² and the second most reduction of is related to P24 with 93.46 kWh/m². By specific view to this package, amount of Heating by Natural Gas is 68.66 KWh/m² and cooling consumption by Electricity is 1.71 KWh/m².

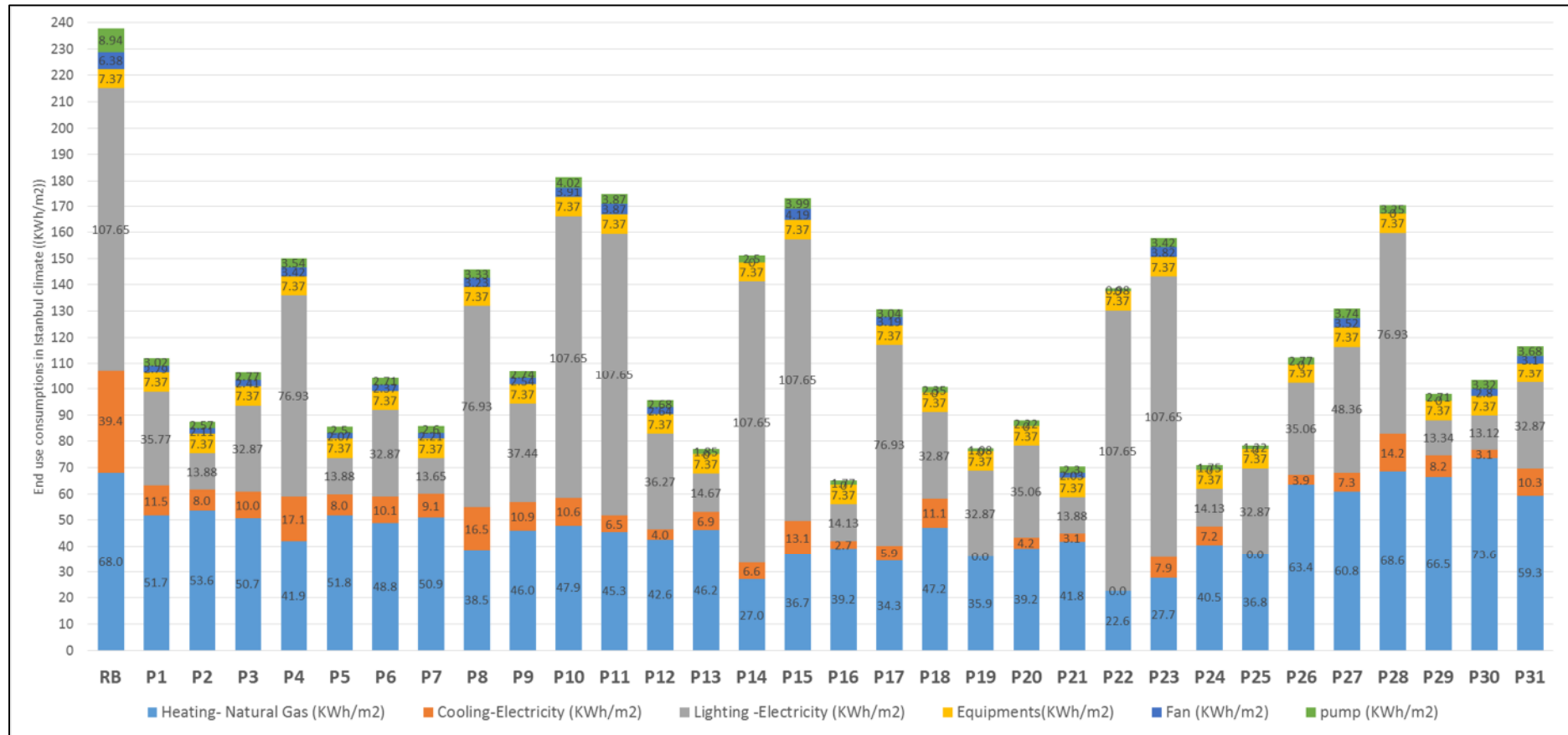


Figure 5.5: Comparison of Reference building's end use and defined packages in Istanbul.

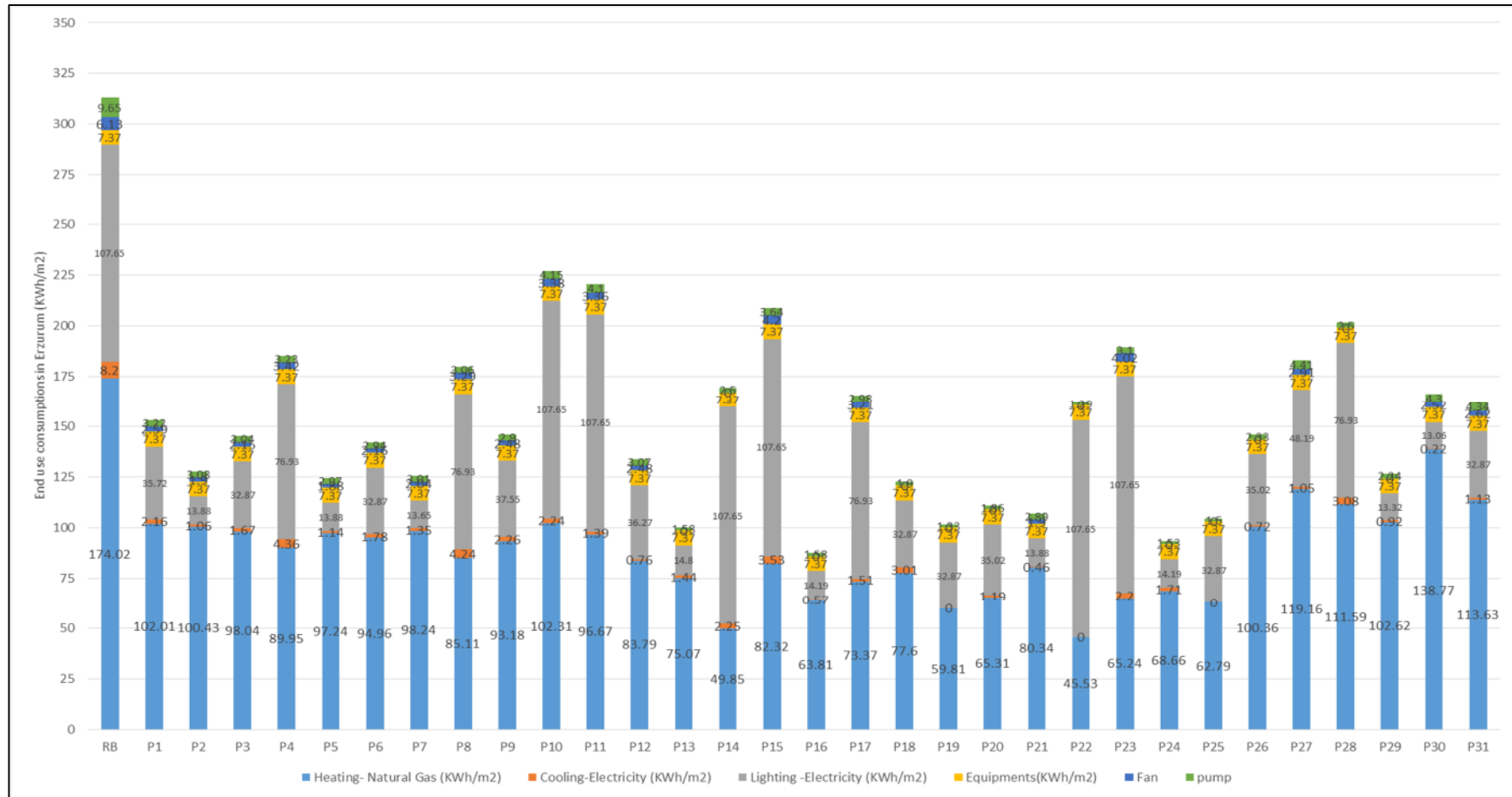


Figure 5.6: Comparison of Reference building's end use and defined packages in Erzurum.

5.4 Comparison of Final Packages Total End Uses Between Istanbul and Erzurum Climate

Figure 5.7 shows total end uses of RB and all final packages for Istanbul and Erzurum climates. By comparison of these two different climate, it's clear that by graph Total end use consumption for Istanbul RB is 238 kWh/m² year while Erzurum RB total end use is 313 kWh/m² year.

It is clear from this bar chart that the least End uses of these packages is P16 for Istanbul and Erzurum climate. Although this package is the least end uses, Istanbul total end use has reduced by 76 per cent while Erzurum climate P16 has decreased total end use by 72 per cent.

The second least end use in Istanbul packages is related to P21 with 70.41 kWh/m² year while at Erzurum packages is related to P24 with 93.46 kWh/m² year.

By comparison of the most end uses among packages between these two climate, P10 for both climate has the most end uses which is for Istanbul and Erzurum climate are 181.43 kWh/m² year and 227.1 kWh/m² year respectively.

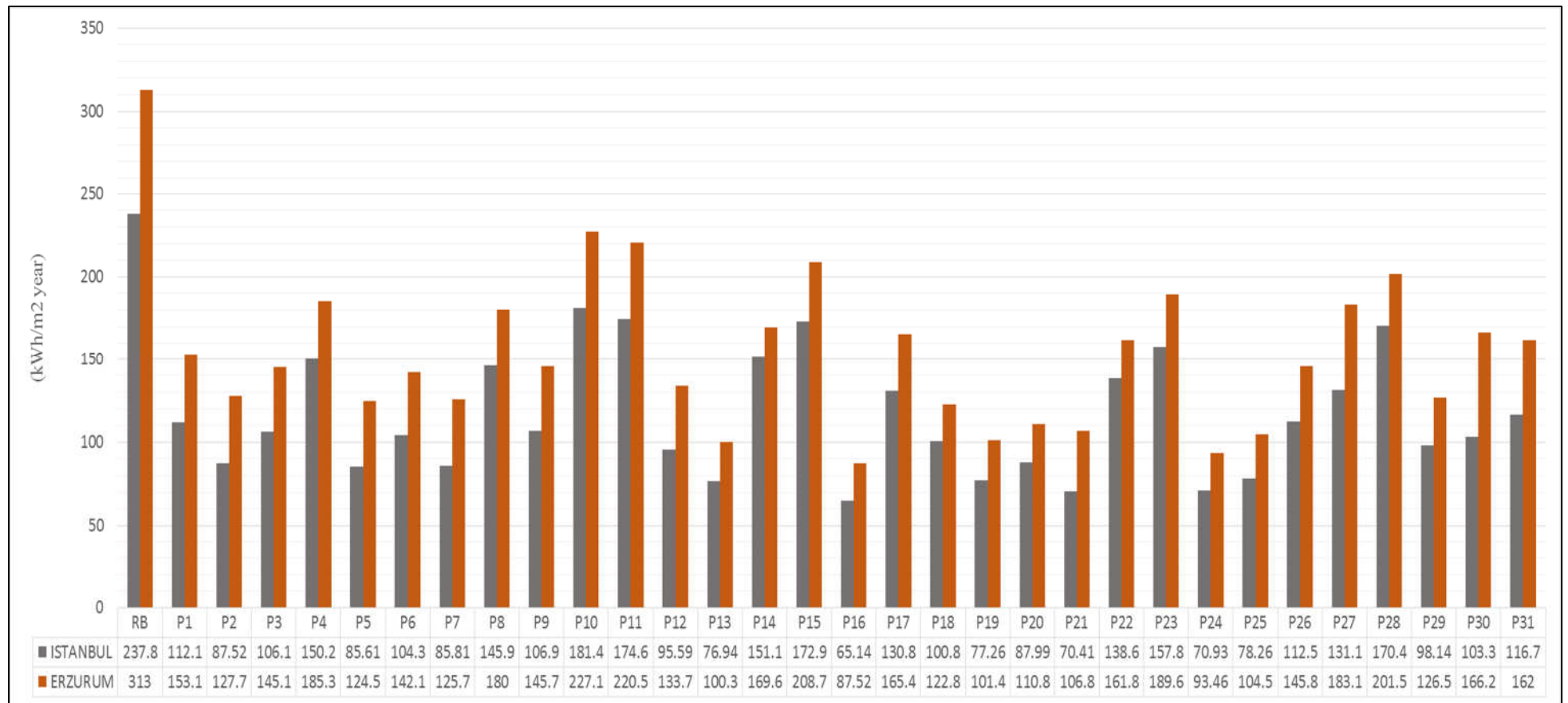


Figure 5.7: Total End use comparison of Istanbul and Erzurum's packages.

5.5 Comparison of Istanbul and Erzurum Primary Energy Consumptions of EEMs and Final Packages

At next page figure 5.8 illustrates Energy Efficiency Measures' primary energy consumption between Istanbul and Erzurum. Reference building's primary energy consumption in Istanbul is 128.4 kWh/m² year while primary energy consumption of RB in Erzurum is 178.9 kWh/m² year.

It is clear that, among envelope measures, least energy consumption is package E9-3 which includes third level of thermal insulation and triple glazing has 92.8 kWh/m² year. L5 renovation package with 63.7 kWh/m² year is minimum amount energy consumption among lighting measures. S3 is combined by radiant floor has 108.53 kWh/m² year which is the most energy consumption among energy efficiency measures.

However, among envelope measures, least energy consumption is package E3-3-3 which includes third level of thermal insulation, with 106.01 kWh/m² year. L5 renovation package with 100.78 kWh/m² year is minimum amount energy consumption among lighting measures. E3-2 is combined with second level of thermal insulation for ground floor; it has 147.38 kWh/m² year with the most energy consumption among energy efficiency measures.

Figure 5.9 summarizes all possible scenarios' primary energy consumption. As it was argued in last graph about reference building primary energy consumption, Reference building primary energy consumption in Istanbul and Erzurum are 128.4 kWh/m² year and 178.9 kWh/m² year respectively. In generally, it's clear that P16 primary energy consumption is 37.6 kWh/m² year which has least amount consumption among packages. Among final package in Erzurum climate, P16 primary energy consumption is 51.84 kWh/m² year, which is the least amount of primary energy consumptions. Energy saving of this packaged almost 70.7 per cent in contrast to Reference building primary energy consumption. This renovation package components are including; different level of EEMs on envelope, Lighting and HVAC systems. First level of thermal insulation, which is defined by TS825, Windows $U_w = 1.49 \text{ W/m}^2\text{k}$, Lighting control, all Lighting type =100% fluorescent, Radiant Floor with (heating & cooling) and Hot water boiler (Nominal 0.95), Electrical chiller (Efficiency 4.0 COP). To sum up, energy saving of this packaged almost 70.7 per cent in contrast to Reference building primary energy consumption.

The second and third least primary energy consumption of Istanbul's final packages have belonged to P21 and P24, which have $40.6 \text{ kWh/m}^2 \text{ year}$ and $40.7 \text{ kWh/m}^2 \text{ year}$ respectively. Besides, P10 primary energy saving is 24.1% which has the most energy consumption with $97.40 \text{ kWh/m}^2 \text{ year}$ among packages. This package of consist of envelope and HVAC refurbishments which are E5 (Glazing $U_w = 1.49 \text{ W/m}^2\text{K}$) and S6 (Hot water boiler (Nominal 0.9) and Electrical chiller (Efficiency 2.5 COP).

However, in Erzurum, second and third least primary energy consumption have belonged to P24 and P19, which have $55.42 \text{ kWh/m}^2 \text{ year}$ and $58.36 \text{ kWh/m}^2 \text{ year}$ respectively. On the contrary, the most energy consumption among packages is P10 by $126.93 \text{ kWh/m}^2 \text{ year}$. This package of consist of envelope and HVAC refurbishments which are E5 (Glazing $U_w = 1.49 \text{ W/m}^2\text{K}$) and S6 (Hot water boiler (Nominal 0.9) and Electrical chiller (Efficiency 2.5 COP).

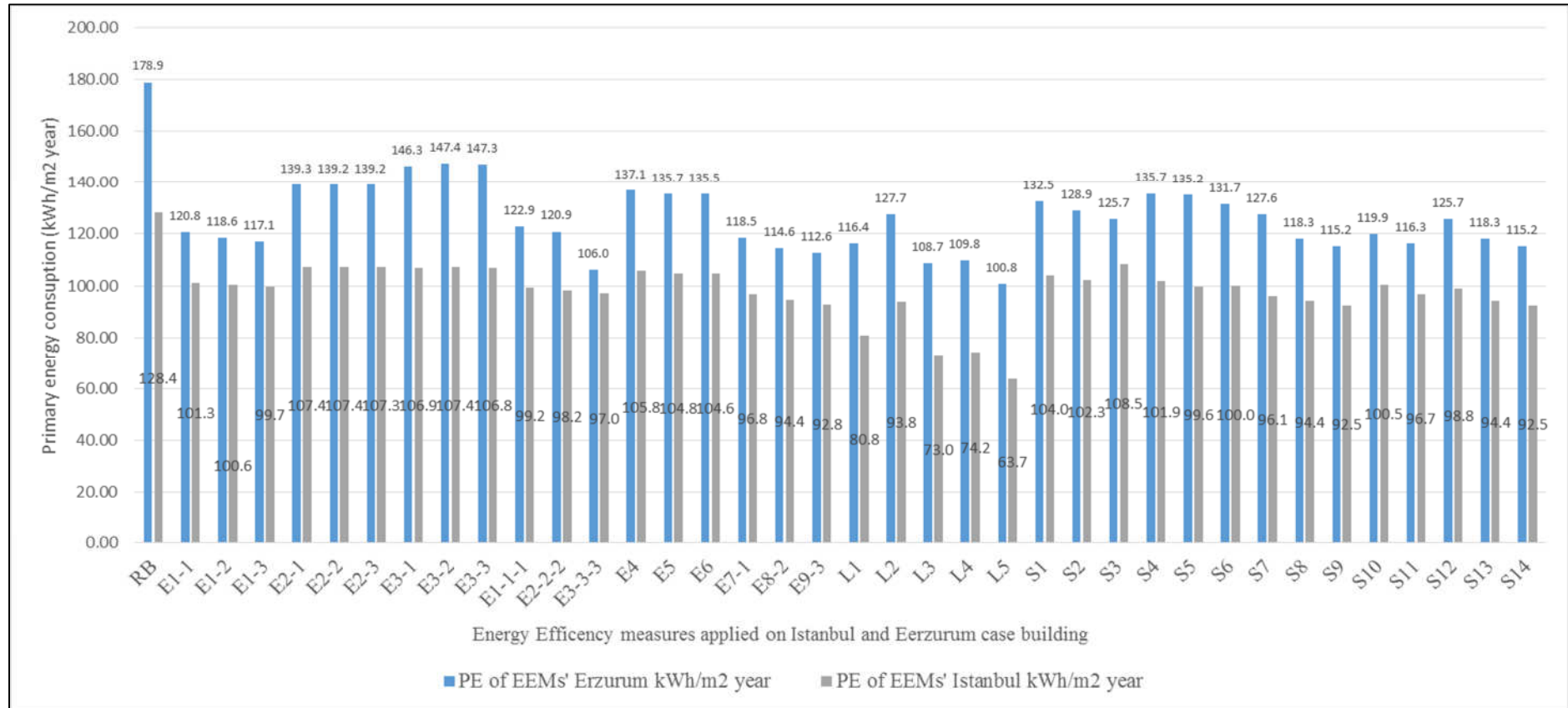


Figure 5.8: Comparison of primary energy consumption of energy efficiency measures between Istanbul and Erzurum.

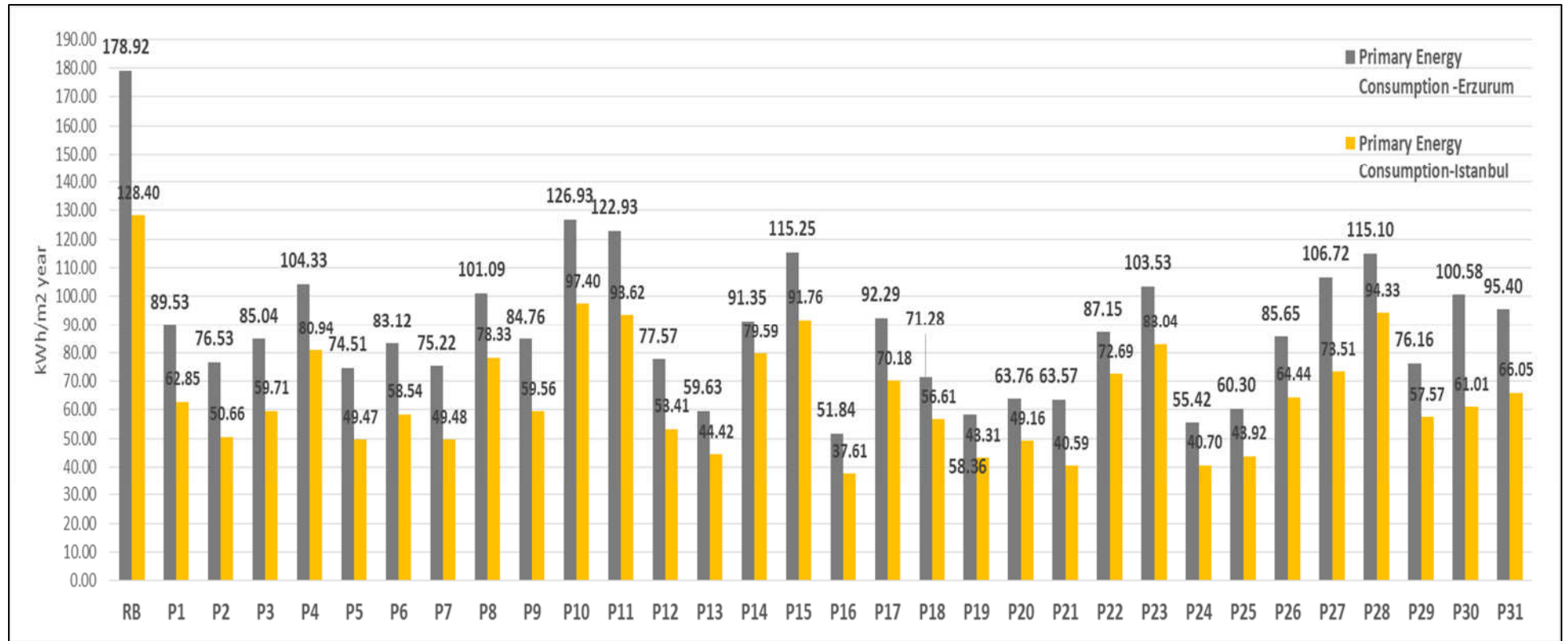


Figure 5.9: Contrasting of Primary energy consumption of final packages between Istanbul and Erzurum.

5.6 Contrast of Natural Gas and Electricity Consumption Between Istanbul and Erzurum's Final Packages

Distribution of natural gas and electricity consumption in Erzurum and Istanbul by final packages are indicated in Figure 5.10 and Figure 5.11. In Erzurum final renovation packages, Reference building natural consumption is 108.73 KWh/m² year and electricity consumption is 29.74 KWh/m² year. While reference building natural consumption is 42.5 KWh/m² and electricity consumption is 36.4 KWh/m² in Istanbul climate.

By comparison of final packages' natural gas consumption in Erzurum, P22 and P25 have the least consumption with 28.45 KWh/m² and 39.23 KWh/m². P22 and P23 in Istanbul's packages have the least consumption with 14.1 KWh/m² and 17.3 KWh/m². Moreover, electricity consumption are varied among packages. It is important issue to remind that all lighting systems, cooling systems and all equipment such as fans have work with electricity. The least consumption of electricity in Erzurum and Istanbul is belonged to P16 with 5.07 KWh/m² and 5.6 KWh/m² respectively. This package components are included lighting control, all Lighting types with fluorescent, Radiant Floor with (heating & cooling) and Electrical chiller (Efficiency 4.0 COP). Conversely, P14 has most electricity consumption among renovation packages in Istanbul. This package consumption has varied from 36.4 KWh/m² to 30.5 KWh/m². However, P30 has most electricity consumption among renovation packages in Erzurum. This package consumption has varied from 108.73 KWh/m² to 86.71 KWh/m².

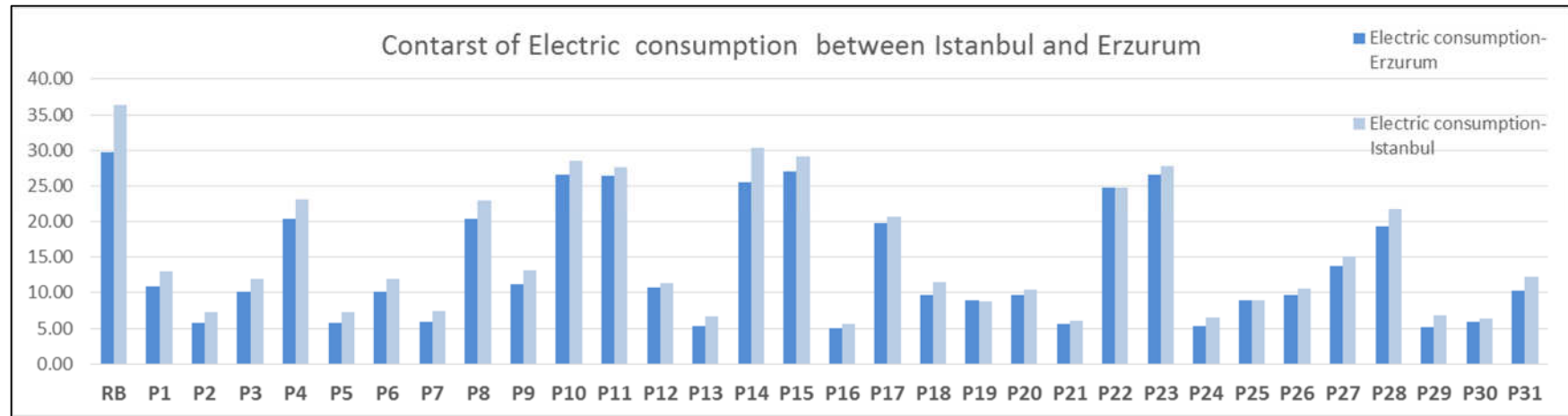


Figure 5.10: Contrast of electric consumption between Istanbul and Erzurum.

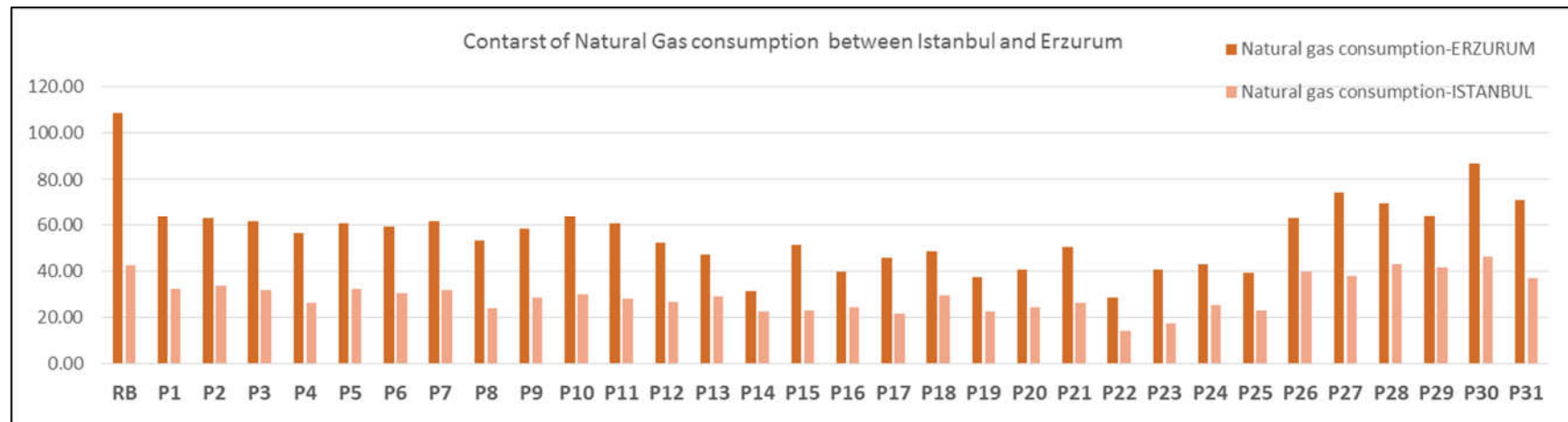


Figure 5.11: Contrast of Natural gas consumption between Istanbul and Erzurum.

5.7 Global Costs Comparison of Final Packages Between Istanbul and Erzurum Climate zones

Figure 5.12 shows global cost of final packages and reference buildings in Istanbul and Erzurum in terms of €/m². From this graph, it is clear that, in Istanbul' RB global cost is 71.08 €/m² while in Erzurum climate RB' global cost is 90.23 €/m².

P14, P22 and P23 global cost in Istanbul's final packages are more than RB which are 79.05 €/m², 72.55 €/m² and 72.11 €/m² respectively. However, in Erzurum's packages there is not any packages, which their global cost, are more than RB.

Even though, in Istanbul, dramatic variation among packages and RB is belonged to P30 which has the least amount of global cost with 39.69 €/m². In Erzurum noticeable reduction of global cost is related to package 31 with 49.27 €/m².

Moreover, Package 30 components includes adding lighting control, changing lamp types to 100% fluorescent and substitution of existed chiller with high efficient chiller (4.0 COP) and package 31 consist of Hot water boiler (Nominal 0.95) and changing lamp types to 100% fluorescent.

Package 22 with only 2% reduction of global cost among final packages in Erzurum and package 14 with 11% exceeding of global cost in Istanbul are the worse renovation packages.

Consequently, in Istanbul and Erzurum package 30 and 31 with 51.5% and 45.4% global cost variations are the best packages in terms of global cost.

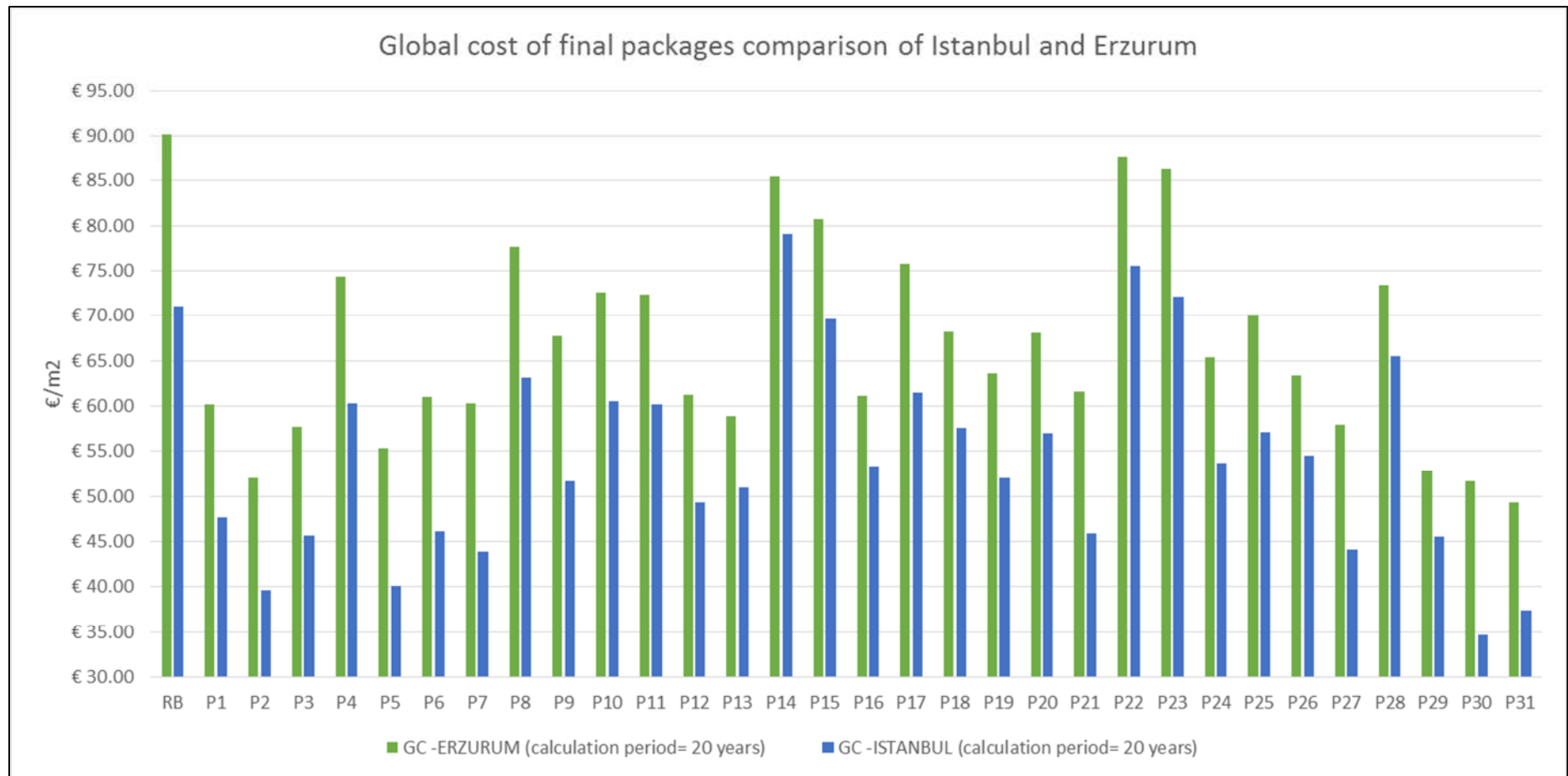


Figure 5.12: Final packages' Global cost comparison between Istanbul and Erzurum.

5.8 Simple Payback Period Comparison Among Packages in Istanbul and Erzurum Climate Zones

Figure 5.13 illustrates simple payback period of Istanbul and Erzurum's final packages. Among renovation packages in Istanbul climate, Package 31, P30 and P27's payback periods are 0.9, 1.2 and 1.7 years respectively, which are the least payback among packages. These packages have 48.6%, 52.5%, and 42.8% primary energy saving and 47.7%, 51.2% and 37.9% global cost saving respectively.

However, by comparison of final packages in Erzurum climate, Package 31, P30 and P27's payback periods are 1.3, 2.1 and 3 years respectively, which are the least payback among packages. These packages have 46.7%, 43.8%, and 40.4% primary energy saving and 45.4%, 42.8% and 35.8% global cost saving respectively.

In addition, these three packages P2, P10 and P11 have about 4-year payback period. These packages have 60.5%, 24.1% and 27.1% primary energy saving and 44.3%, 14.8%, and 15.4% global cost saving respectively. There are five packages, which have about 5-year payback period. These packages are P1, P3, P5, P6, and P29. These packages have 51.5%, 53.5%, 61.5%, 54.4%, and 55.2% primary energy saving and 33%, 35.7%, 43.6%, 35.1%, and 36% global cost saving respectively.

Undoubtedly, In Istanbul final packages these 11 packages are also desirable packages among others from investors' point of view. However, most of the packages have less than 10 years payback time; there are four packages with more than 10 years payback time that are undesirable.

However, in Erzurum climates, except three packages that mentioned before other packages' simple payback periods are more almost 6 years. the packages between 5 and 10 years simple pay back times include P29 with 5.8 years payback period ,P1, P2, P3, P5, P6, P7, P12, P13, P16 and P26.

Indeed, packages 14, 15, 22, and 23 their simple payback times are more than 20 years, which are allocated the most pay pack periods among packages. Therefore, these packages are not desirable to renovation investors.

To sum up, package 31 with 0.9 and 1.3 years payback periods in Istanbul and Erzurum respectively are the finest package in terms of investment returns.

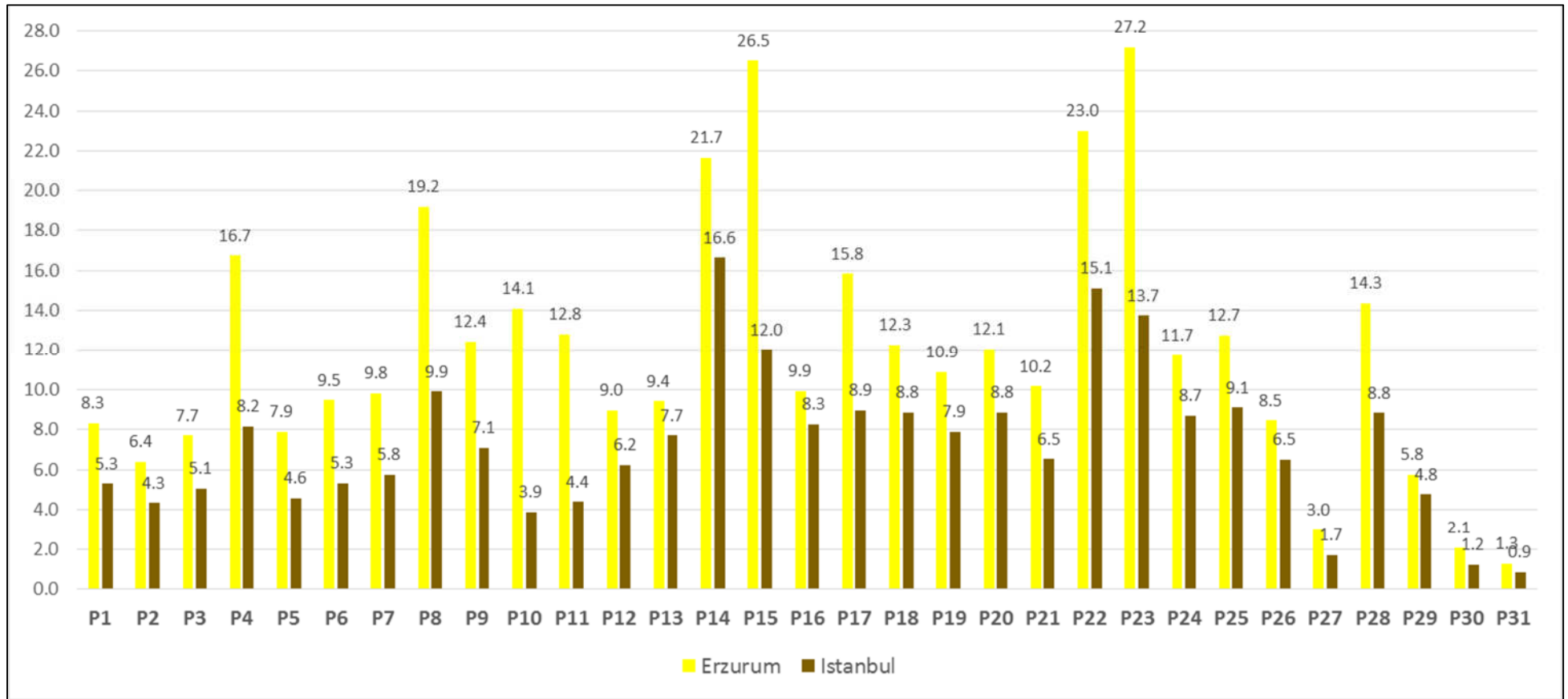


Figure 5.13: Simple payback period comparison among same packages in Istanbul and Erzurum.

5.9 Variation of the Calculation Period on Final Packages of Istanbul and Erzurum Climates Zones

The entire calculation procedure has been done again changing the calculation period, in order to assess how a shorter (10 years) or a longer (30 years) investment perspective influences results and cost-optimal levels.

As expected, a shorter calculation period lead to lower global costs, while a longer lifecycle of the building entails an increase of global costs due to cost required to the management of the building itself. The relative position among packages is almost unchanged, but the gap between the cost-optimal curves points out the incidence of running and energy costs compared to initial investment costs.

Higher costs after 30 years are also due to replacement and disposal costs of some building elements, which have a lifespan shorter than the calculation period. In particular, all HVAC components (boiler, chiller) need to be replaced after about 20 years (the only exception is represented by the radiant floor system whose lifespan is equal to 30 years).

In essence, in Istanbul final packages, changing calculation period to 10 years cause to decrease global cost from 71.08 €/m² to 43.16 €/m², Which is shown in figure 5.14. Conversely, with changing calculation period to 30 years that is presented in figure 5.16 global cost have increased from 71.08 €/m² to 87.15 €/m².

Besides, according to figure 5.15, in Erzurum final packages' sensitivity analysis, changing calculation period to 10 years cause to reduce global cost from 90.23 €/m² to 55.24 €/m². Conversely, with changing calculation period to 30 years, which is presented in figure 5.17, global cost have exceeded from 90.23 €/m² to 110.44 €/m².

By considering everything, in order to find cost optimal level by sensitivity analyses by changing calculation period from 20 years to 10 and 30 years in Istanbul final packages, package 30 is the cost optimum level among other packages and in Erzurum package 31 is the cost optimum level among other packages.

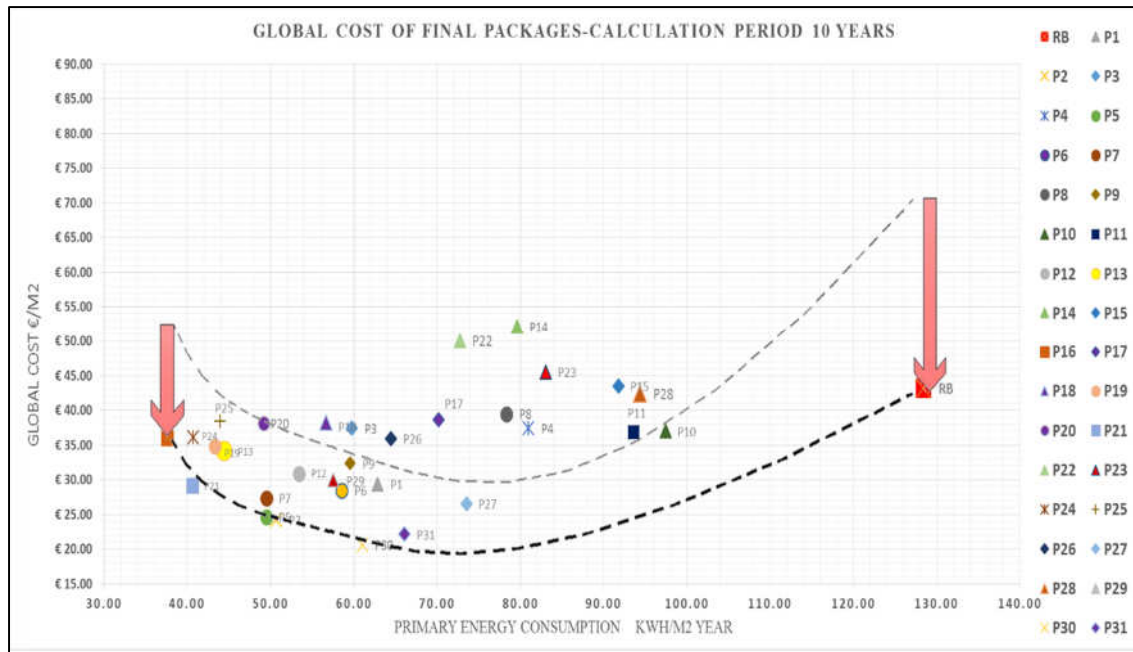


Figure 5.14: Sensitivity analysis with a calculation period of 10 years – Istanbul's final packages.

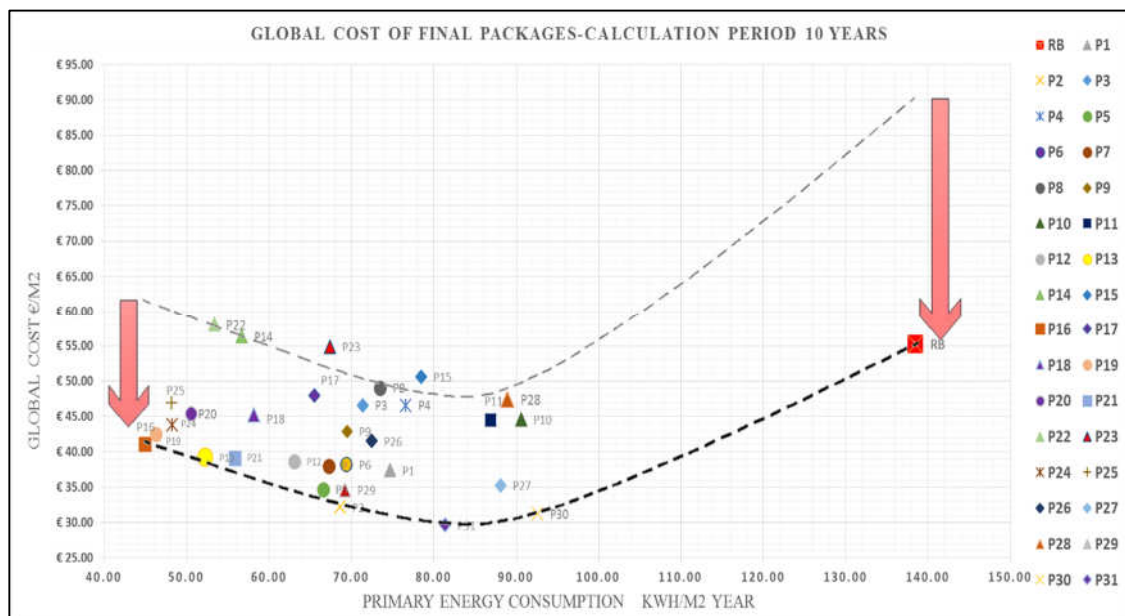


Figure 5.15: Sensitivity analysis with a calculation period of 10 years – Erzurum's final packages.

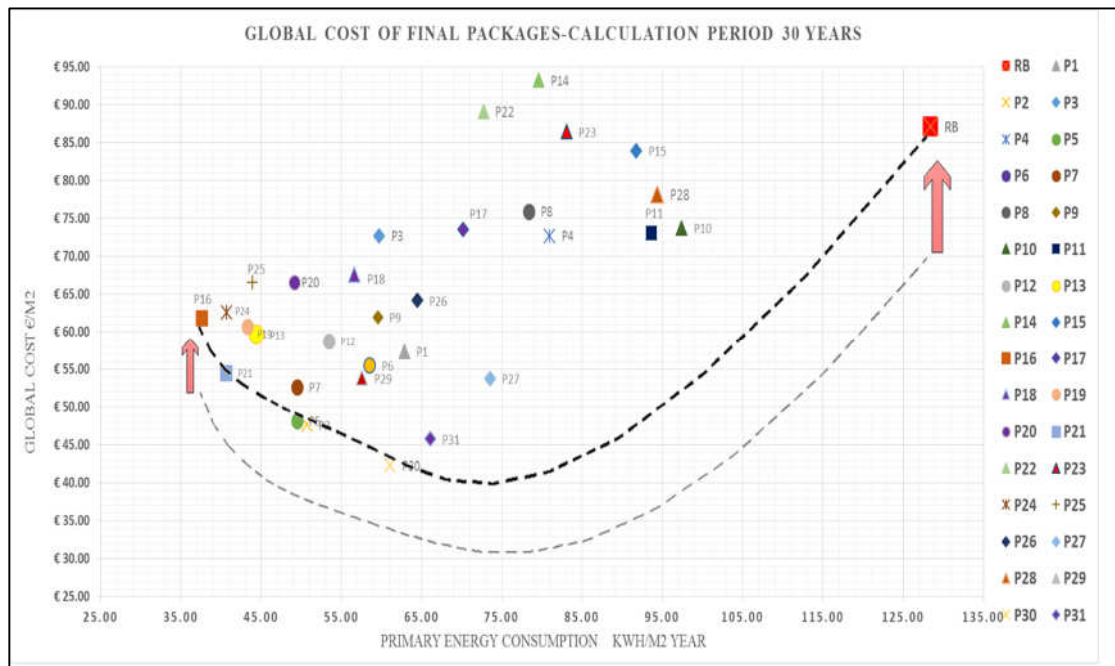


Figure 5.16: Sensitivity analysis with a calculation period of 30 years –Istanbul’s final packages.

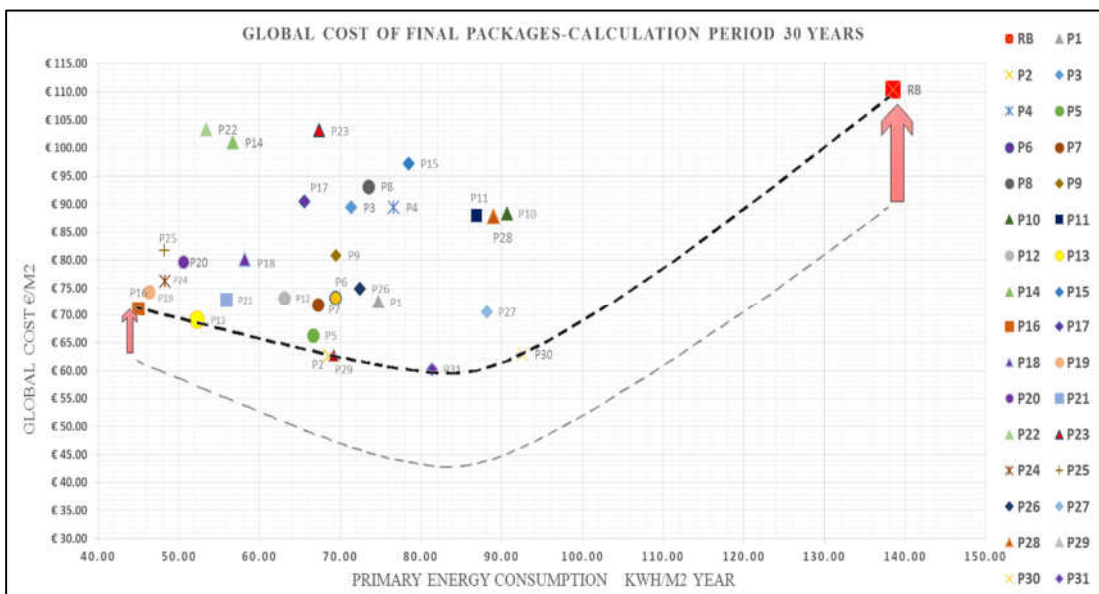


Figure 5.17: Sensitivity analysis with a calculation period of 30 years –Erzurum’s final packages.

5.10 Variation of the Discount Rate on Final Packages in Istanbul and Erzurum Climate Zones

In particular, during the global cost analysis the discount rate is used to determine the present value of future running cost and energy costs. The greater the discount rate, the lower the present value of future costs because of the sum of interests, which will be accumulated year after year. On the contrary, the lower the discount rate, the higher the present value of future expenditure.

Four different values have been taken in this project calculation period is 20 years according to member state for non-residential buildings.

Discount rate= 3% (figure 5.18), (figure 5.19);

Discount rate= 4% (figure 5.20), (figure 5.21);

Discount rate= 5% (figure 5.22), (figure 5.23);

Discount rate= 6% (figure 5.24), (figure 5.25).

As shown in figure 5.18 in the next page, the lower discount rate (3%) cause to increasing global cost which is varied in reference building from 71.08 €/m² to 88.31 €/m² and the cost optimal level by this variation is package 30. Figure 5.19 indicates sensitivity analysis with a discount rate of 3% in Erzurum which cause to changing global cost from 90.23 €/m² to 112.16 €/m² and the cost optimal level by this variation is package 2.

As a result, by variation of discount rate to 3%, it is clear that in Istanbul and Erzurum optimum cost levels are belonged to P30 and P2 respectively.

Figure 5.20 represents the lower discount rate (4%) cause to increasing global cost which is varied in reference building from 71.08 €/m² to 80.74 €/m² and the cost optimal level by this variation is package 30. Figure 5.21 indicates sensitivity analysis with a discount rate of 4% in Erzurum which cause to changing global cost from 90.23 €/m² to 102.52 €/m² and the cost optimal level by this variation is package 2.

To sum up, by variation of discount rate to 4%, it is clear that in Istanbul and Erzurum optimum cost levels are belonged to P30 and P2 respectively.

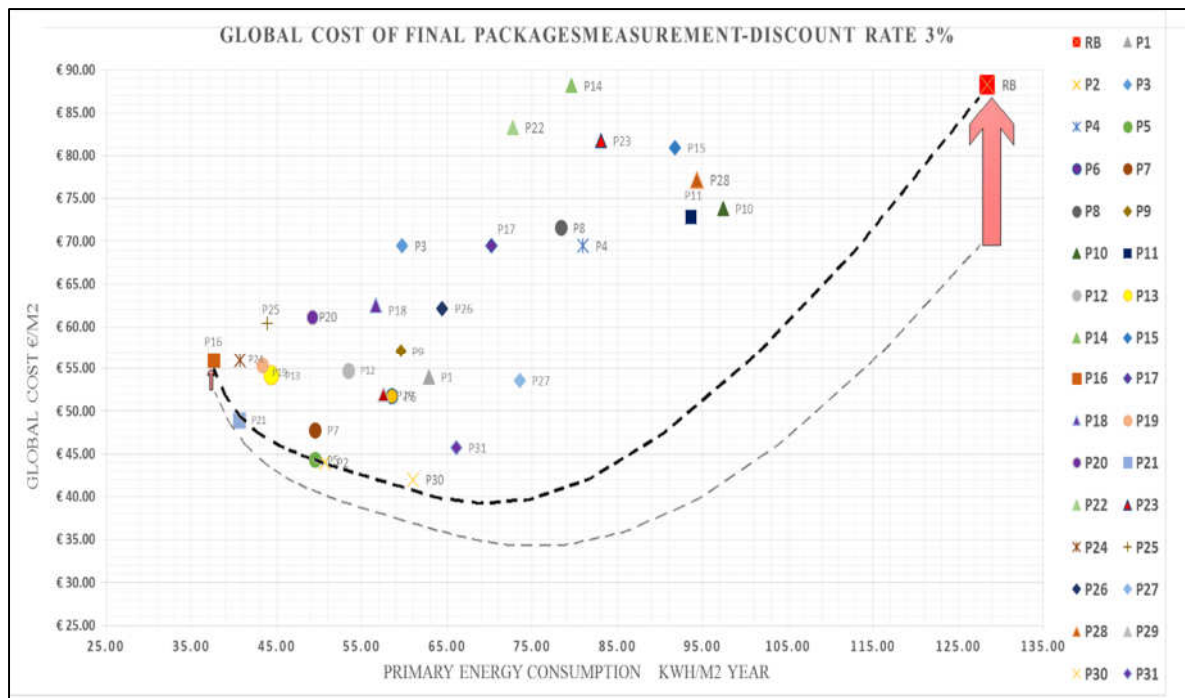


Figure 5.18: Sensitivity analysis with a discount rate of 3% -Istanbul.

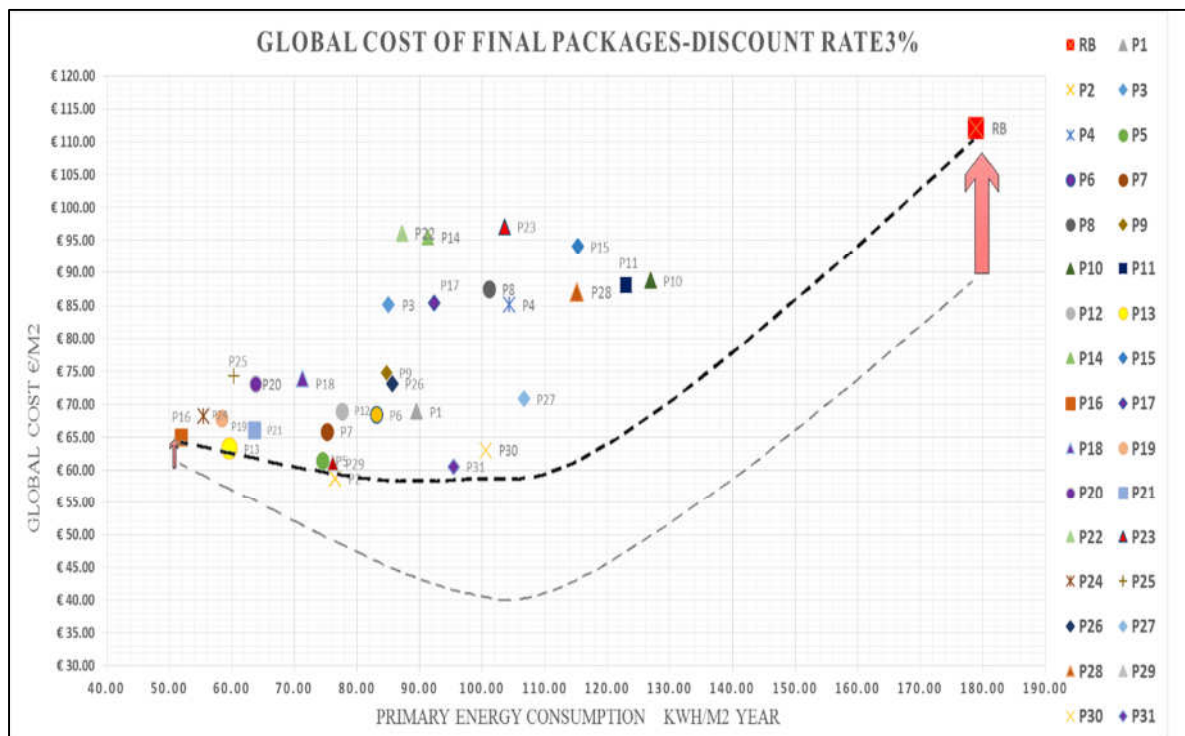


Figure 5.19: Sensitivity analysis with a discount rate of 3% -Erzurum.

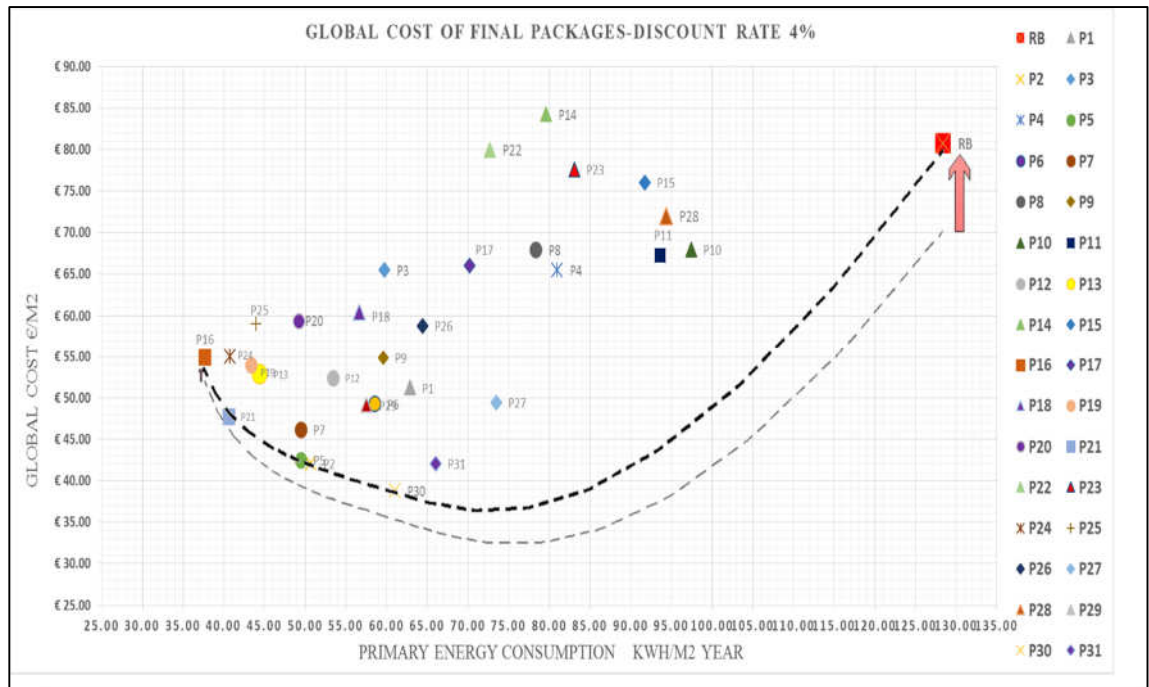


Figure 5.20: Sensitivity analysis with a discount rate of 4%-Istanbul.

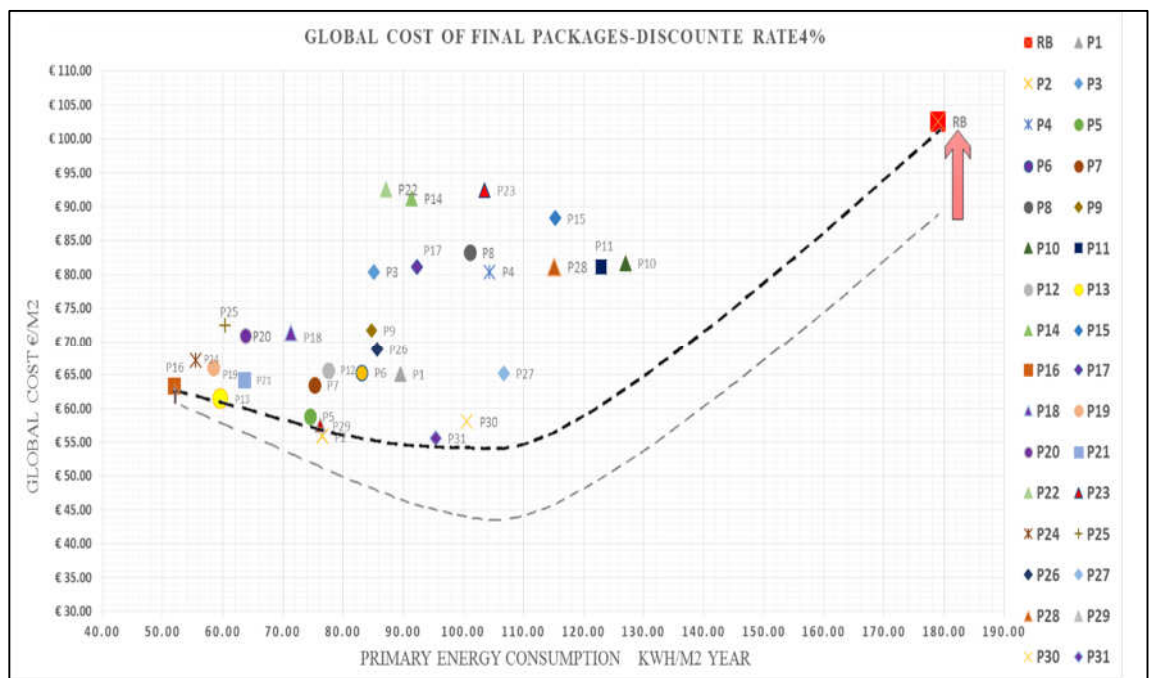


Figure 5.21: Sensitivity analysis with a discount rate of 4%-Erzurum.

As shown in figure 5.22 in the next page, the lower discount rate (5%) cause to increasing global cost which is varied in reference building from 71.08 €/m² to 74.10 €/m² and the cost optimal level by this variation is package 30. Figure 5.23 indicates sensitivity analysis with a discount rate of 5% in Erzurum which cause to changing global cost from 90.23 €/m² to 94.07 €/m² and the cost optimal level by this variation is package 31.

Overall, by variation of discount rate to 5%, it is clear that in Istanbul and Erzurum optimum cost levels are belonged to P30 and P31 respectively.

As shown in figure 5.24 in the next page, the lower discount rate (6%) cause to increasing global cost which is varied in reference building from 71.08 €/m² to 68.24 €/m² and the cost optimal level by this variation is package 30. Figure 5.25 indicate sensitivity analysis with a discount rate of 6% in Erzurum which cause to changing global cost from 90.23 €/m² to 86.62 €/m² and the cost optimal level by this variation is package 31.

Consequently, by variation of discount rate to 6%, it is clear that in Istanbul and Erzurum optimum cost levels are belonged to P30 and P31 respectively.

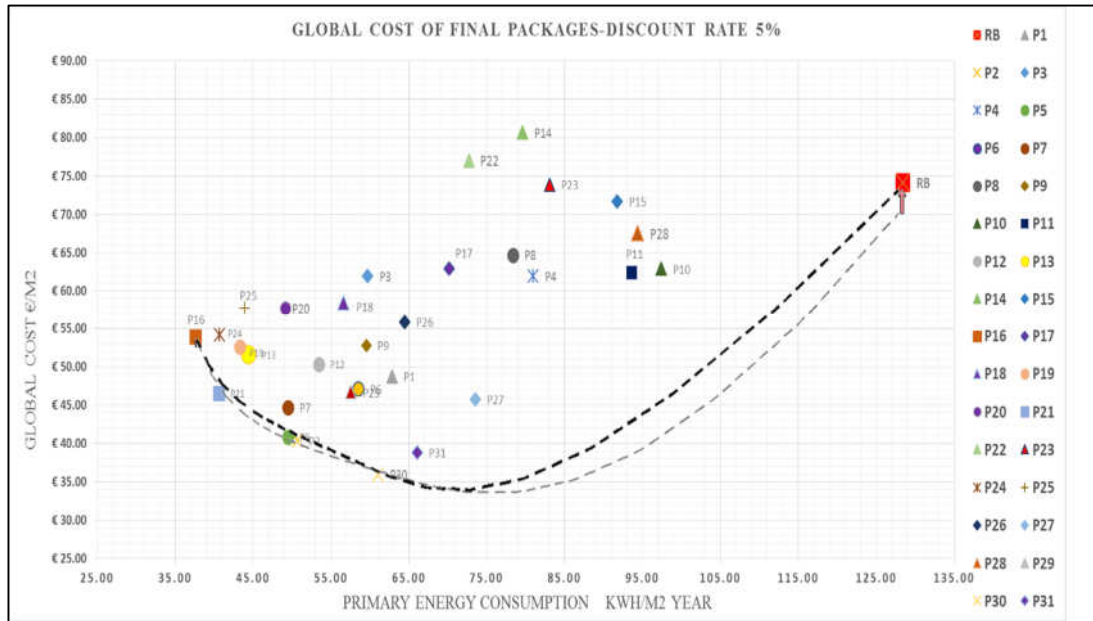


Figure 5.22: Sensitivity analysis with a discount rate of 5%-Istanbul.

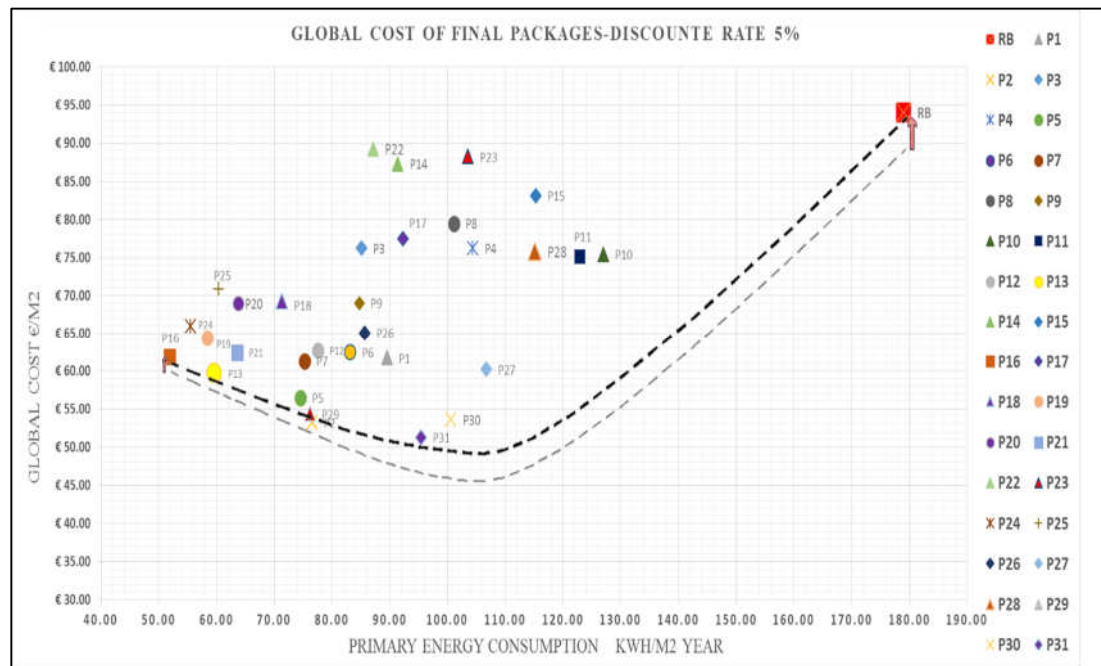


Figure 5.23: Sensitivity analysis with a discount rate of 5%-Erzurum.

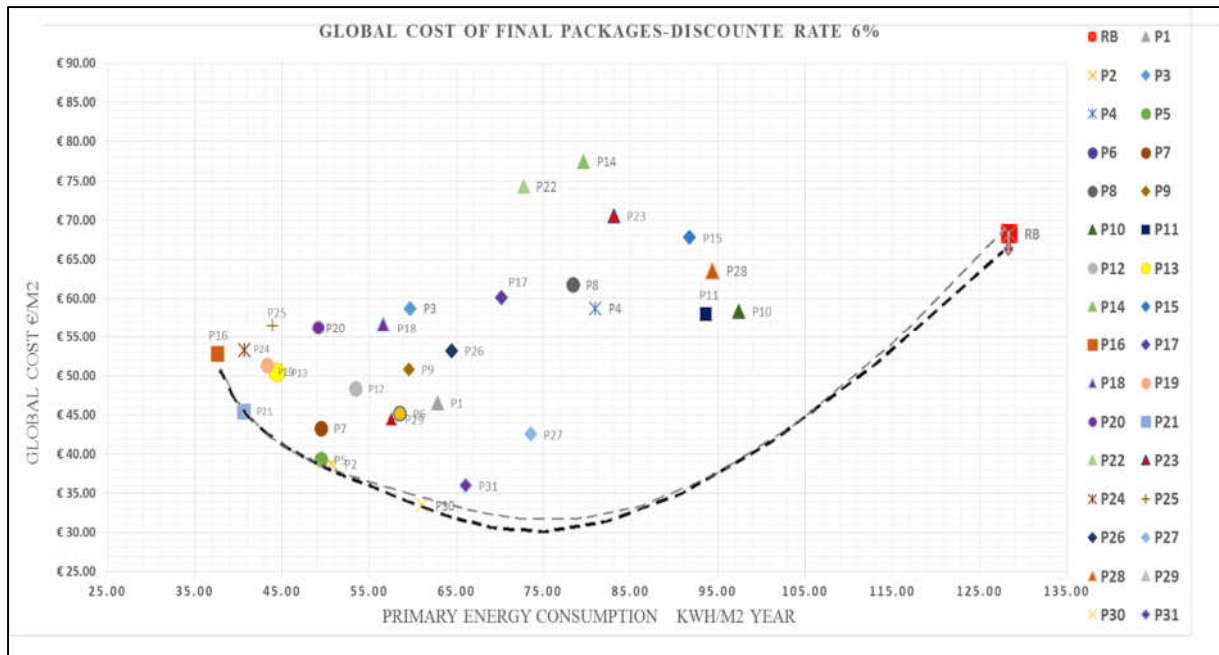


Figure 5.24: Sensitivity analysis with a discount rate of 6%-Istanbul.

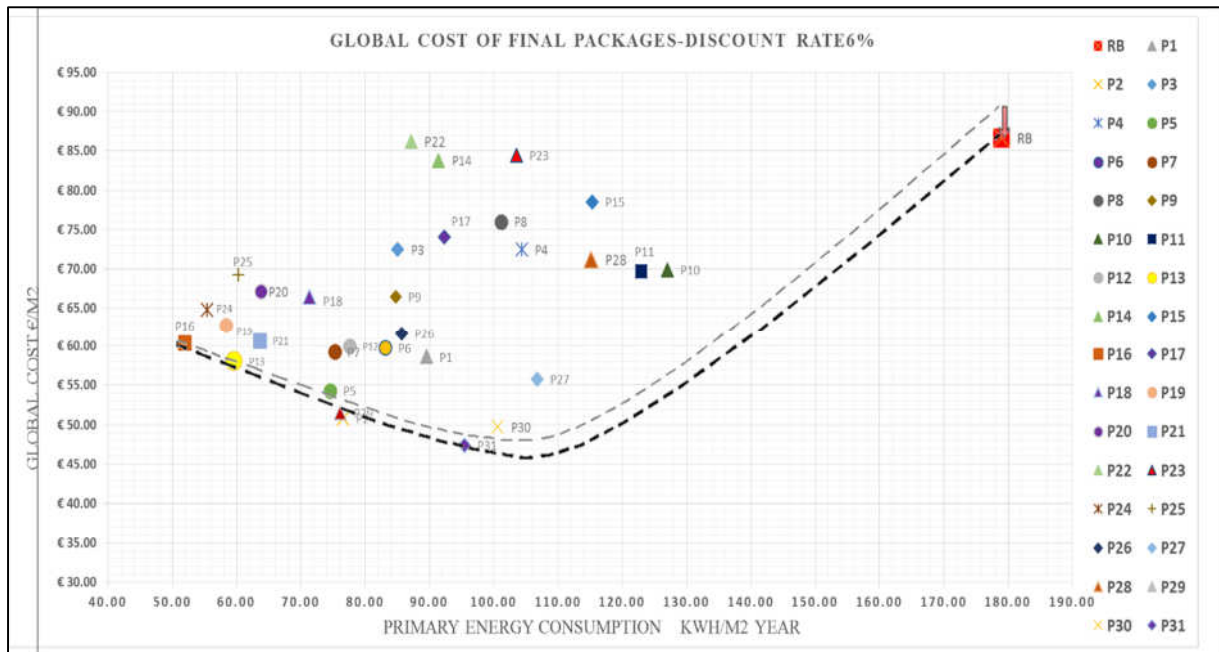


Figure 5.25: Sensitivity analysis with a discount rate of 6%-Erzurum.

At next pages, figure 5.26 shows distribution of retrofit measures global cost (TL/m²) through Pay back periods (PBPs). According to this graph, there are seven final packages which their pay back periods of them are less than 5 years. These packages are P30, P31, P27, P2, P5, P10, and P11. Among of them, Package 30, 31, and package 27's payback periods are less than two years and have the least amount of global cost in contrast to other packages. Conversely, the package, which the most pay, pack times and global cost by comparison of all packages are P14, P22, P23 and P15. These packages payback periods are not only more than ten years but also their global cost variation are equal or more than Reference building. Consequently, these packages could not be appropriate options for cost optimal level.

In addition, figure 5.27 reveals distribution of retrofit measures global cost (TL/m²) through Investment cost (TL/m²). By comparison of final packages in terms of initial investment cost and global cost, Package 2, P3, P5, and P27 have the least amount of initial investments cost through global cost. However, P14 and P22's initial investment cost and global cost are almost at the peak by contrast to other packages. Although, package 10 and 11 initial investment cost are almost 20 TL/m², their global cost variation are not remarkable. Therefore, these packages are not reasonable choice in terms of energy saving.

Figure 5.28 gives the details concerning of the final packages Pay back periods (PBPs) through Investment cost (TL). According to this graph, there are existed three hypothetical groups which are divided by pay periods and initial investment cost. It is clear that the least amount of payback period and initial investment cost are belonged to package 30, P31, P27, P10, and P11. On the contrary, packages 14, P15, P22, and P23 are not only high initial cost but also their payback times are more than 10 years. Moreover, large group of packages their payback periods are between 5-10 years and have 400 thousand to 1000 thousand TL initial investment costs

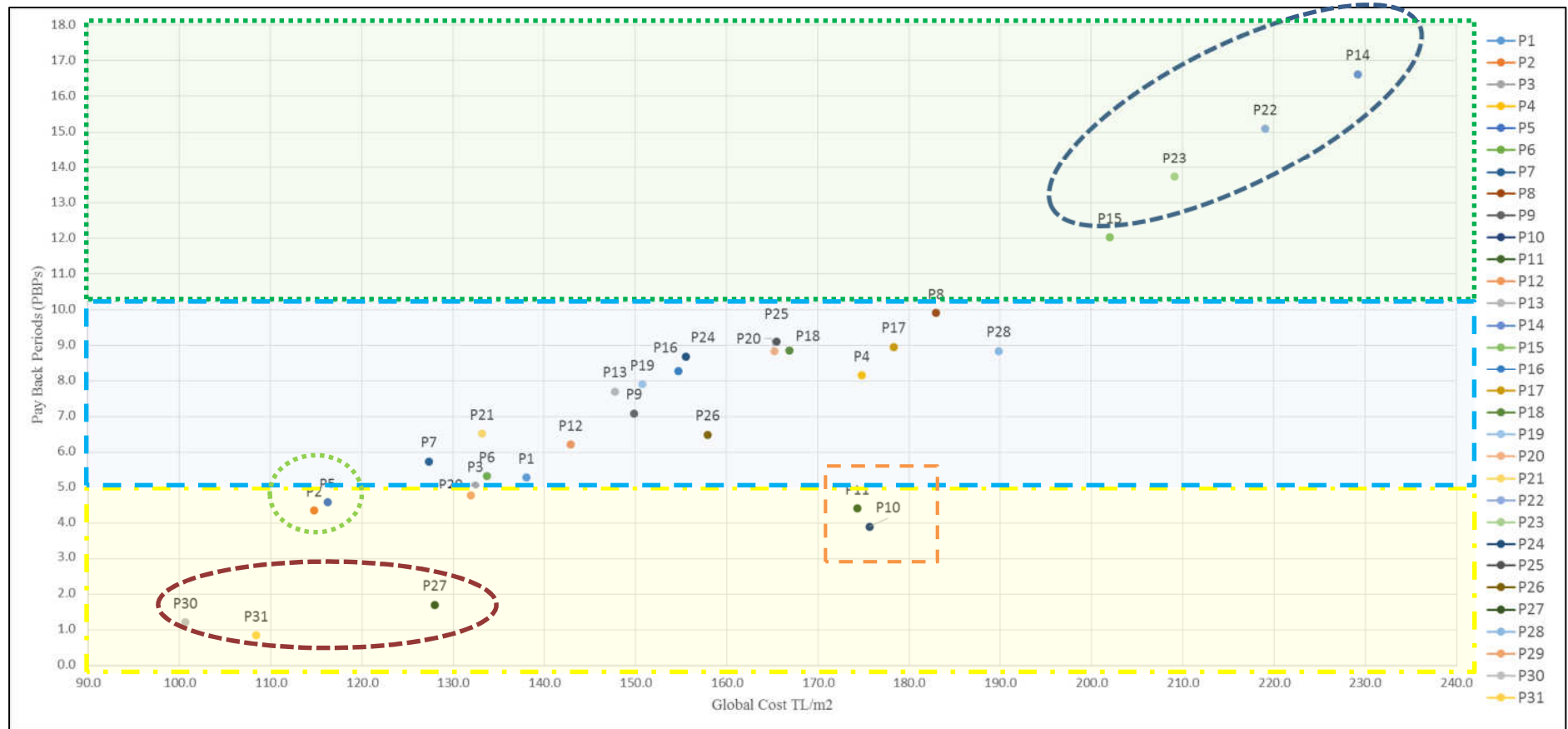


Figure 5.26: Distribution of retrofit measures global cost (TL/m²) through Pay back periods (PBP)-Istanbul.

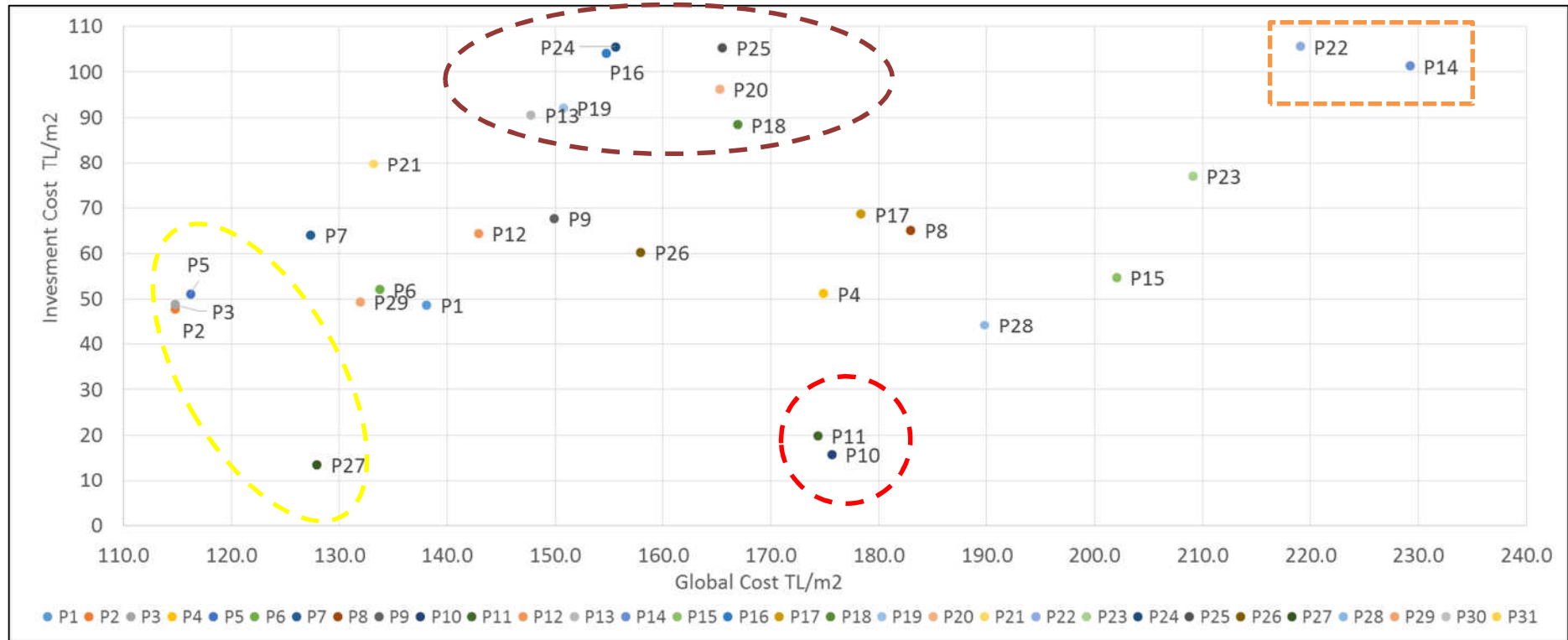


Figure 5.27: Distribution of retrofit measures global cost (TL/m²) through Investment cost (TL/m²)-Istanbul.

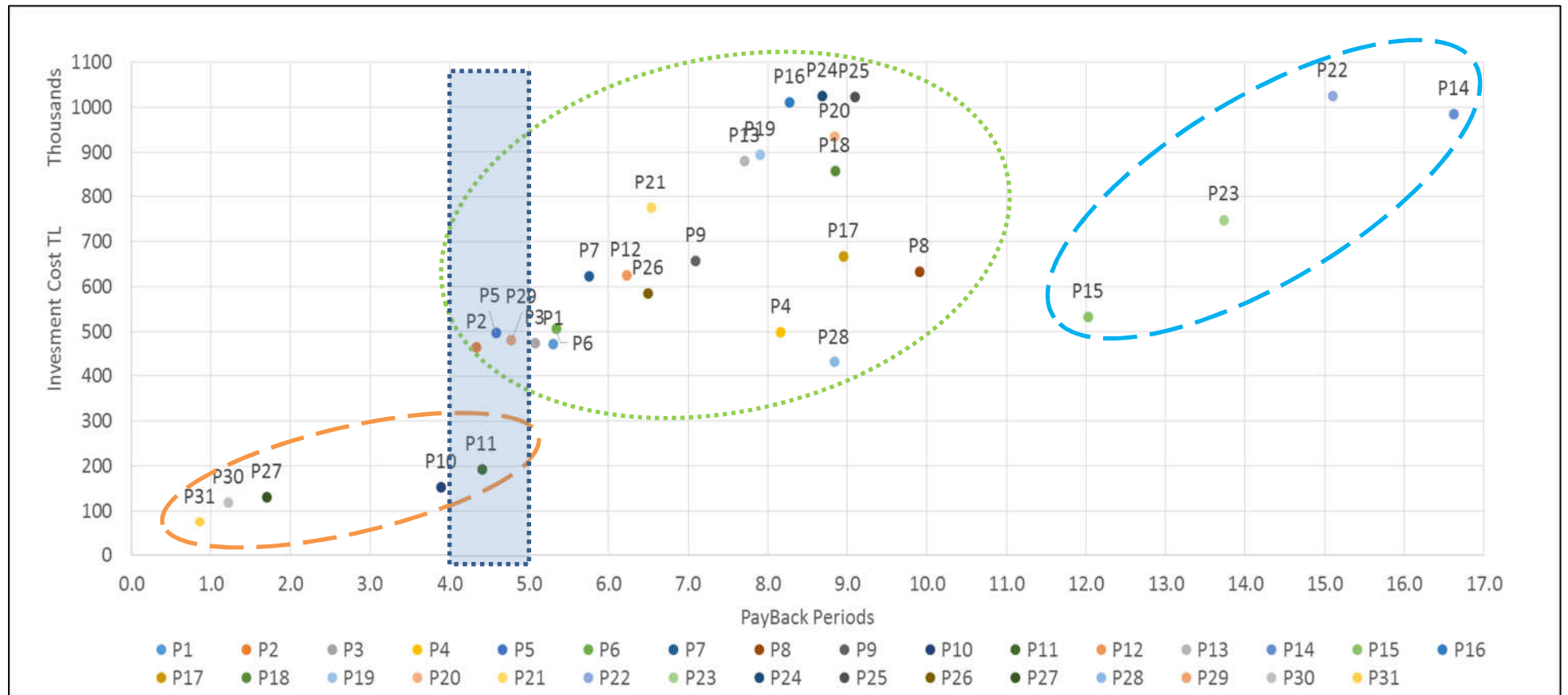


Figure 5.28: Distribution of retrofit measures of Pay back periods (PBPs) through Investment cost (TL)-Istanbul.

5.11 Comparison of Energy Levels and Global Cost of EEMs in Istanbul and Erzurum

The first cost-optimal analysis (see figure 5.29 and figure 5.30) refers to energy efficiency measures, which include Envelope, Lighting and Mechanical Systems in Istanbul and Erzurum climate zones.

The first graph reveals that the measures such as S3, S10, E3-3-3, and S11 have negative effect due to having high global cost in contrast to reference building in spite of energy saving almost between 12.5% and 27%. By comparison of all measures, it is obvious that lighting measures not only account to energy saving but also cause to reducing global cost. Consequently, lighting measures have positive effects. L5, which comprise lighting control and all lighting are 100% fluorescents, causes to primary energy saving to reach 50.37% and global cost variation is 54.5% as well. In fact, the package that comprised with lighting control have lower primary energy consumption in comparison with others. Hence, cost optimum starting range are between L1 primary energy saving 37% and L5 with almost 50% primary energy savings.

The second graph illustrates that the measures such as E3-2, E3-3 have least energy saving almost 17%. By comparison of all measures, it is obvious that lighting measures not only account to energy saving but also cause to reducing global cost. Consequently, lighting measures have positive effects. L5, which comprise lighting control and all lighting are 100% fluorescents, causes to primary energy saving to reach 43.68 % and global cost variation is 47.1% as well. In fact, the package that comprised with lighting control have lower primary energy consumption in comparison with others. Hence, cost optimum starting range are between L1 primary energy saving 35% and L5 with almost 44% primary energy savings.

Finally, L5 energy efficient measures is optimum cost level among all measures in Istanbul and Erzurum climate zones.

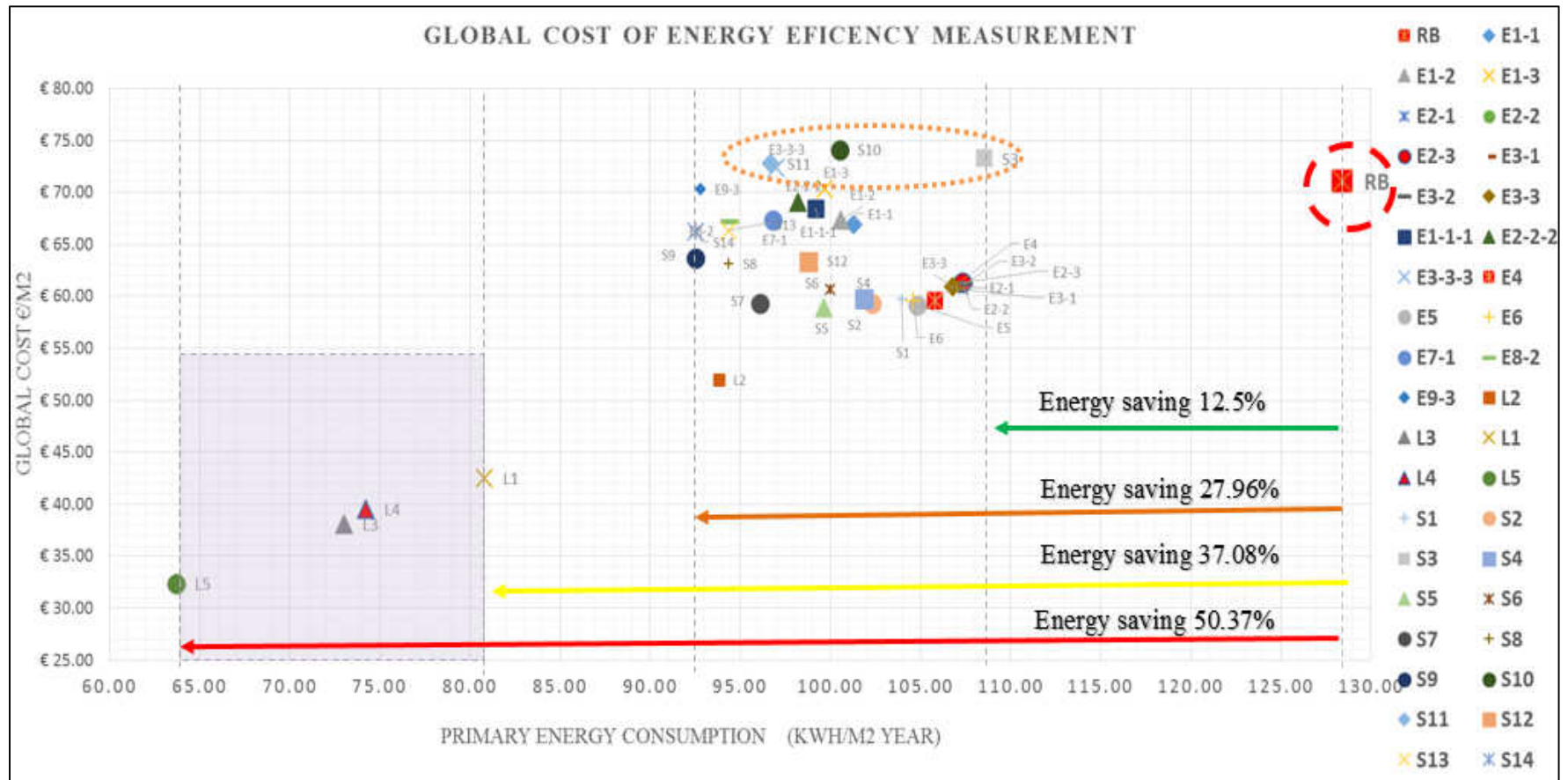


Figure 5.29: Determination of cost optimum level among energy efficiency measures –Istanbul.

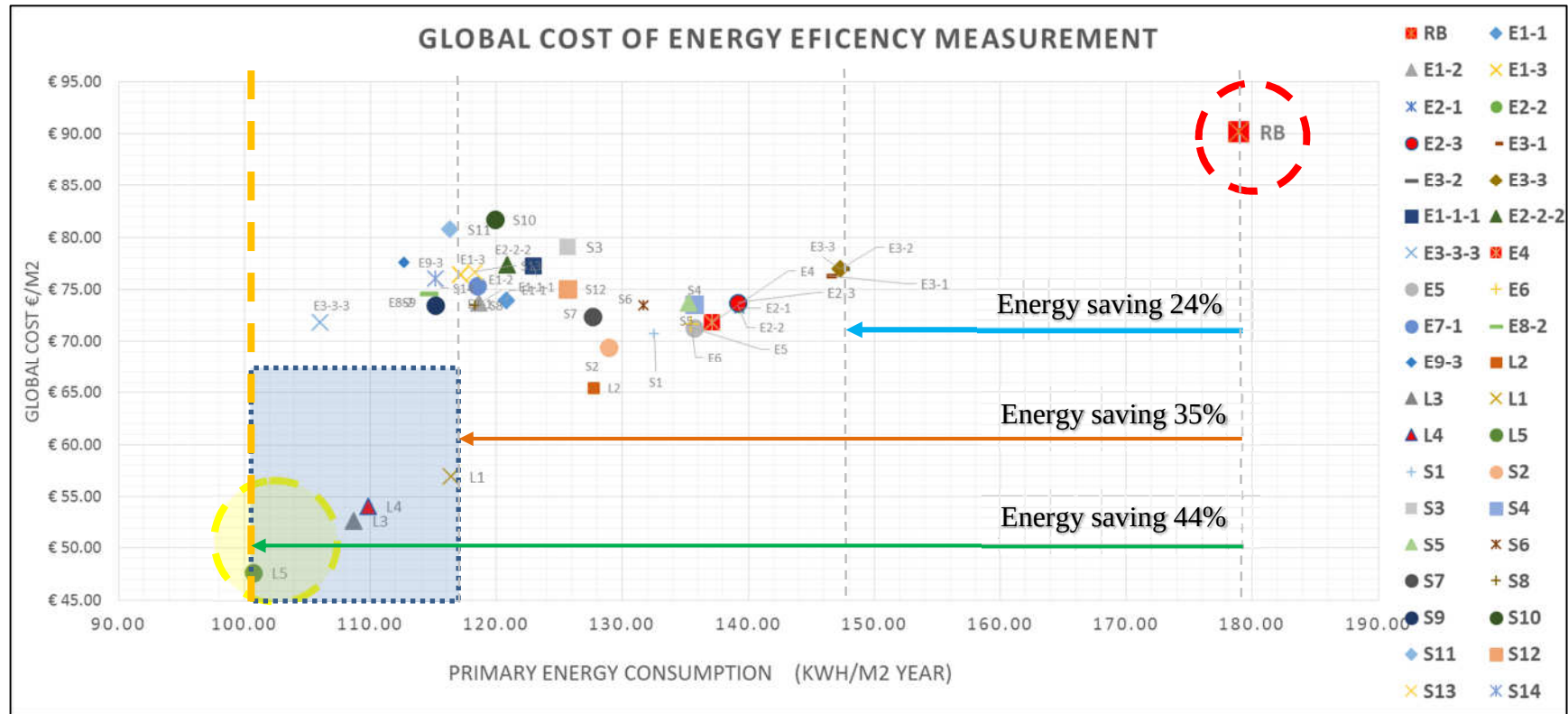


Figure 5.30: Determination of cost optimum level among energy efficient measures-Erzurum.

5.12 Comparison of Energy Levels and Global Cost of Final Packages in Istanbul and Erzurum

The second cost-optimal analysis (see figure 5.31 and figure 5.32) illustrate final packages the cost-optimal level is obtained by comparing the global cost and the correspondent primary energy, both calculated for packages in Istanbul. Results of this comparison can be reported on a graph that describes primary energy use [kWh / m^2 year] on the x-axis and global costs on the y-axis [$\text{€}/\text{m}^2$].

From the number of combination of measures assessed in Istanbul, which have illustrated by figure 5.28, package 10, 11 and P28 have primary energy saving almost 25 per cent. Even though packages 14, 22 and 23 their primary energy consumption are less than RB, their global costs are more than RB. Therefore, these packages have negative effects. Cost optimum range of packages is belonged to the lowest primary energy consumption and global cost. Consequently, package 2, P5, P30 and P31 are located in this region. In particular, Package 30 have $61.01 \text{ kWh} / \text{m}^2$ year primary energy consumption with 52.5% primary energy saving and 34.69 €/m^2 global cost have allocated optimum cost level place among all renovation package. Furthermore, this package measures are including L5 and S5 compositions.

However, in Erzurum, which have illustrated by figure 5.29, package 10, 11, 15 and P28 have primary energy saving almost 29 per cent. Even though packages 14, 22 and 23 their primary energy consumption are less than RB, their global costs variation are almost 3 per cent. Cost optimum range of packages is belonged to the lowest primary energy consumption and global cost. Consequently, package 2, P29, P30 and P31 are located in this region. In particular, Package 31 have $95.40 \text{ kWh} / \text{m}^2$ year primary energy consumption with 46.7 % primary energy saving and 49.27 €/m^2 global cost have allocated optimum cost level place among all renovation package. Furthermore, this package measures are including L3 and S2 compositions.

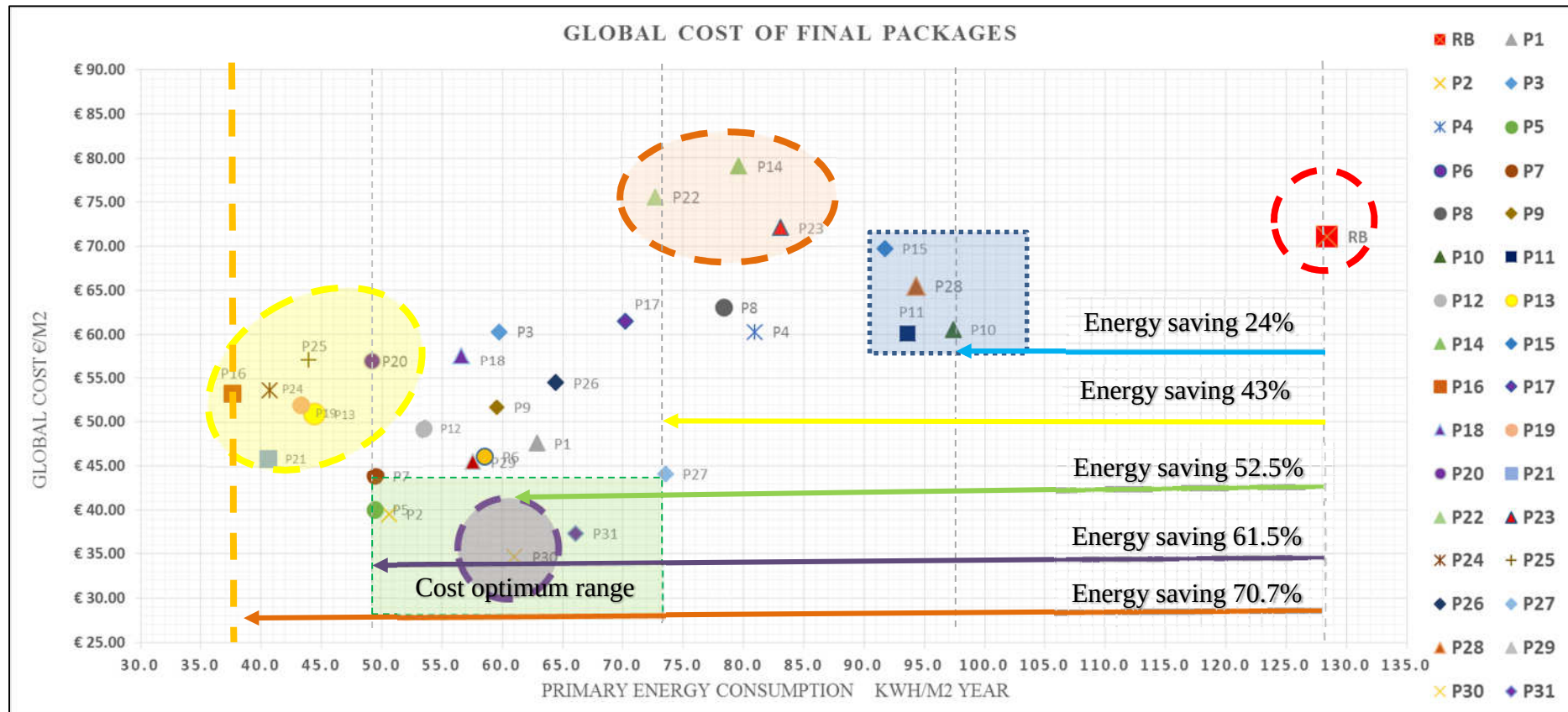


Figure 5.31: Determination of cost optimum level among final packages – Istanbul.

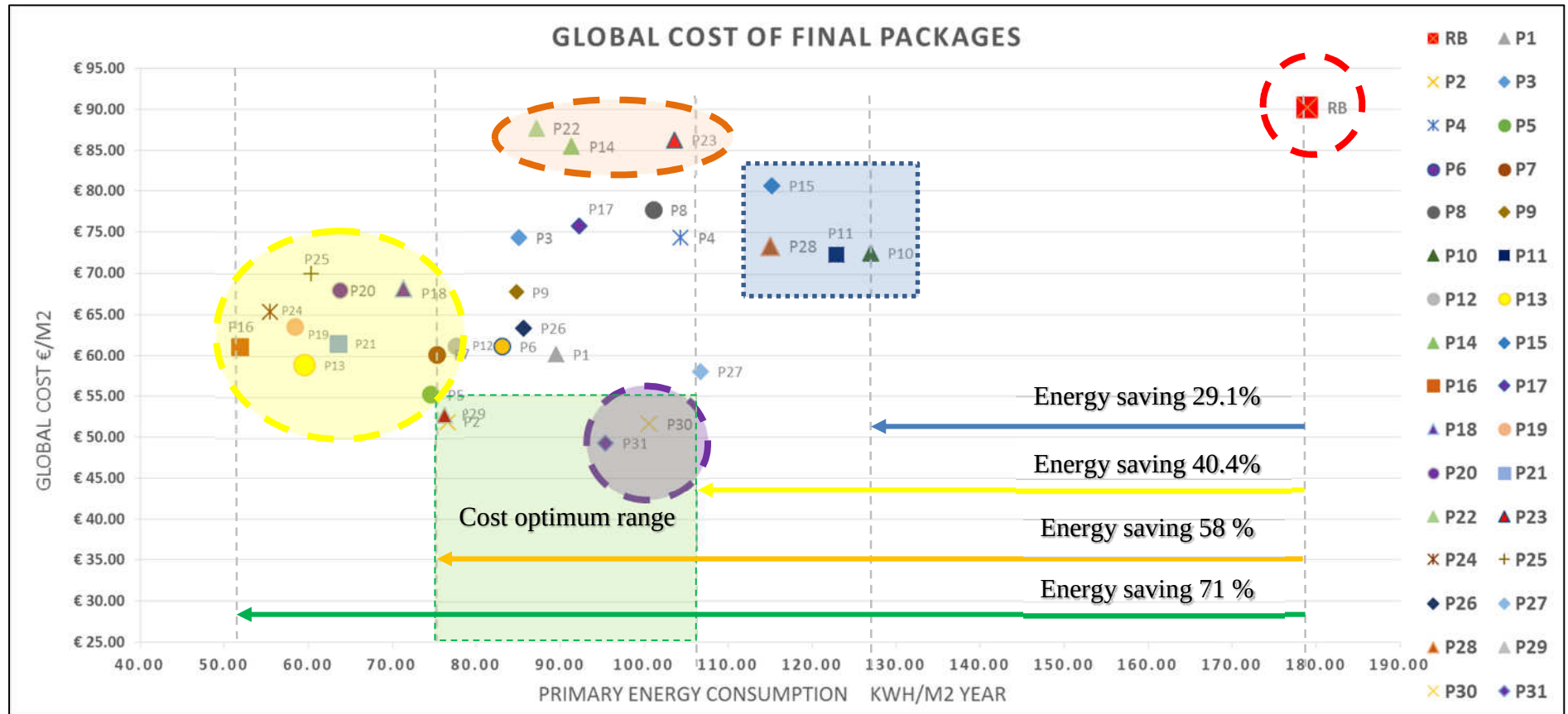


Figure 5.32: Determination of cost optimum level among final packages-Erzurum.

5.13 Determination of Cost Optimal Levels of Retrofit Packages Istanbul and Erzurum

For each reference building, Member States shall compare the global cost results calculated for different energy efficiency measures and measures based on renewable energy sources and packages/variants of those measures. Among the results, cost-optimal is represented by the retrofit scenario with the lowest cost during the estimated lifecycle.

In this stage, in order to find derivation of cost optimal levels which all results are analyzed at early of chapter 5, For Istanbul climate, Package 30 is the reasonable package, which is located in cost optimum ranges. This package global cost is the lowest amount among with 34.69 €/m² and primary energy consumption of this package is 61.01 kWh/m² year .In particular, primary energy saving is P30 is 52.5% and global cost variation of its is -51.2% .This package is recommended in Istanbul region due to having minimum payback times less than 2 years.

However, in Erzurum climate, Package 31 is the reasonable package, which is located in cost optimum ranges. This package global cost is the lowest amount among with 49.27 €/m² and primary energy consumption of this package is 95.4 kWh/m² year .In particular, primary energy saving is P31 is 46.7% and global cost variation of it is -45.4% .This package is recommended in Erzurum region due to having minimum payback times less than 2 years.

6. CONCLUSIONS

In Turkey ratio of educational building is great in comparison with other kind of building and the number of young people, which are spend their time in schools, are almost one quarter of population.

From other point of view, existed educational building with high-energy consumption and lack of budget of public school buildings are the main troubles of educational building of Turkey. Furthermore, construction of new energy efficient school while life span of building is almost is 60-80 years hence this concept for reduction energy consumption of public school is not reasonable approach.

Overall, energy retrofit in primary school building is not only improving students' performance and boosting teacher moral and retention but also have positive economic impact, by reducing energy demand.

In this project, energy savings and optimum cost level of primary school buildings through energy efficient renovation actions is targeted. In order to reach to this target, a case study school building is selected based on typical construction types of building in Istanbul, and then different energy efficient measurements, which are acceptable according to Turkish and international standards are applied to the case study building. Cost calculation method is based on supplementing Directive 2010/31/EU of the European Parliament on the energy performance of buildings.

As mentioned before, one of the typical existed primary schools in Turkey is defined as a reference building. This reference building is located in Istanbul and more precisely it is one the seven existed reference buildings in Istanbul, which is numbered MEB.2004-53 and constructed in different regions of Istanbul. In this research, in order to have an overview about the result in different climatic regions of Turkey, two different cities are selected to investigate. One of them is Istanbul, which is original building's location and is located in Mild-Humid Climate Zone, and the other one is Erzurum which is located in Cold Climate Zone. Besides, simulation of reference building is applied with the help of a dynamic simulation tools such as Design Builder and energy Plus.

This study is based on both current energy performance and hypothesized solution packages for finding optimized energy efficient renovation package. For achieving cost optimum energy efficiency, several improvements are done regarding to the building envelope, lighting systems and mechanical systems substation.

Another important aspect of this thesis is related to calculation of cost of renovated packages according to ministry of environment and urbanism cost. This table cost are related to 2013 that is accepted in Turkey. Hence, the economic evaluation of renovation packages are accounted as EPBD recast 2010. Calculation period of packages as stated in EPBD is 20 years for non-residential buildings.

Inflation rate of Turkey according to the Regulation advice financial data gathered at Central Bank of Turkey, in 2013 is 7.5% and discount rate of Turkey according to recent statics of central bank is 5.5%. Moreover, exchange rate for conversion of Turkish Lira (TL) to Euro (€) is 2.9. Electricity unit price, which is taken from TEDAŞ (Turkish Electricity Distribution Company), is 0.3465 TL/kWh and Natural gas unit price is 0.105 TL/kWh according to İGDAŞ (Istanbul Gas Distribution Industry and Trade Incorporated Company).

For best determination in terms of minimum cost with optimum energy efficiency, simple paybacks periods and sensitivity analysis with variation discount rate and calculation period with a shorter (10 years) and longer (30 years) are calculated.

Moreover, all of these actions have done to exist identical building in cold climate zone (Erzurum) for reaching and comparing two different results.

Overall, in Istanbul's reference building and packages, electricity consumption is almost double to natural gas due to high consumption of lighting and cooling in contrast to natural gas. Conversely, in Erzurum's RB and most packages, which is located in cold climate zone of Turkey, natural gas consumption is higher than electricity. Moreover, natural gas fuel is used by boiler and electricity fuel, is used by electric chiller, lighting, equipment, fans and pumps.

By application of thermal insulation requirements of TS 825 standard on RB in Istanbul and Erzurum climate zone, total primary energy consumption have reduced by 23% and 31% respectively. In Istanbul by adding thermal insulation according to TS 825, natural gas consumption has varied from 42.5 kWh/m² year to 25.76 kWh/m² year while in Erzurum it's varied from 108.73 kWh/m² year to 57.87 kWh/m² year. Hence, primary energy saving of natural gas in Istanbul and Erzurum are 39.5% and 47% respectively.

Besides, primary energy saving from electricity in Istanbul and Erzurum are 14.5% and 7.5% respectively.

It can conclude that, by adding thermal insulation according to TS825 and window renovation from U-value $5.77 \text{ W/m}^2\text{k}$ to $1.8 \text{ W/m}^2\text{k}$, in Istanbul has 25% primary energy saving while in Erzurum has 34% primary energy saving.

From cost optimal point of view among all packages, by variation of discount rate to 3%, 4%, 5% and 6%, in Istanbul climate optimum cost level is same for all variation and it's Package 30 (chiller with 4 COP, 100% fluorescent lamp and lighting control). In Erzurum optimum cost level by variation of discount rate to 3% and 4% are belonged to P2 (First level Thermal insulation (TS825) + Glazing with U value $1.8 \text{ W/m}^2\text{k}$ + Lighting Control + 100% fluorescent lamp) and also by 5% and 6% discount rate optimum cost level changed to P31 (boiler 0.95 efficiency and 100% fluorescent lamp). In addition, by variation of calculation period from 20 years to 10 years and 30 years optimum cost level for Istanbul and Erzurum are package 30, package 31 respectively.

By comparison of all packages in Istanbul, it could derive that, Package 30 is the reasonable package, which is located in cost optimum ranges. This package measures are chiller with 4 COP, 100% fluorescent lamp and lighting control. Also, this package global cost is the lowest amount among with 34.69 €/m^2 and primary energy consumption of this package is $61.01 \text{ kWh/m}^2 \text{ year}$. In particular, primary energy saving is P30 is 52.5% and global cost variation of its is -51.2%. This package is recommended in Istanbul region due to having minimum payback times less than 2 years.

While, in Erzurum climate, Package 31 is the reasonable package, which is located in cost optimum ranges. This package global cost is the lowest amount among with 49.27 €/m^2 and primary energy consumption of this package is $95.4 \text{ kWh/m}^2 \text{ year}$. The measures of this package are boiler 0.95 efficiency and 100% fluorescent lamp. In particular, primary energy saving is P31 is 46.7% and global cost variation of it is -45.4%. Consequently, this package is recommended in Erzurum region due to having minimum payback times less than 2 years instead of package 2 with 6.4 years simple payback periods.

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APPENDICES

APPENDIX A: Global Cost calculation procedure

COMPARISON of PRIMARY ENERGY CONSUMPTION and GLOBAL COST						
	Building component	Package of energy efficiency measure	EP ₀ Primary Energy Consumption	Primary Energy Saving	GC Global Cost (calculation period: 20 years)	Global cost variation
			kWh/m ² year	%	TL/m ²	%
RB		Reference Building	128.40	0%	€ 71.08	0%
E1-1	External Wall insulation	U= 0,57 W/m ² K	101.29	21.12%	€ 66.92	-5.9%
E1-2		U= 0,45 W/m ² K	100.56	21.68%	€ 67.30	-5.3%
E1-3		U= 0,30 W/m ² K	99.65	22.39%	€ 70.29	-1.1%
E2-1	Roof	U= 0,38 W/m ² K	107.39	16.36%	€ 60.80	-14.5%
E2-2		U= 0,30 W/m ² K	107.37	16.38%	€ 60.97	-14.2%
E2-3		U= 0,20 W/m ² K	107.34	16.40%	€ 61.35	-13.7%
E3-1	Ground Floor	U= 0,57 W/m ² K	106.93	16.72%	€ 60.72	-14.6%
E3-2		U= 0,50 W/m ² K	107.43	16.33%	€ 61.16	-14.0%
E3-3		U= 0,40 W/m ² K	106.79	16.83%	€ 60.89	-14.3%
E1-1-1	Thermal insulation	First level	99.16	22.77%	€ 68.45	-3.7%
E2-2-2		Second level	98.19	23.53%	€ 69.00	-2.9%
E3-3-3		Third level	97.00	24.45%	€ 72.39	1.8%
E4	windows	U= 1.8 W/m ² K	105.81	17.59%	€ 59.59	-16.2%
E5		U= 1.49 W/m ² K	104.82	18.36%	€ 59.17	-16.7%
E6		U= 1.10 W/m ² K	104.60	18.54%	€ 59.54	-16.2%
E7-1	Thermal insulation+windows	First level thermal insulationGlazing Uw=1.8 W/m2K	96.81	24.60%	€ 67.36	-5.2%
E8-2		Second level thermal insulationGlazing Uw= 1.49 W/m2K	94.41	26.47%	€ 67.16	-5.5%
E9-3		Third Level thermal insulationGlazing Uw= 1,1 W/m2K	92.78	27.74%	€ 70.33	-1.1%
L1	lighting control	Lighting control	80.79	37.08%	€ 42.50	-40.2%
L2	Lighting Type	Lighting type = 70% flu,30%inc	93.79	26.95%	€ 51.99	-26.9%
L3		Lighting type = 100% fluorescent	73.00	43.14%	€ 38.06	-46.4%
L4	lighting type+lighting control	Lighting control Lighting type = 70% flu,30%inc	74.20	42.21%	€ 39.54	-44.4%
L5		Lighting control Lighting type =100% flu	63.72	50.37%	€ 32.37	-54.5%
S1		Hot water boiler (Nominal 0.9)	103.96	19.03%	€ 59.75	-15.9%
S2		Hot water boiler (Nominal 0.95)	102.29	20.33%	€ 59.29	-16.6%
S3		Radiant floor (heating & cooling)	108.53	15.47%	€ 73.28	3.1%
S4		Electrical chiller (EER 2.5 COP)	101.86	20.67%	€ 59.77	-15.9%
S5		Electrical chiller (EER 4.0 COP)	99.63	22.41%	€ 58.85	-17.2%
S6		Hot water boiler (Nominal 0.9)	99.99	22.12%	€ 60.64	-14.7%
S7		Hot water boiler (Nominal 0.95)	96.09	25.16%	€ 59.27	-16.6%
S8		Radiant floor (Heating) Hot water boiler (Nominal 0.9)	94.37	26.51%	€ 63.12	-11.2%
S9		Radiant floor (Heating) Hot water boiler (Nominal 0.95)	92.50	27.96%	€ 63.68	-10.4%
S10		Radiant floor (Heating & cooling) Hot water boiler (Nominal 0.9) Electrical chiller (EER 2.5 COP)	100.53	21.71%	€ 74.09	4.2%
S11		Radiant panel (Heating & cooling) Hot water boiler (Nominal 0.95) Electrical chiller (EER 4.0 COP)	96.65	24.73%	€ 72.77	2.4%
S12		Radiant floor (Heating)	98.79	23.06%	€ 63.35	-10.9%
S13		Radiant floor (Heating) Hot water boiler (Nominal 0.9) Electrical chiller (EER 2.5 COP)	94.37	26.51%	€ 66.33	-6.7%
S14		Radiant floor (Heating) Hot water boiler (Nominal 0.95) Electrical chiller (EER 4.0 COP)	92.50	27.96%	€ 66.23	-6.8%

Figure A.1: Comparison of Primary Energy Consumption and Global Cost of Energy Efficiency Measures

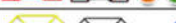
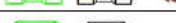
COMPARISON of PRIMARY ENERGY CONSUMPTION and GLOBAL COST					
Package of energy efficiency measure		EP _d Primary Energy Consumption	Primary Energy Saving	GC Global Cost (calculation period=20 years)	Global cost variation
		kWh/m ² year	%	€/m ²	%
RB	RB	128.40	0%	€ 71.08	0%
P1		62.85	51.1%	€ 47.6	-33.0%
P2		50.66	60.5%	€ 39.6	-44.3%
P3		59.71	53.5%	€ 45.7	-35.7%
P4		80.94	37.0%	€ 60.3	-15.2%
P5		49.47	61.5%	€ 40.1	-43.6%
P6		58.54	54.4%	€ 46.11	-35.1%
P7		49.48	61.5%	€ 43.91	-38.2%
P8		78.33	39.0%	€ 63.10	-11.2%
P9		59.56	53.6%	€ 51.69	-27.3%
P10		97.40	24.1%	€ 60.56	-14.8%
P11		93.62	27.1%	€ 60.11	-15.4%
P12		53.41	58.4%	€ 49.28	-30.7%
P13		44.42	65.4%	€ 50.96	-28.3%
P14		79.59	38.0%	€ 79.05	11.2%
P15		91.76	28.5%	€ 69.67	-2.0%
P16		37.61	70.7%	€ 53.37	-24.9%
P17		70.18	45.3%	€ 61.50	-13.5%
P18		56.61	55.9%	€ 57.55	-19.0%
P19		43.31	66.3%	€ 51.99	-26.9%
P20		49.16	61.7%	€ 56.99	-19.8%
P21		40.59	68.4%	€ 45.93	-35.4%
P22		72.69	43.4%	€ 75.55	6.3%
P23		83.04	35.3%	€ 72.11	1.4%
P24		40.70	68.3%	€ 53.65	-24.5%
P25		43.92	65.8%	€ 57.08	-19.7%
P26		64.44	49.8%	€ 54.46	-23.4%
P27		73.51	42.8%	€ 44.12	-37.9%
P28		94.33	26.5%	€ 65.45	-7.9%
P29		57.57	55.2%	€ 45.50	-36.0%
P30		61.01	52.5%	€ 34.69	-51.2%
P31		66.05	48.6%	€ 37.37	-47.4%

Figure A.2: Comparison of Primary Energy Consumption and Global Cost of final packages

Table A.1: Energy cost of final packages

	Total Electricity demand kwh	Total Natural Gas demand kwh	Electricity cost TL	Natural Gas cost TL	Total cost TL
P1	125763.16	313638.26	43,576.93 ₺	32,932.02 ₺	76,508.95 ₺
P2	70591.93	325442.75	24,460.10 ₺	34,171.49 ₺	58,631.59 ₺
P3	115309.16	307878.25	39,954.62 ₺	32,327.22 ₺	72,281.84 ₺
P4	225445.47	254133.7	78,116.86 ₺	26,684.04 ₺	104,800.89 ₺
P5	70428.82	314330.57	24,403.59 ₺	33,004.71 ₺	57,408.30 ₺
P6	115327.15	296384.71	39,960.86 ₺	31,120.39 ₺	71,081.25 ₺
P7	72695.24	309026.56	25,188.90 ₺	32,447.79 ₺	57,636.69 ₺
P8	223445.89	233464.18	77,424.00 ₺	24,513.74 ₺	101,937.74 ₺
P9	126949.55	278866.37	43,988.02 ₺	29,280.97 ₺	73,268.99 ₺
P10	277682.76	290714.76	96,217.08 ₺	30,525.05 ₺	126,742.13 ₺
P11	268785.19	275019.65	93,134.07 ₺	28,877.06 ₺	122,011.13 ₺
P12	110216.57	258644.03	38,190.04 ₺	27,157.62 ₺	65,347.66 ₺
P13	64069.07	280291.61	22,199.93 ₺	29,430.62 ₺	51,630.55 ₺
P14	258158.29	163753.5	89,451.85 ₺	17,194.12 ₺	106,645.96 ₺
P15	283394.14	222426.79	98,196.07 ₺	23,354.81 ₺	121,550.88 ₺
P16	54023.27	237842.7	18,719.06 ₺	24,973.48 ₺	43,692.55 ₺
P17	200573.51	208287.52	69,498.72 ₺	21,870.19 ₺	91,368.91 ₺
P18	111736.85	286167.95	38,716.82 ₺	30,047.63 ₺	68,764.45 ₺
P19	85838.69	218133.3	29,743.11 ₺	22,904.00 ₺	52,647.10 ₺
P20	101649.18	237608.83	35,221.44 ₺	24,948.93 ₺	60,170.37 ₺
P21	59616.87	253531.89	20,657.25 ₺	26,620.85 ₺	47,278.09 ₺
P22	240971.55	137362.82	83,496.64 ₺	14,423.10 ₺	97,919.74 ₺
P23	270652.59	167835.26	93,781.12 ₺	17,622.70 ₺	111,403.82 ₺
P24	63493.97	245485.1	22,000.66 ₺	25,775.94 ₺	47,776.60 ₺
P25	86128.46	223350.09	29,843.51 ₺	23,451.76 ₺	53,295.27 ₺
P26	102136.83	384821.95	35,390.41 ₺	40,406.30 ₺	75,796.72 ₺
P27	146191.79	368974	50,655.46 ₺	38,742.27 ₺	89,397.73 ₺
P28	211732.51	416526.3	73,365.31 ₺	43,735.26 ₺	117,100.58 ₺
P29	65961.88	403490.44	22,855.79 ₺	42,366.50 ₺	65,222.29 ₺
P30	61894.85	446507.86	21,446.57 ₺	46,883.33 ₺	68,329.89 ₺
P31	119350.21	359922.61	41,354.85 ₺	37,791.87 ₺	79,146.72 ₺

Table A.2: Global cost calculation procedure for final packages

Energy efficiency measure		Lifespan YEARS	Calculation period YEARS	Discount rate %	Initial investment costs TL	Energy costs TL / YEAR	Inflation rate %	Running costs TL/YEAR	Replacement costs TL/YEAR	Residual value TL	GLOBAL COST TL	GLOBAL COST €	GLOBAL COST TL/m2	GLOBAL COST €/m2
RB	/	20	5.50%	/	165,837.39 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	18,520.89 ₺	2,002,082.21 ₺	€ 690,373.17	206.12	71.08	
Package 1	First level Thermal insulation	40	20	5.50%	409,382.30 ₺	76,508.95 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	66,496.29 ₺	1,341,091.72 ₺	€ 462,445.42	138.07	47.61
	Glazing Uw= 2.51 W/m2K	40			24,392.61 ₺			0.00 ₺		3,962.11 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Lighting type =70% flu,30%inc	15			32,349.00 ₺			0.00 ₺		-3,502.98 ₺				
Package 2	First level Thermal insulation	40	20	5.50%	409,382.30 ₺	58,631.59 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	66,496.29 ₺	1,114,779.78 ₺	€ 384,406.82	114.77	39.58
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Lighting type =100% flu	20			19,320.00 ₺			0.00 ₺		0.00 ₺				
Package 3	First level Thermal insulation	40	20	5.50%	409,382.30 ₺	72,281.84 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	66,496.29 ₺	1,286,644.88 ₺	€ 443,670.65	132.47	45.68
	Glazing Uw= 1.1 W/m2K	40			45,714.60 ₺			0.00 ₺		7,425.46 ₺				
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
Package 4	Second level Thermal insulation	40	20	5.50%	441,096.25 ₺	104,800.89 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	71,647.61 ₺	1,698,403.87 ₺	€ 585,656.51	174.86	60.30
	Glazing Uw= 2.51 W/m2k	40			24,392.61 ₺			0.00 ₺		3,962.11 ₺				
	Lighting type =70% flu,30%inc	15			32,349.00 ₺			0.00 ₺		-3,502.98 ₺				
Package 5	Second level Thermal insulation	40	20	5.50%	441,096.25 ₺	57,408.30 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	71,647.61 ₺	1,128,815.65 ₺	€ 389,246.78	116.22	40.07
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
Package 6	Second level Thermal insulation	40	20	5.50%	441,096.25 ₺	71,081.25 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	71,647.61 ₺	1,298,860.02 ₺	€ 447,882.77	133.72	46.11
	Glazing Uw= 1.1 W/m2K	40			45,714.60 ₺			0.00 ₺		7,425.46 ₺				
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
Package 7	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	57,636.69 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	92,822.44 ₺	1,236,871.04 ₺	€ 426,507.25	127.34	43.91
	Glazing Uw= 2.51 W/m2k	40			24,392.61 ₺			0.00 ₺		3,962.11 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
Package 8	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	101,937.74 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	92,822.44 ₺	1,777,236.74 ₺	€ 612,840.25	182.98	63.10
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Lighting type =70% flu,30%inc	15			32,349.00 ₺			0.00 ₺		-3,502.98 ₺				
Package 9	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	73,268.99 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	92,822.44 ₺	1,455,981.50 ₺	€ 502,062.59	149.90	51.69
	Glazing Uw= 1.1 W/m2K	40			45,714.60 ₺			0.00 ₺		7,425.46 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Lighting type =70% flu,30%inc	15			32,349.00 ₺			0.00 ₺		-3,502.98 ₺				
Package 10	Glazing Uw= 1.49 W/m2k	40	20	5.50%	29,002.77 ₺	126,742.13 ₺	7.50%	0.00 ₺	12,271.24 ₺	4,710.94 ₺	1,705,966.25 ₺	€ 588,264.22	175.64	60.56
	Hot water boiler (Nomianal 0.9)	20			47,900.00 ₺			2,692.12 ₺		0.00 ₺				
	Electrical chiller (Eff 2.5 COP)	20			75,250.00 ₺			1,505.00 ₺		0.00 ₺				
Package 11	Glazing Uw= 1.1 W/m2K	40	20	5.50%	45,714.60 ₺	122,011.13 ₺	7.50%	0.00 ₺	12,271.24 ₺	7,425.46 ₺	1,693,286.45 ₺	€ 583,891.88	174.33	60.11
	Hot water boiler (Nomianal 0.95)	20			55,000.00 ₺			2,834.12 ₺		0.00 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				

Table A.3: Global cost calculation procedure for final packages

Energy efficiency measure		Lifespan YEARS	Calculation period YEARS	Discount rate %	Initial investment costs TL	Energy costs TL / YEAR	Inflation rate %	Running costs TL/YEAR	Replacement costs TL/YEAR	Residual value TL	GLOBAL COST TL	GLOBAL COST €	GLOBAL COST TL/m2	GLOBAL COST €/m2
RB		/	20	5.50%	/	165,837.39 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	18,520.89 ₺	2,002,082.21 ₺	€ 690,373.17	206.12	71.08
Package 12	First level Thermal insulation	40	20	5.50%	409,382.30 ₺	65,347.66 ₺	7.50%	0.00 ₺	12,271.24 ₺	66,496.29 ₺	1,388,227.03 ₺	€ 478,698.98	142.93	49.28
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Hot water boiler (Nomianal 0.95)	20			55,000.00 ₺			2,834.12 ₺		0.00 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				
Package 13	Lighting type =70% flu,30%inc	15	20	5.50%	32,349.00 ₺	51,630.55 ₺	7.50%	0.00 ₺	0.00 ₺	-3,502.98 ₺	1,435,386.69 ₺	€ 494,960.93	147.78	50.96
	First level Thermal insulation	40			409,382.30 ₺			0.00 ₺		66,496.29 ₺				
	Glazing Uw= 1.1 W/m2K	40			45,714.60 ₺			0.00 ₺		7,425.46 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			4,466.26 ₺		43,118.88 ₺				
Package 14	Lighting type =100% flu	15	20	5.50%	19,320.00 ₺	106,645.96 ₺	7.50%	0.00 ₺	0.00 ₺	-2,092.11 ₺	2,226,738.14 ₺	€ 767,840.74	229.25	79.05
	First level Thermal insulation	40			409,382.30 ₺			0.00 ₺		66,496.29 ₺				
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			3,981.90 ₺		43,118.88 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				
Package 15	Hot water boiler (Nomianal 0.95)	20	20	5.50%	55,000.00 ₺	121,550.88 ₺	7.50%	1,100.00 ₺	12,271.24 ₺	0.00 ₺	1,962,523.08 ₺	€ 676,732.10	202.05	69.67
	First level Thermal insulation	40			409,382.30 ₺			0.00 ₺		66,496.29 ₺				
	Hot water boiler (Nomianal 0.9)	20			47,900.00 ₺			2,692.12 ₺		0.00 ₺				
	Electrical chiller (Eff 2.5 COP)	20			75,250.00 ₺			1,505.00 ₺		0.00 ₺				
	First level Thermal insulation	40			409,382.30 ₺			0.00 ₺		66,496.29 ₺				
Package 16	Glazing Uw= 1.49 W/m2k	40	20	5.50%	29,002.77 ₺	43,692.55 ₺	7.50%	0.00 ₺	0.00 ₺	4,710.94 ₺	1,503,182.82 ₺	€ 518,338.90	154.76	53.37
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			3,981.90 ₺		43,118.88 ₺				
	Hot water boiler (Nomianal 0.95)	20			55,000.00 ₺			1,100.00 ₺		0.00 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				
Package 17	Lighting type =100% flu	15	20	5.50%	19,320.00 ₺	91,368.91 ₺	7.50%	0.00 ₺	12,271.24 ₺	-2,092.11 ₺	1,732,400.82 ₺	€ 597,379.59	178.36	61.50
	Second level Thermal insulation	40			441,096.25 ₺			0.00 ₺		71,647.61 ₺				
	Glazing Uw= 1.1 W/m2K	40			45,714.60 ₺			0.00 ₺		7,425.46 ₺				
	Lighting type =70% flu,30%inc	15			32,349.00 ₺			0.00 ₺		-3,502.98 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				
Package 18	Hot water boiler (Nomianal 0.95)	20	20	5.50%	55,000.00 ₺	68,764.45 ₺	7.50%	2,834.12 ₺	0.00 ₺	0.00 ₺	1,621,066.86 ₺	€ 558,988.57	166.90	57.55
	Second level Thermal insulation	40			441,096.25 ₺			0.00 ₺		71,647.61 ₺				
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			4,466.26 ₺		43,118.88 ₺				
	Second level Thermal insulation	40			441,096.25 ₺			0.00 ₺		71,647.61 ₺				
Package 19	Glazing Uw= 1.1 W/m2K	40	20	5.50%	45,714.60 ₺	52,647.10 ₺	7.50%	0.00 ₺	0.00 ₺	7,425.46 ₺	1,464,416.39 ₺	€ 504,971.17	150.77	51.99
	Radiant panel (Heating)	30			285,090.00 ₺			0.00 ₺		30,871.60 ₺				
	Electrical chiller (Eff 2.5 COP)	20			75,250.00 ₺			3,239.12 ₺		0.00 ₺				
	Hot water boiler (Nomianal 0.9)	20			47,900.00 ₺			958.00 ₺		0.00 ₺				
	Second level Thermal insulation	40			441,096.25 ₺			0.00 ₺		71,647.61 ₺				
Package 20	Lighting Control	20	20	5.50%	7,350.00 ₺	60,170.37 ₺	7.50%	0.00 ₺	0.00 ₺	0.00 ₺	1,605,202.65 ₺	€ 553,518.16	165.26	56.99
	Lighting type =70% flu,30%inc	15			32,349.00 ₺			0.00 ₺		-3,502.98 ₺				
	Hot water boiler (Nomianal 0.95)	20			55,000.00 ₺			1,325.21 ₺		0.00 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			3,981.90 ₺		43,118.88 ₺				
	Second level Thermal insulation	40			441,096.25 ₺			0.00 ₺		71,647.61 ₺				

Table A.4: Global cost calculation procedure for final packages

Energy efficiency measure		Lifespan YEARS	Calculation period YEARS	Discount rate %	Initial investment costs TL	Energy costs TL / YEAR	Inflation rate %	Running costs TL/YEAR	Replacement costs TL/YEAR	Residual value TL	GLOBAL COST TL	GLOBAL COST €	GLOBAL COST TL/m2	GLOBAL COST €/m2
RB		/	20	5.50%	/	165,837.39 ₺	7.50%	2,218.48 ₺	12,271.24 ₺	18,520.89 ₺	2,002,082.21 ₺	€ 690,373.17	206.12	71.08
Package 21	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	47,278.09 ₺	7.50%	0.00 ₺	12,271.24 ₺	92,822.44 ₺	1,293,598.82 ₺	€ 446,068.56	133.18	45.93
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Hot water boiler (Nominal 0.95)	20			55,000.00 ₺			1,100.00 ₺		0.00 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			3,579.12 ₺		0.00 ₺				
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
Package 22	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	97,919.74 ₺	7.50%	0.00 ₺	0.00 ₺	92,822.44 ₺	2,127,974.97 ₺	€ 733,784.47	219.09	75.55
	Glazing Uw= 1.1 W/m2K	40			45,714.60 ₺			0.00 ₺		7,425.46 ₺				
	Radiant panel (Heating)	30			285,090.00 ₺			2,850.90 ₺		30,871.60 ₺				
	Electrical chiller (Eff 2.5 COP)	20			75,250.00 ₺			1,505.00 ₺		0.00 ₺				
	Hot water boiler (Nominal 0.9)	20			47,900.00 ₺			958.00 ₺		0.00 ₺				
Package 23	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	111,403.82 ₺	7.50%	0.00 ₺	12,271.24 ₺	92,822.44 ₺	2,031,163.73 ₺	€ 700,401.29	209.12	72.11
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Hot water boiler (Nominal 0.95)	20			55,000.00 ₺			2,834.12 ₺		0.00 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				
Package 24	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	47,776.60 ₺	7.50%	0.00 ₺	0.00 ₺	92,822.44 ₺	1,511,083.09 ₺	€ 521,063.13	155.57	53.65
	Glazing Uw= 1.49 W/m2k	40			29,002.77 ₺			0.00 ₺		4,710.94 ₺				
	Lighting Control	20			7,350.00 ₺			0.00 ₺		0.00 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			4,466.26 ₺		43,118.88 ₺				
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
Package 25	Third level Thermal insulation	40	20	5.50%	571,458.40 ₺	53,295.27 ₺	7.50%	0.00 ₺	0.00 ₺	92,822.44 ₺	1,607,678.57 ₺	€ 554,371.92	165.52	57.08
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
	Radiant panel (Heating)	30			285,090.00 ₺			2,850.90 ₺		30,871.60 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				
	Hot water boiler (Nominal 0.95)	20			55,000.00 ₺			1,100.00 ₺		0.00 ₺				
Package 26	Lighting Control	20	20	5.50%	7,350.00 ₺	75,796.72 ₺	7.50%	0.00 ₺	0.00 ₺	0.00 ₺	1,534,101.96 ₺	€ 529,000.68	157.94	54.46
	Lighting type =70% flu,30%inc	15			32,349.00 ₺			0.00 ₺		-3,502.98 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			3,981.90 ₺		43,118.88 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			1,845.00 ₺		0.00 ₺				
	Hot water boiler (Nominal 0.95)	20			55,000.00 ₺			1,100.00 ₺		0.00 ₺				
Package 27	Lighting Control	20	20	5.50%	7,350.00 ₺	89,397.73 ₺	7.50%	0.00 ₺	12,271.24 ₺	0.00 ₺	1,242,744.55 ₺	€ 428,532.60	127.95	44.12
	Hot water boiler (Nominal 0.9)	20			47,900.00 ₺			2,692.12 ₺		0.00 ₺				
	Electrical chiller (Eff 2.5 COP)	20			75,250.00 ₺			1,505.00 ₺		0.00 ₺				
Package 28	Lighting type =70% flu,30%inc	15	20	5.50%	32,349.00 ₺	117,100.58 ₺	7.50%	0.00 ₺	0.00 ₺	-3,502.98 ₺	1,843,693.25 ₺	€ 635,756.29	189.82	65.45
	Radiant panel (heating & cooling)	30			398,190.00 ₺			4,466.26 ₺		43,118.88 ₺				
Package 29	Lighting Control	20	20	5.50%	7,350.00 ₺	65,222.29 ₺	7.50%	0.00 ₺	0.00 ₺	0.00 ₺	1,281,686.51 ₺	€ 441,960.87	131.96	45.50
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
	Radiant panel (heating & cooling)	30			398,190.00 ₺			3,981.90 ₺		43,118.88 ₺				
	Hot water boiler (Nominal 0.95)	20			55,000.00 ₺			1,325.21 ₺		0.00 ₺				
Package 30	Lighting Control	20	20	5.50%	7,350.00 ₺	68,329.89 ₺	7.50%	0.00 ₺	12,271.24 ₺	0.00 ₺	977,199.53 ₺	€ 336,965.36	100.61	34.69
	Lighting type =100% flu	15			19,320.00 ₺			0.00 ₺		-2,092.11 ₺				
	Electrical chiller (Eff 4.0 COP)	20			92,250.00 ₺			3,838.27 ₺		0.00 ₺				
Package 31	Lighting type =100% flu	15	20	5.50%	19,320.00 ₺	79,146.72 ₺	7.50%	0.00 ₺	12,271.24 ₺	-2,092.11 ₺	1,052,556.22 ₺	€ 362,950.42	108.37	37.37
	Hot water boiler (Nominal 0.95)	20			55,000.00 ₺			3,059.33 ₺		0.00 ₺				

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