ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

CALCULATION OF COST OPTIMAL LEVELS OF MINIMUM ENERGY PERFORMANCE REQUIREMENTS FOR OFFICE BUILDING RETROFITS

M.Sc. THESIS

Neşe GANİÇ

Department of Architecture

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JUNE 2012

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

MİMİMUM ENERJİ PERFORMANS GEREKSİNİMLERİNE İLİŞKİN OPTİMUM MALİYET DÜZEYİNİN OFİS BİNALARINDAKİ İYİLEŞTİRMELER İÇİN HESAPLANMASI

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ABBREVIATIONS

EPBD	**:** Energy Performance of Buildings Directive
EN	**:** European Standard
TS	**:** Turkish Standard
BEP-TR	**:** National Building Energy Performance Calculation Methodology of Turkey
EU	**:** European Union
MS	**:** Member States

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CALCULATION OF COST OPTIMAL LEVELS OF MINIMUM ENERGY PERFORMANCE REQUIREMENTS OF OFFICE BUILDING RETROFITS

SUMMARY

Energy performance of buildings has become a key issue since buildings are responsible from 40% of countries' energy consumption and 36% of CO_2 emmissions in Europe. Therefore, energy used in buildings is restricted by EU legislations. Energy Performance of Buildings Directive (EPBD) is the main legal tool which aims tolimit energy consumption and to increase efficiency in buildings sector. EPBD also requires to certificate buildings by using a national method. This directive is adopted in 2002 and recast in 2010 with new requirements.

Recast EPBD clarifies and strengthens the requirements of EPBD and introduces EU targets regrding year 2020: reducing greenhouse gas emmissions, reducing total energy consumption and ensuring all new buildings are nearly zero energy buildings. Besides, calculations on cost optimal levels of minimum energy performance requirements and adopting this calculation into the national energy performance calulation methods is obliged with recast EPBD.

Cost optimality calculation includes several phases such as establishing reference building and defining minimum energy performance requirements, and also calculations of primary energy and overall cost in order to derive cost optimal level of energy performance of the reference buildings. In EU countries, several national studies are ongiong in order to identify cost optimal levels using required steps.

Turkey, as a candidate country of European Union, enacted relevant legislation and launched building energy performance certification with the national calculation methodology, Bep-Tr, based on EPBD requirements. Therefore, necessary further study is to adopt cost optimality calculations to the national methodology.

In this thesis, the methodology of cost optimality calculations and priority of the implementation for Turkey is discussed. Through a case study, an example office building, that is assumed as an existing building, is analysed in terms of cost optimal levels of retrofit actions applied to the building. The method, which is required by recast EPBD, is followed in the case study considering national onditions.

Evaluation of primary energy use is performed by using Energy Plus dynamic simulation tool for two diffrernt climatic regions of Turkey: hot humid climate and tempered dry climate. Global costs are calculated for different calculation periods in accordance with related standard. At last, primary energy and global cost calculations put together in order to derive cost optimal levels.

In conclusion, importance of the cost optimal level calculations for Turkey is displayed with the analyses and results. Also necessary further national studies are explained.

MİMİMUM ENERJİ PERFORMANSI GEREKSİNİMLERİNİN OPTİMUM MALİYET DÜZEYİNİN OFİS BİNALARINDAKİ İYİLEŞTİRMELER İÇİN HESAPLANMASI

ÖZET

Son yıllarda ihtiyaçların artmasına bağlı olarak enerji tüketiminin artışı, fosil kaynakların tükenmesi ve buna bağlı olarak enerji fiyatlarındaki yükselişş, günümüzde küresel ısınmaya ve sürdürülebilirliğe etki eden en önemli etkenlerdir. Bu nedenle, tüm dünyada enerji tüketimini azaltacak yönde tedbirler uygulanmaya başlanmıştır. Avrupa'da da bu konuda önemli adımlar atılmış, yasal düzenlemeler oluşturulmuştur.

Enerji tüketimini azaltma yönündeki hedeflerde, binalarda enerji verimliliği önemli rol oynamaktadır. Avrupa'da enerji tüketiminin %40'ı ve karbon salımının %36'sı binalardan kaynaklanmaktadır. Bu nedenle, binaların enerji performansının iyileştirilmesi önemli bir toplumsal ve ekonomik gereklilik haline gelmiştir.

Binalarda enerji performansını arttırmak amacıyla, Avrupa Birliği (AB) tarafından 2002 yılında Bina Enerji Performansı Direktifi (EPBD) yayımlanmıştır. Bu direktif ile, yeni ve mevcut binalarda, yasal mevzuat ile tanımlanmış olan minimum enerji performans gereksinimlerinin sağlanması, binaların enerji performansının hesaplanması için ulusal yöntemlerin geliştirilmesi ve bu yolla tüm binaların sertifikalandırılması, ayrıca binadaki aktif iklimlendirme sistemlerinin periyodik olarak denetlenmesi zorunlu kılınmaktadır.

EPBD kapsamında, Avrupa Birliği üyesi ve aday ülkeler kendi yasal mevzuatlarını geliştirmiş ve sertifikalandırma amacıyla kullanılacak olan ulusal bina enerji performansı hesap yöntemlerini oluşturmuştur.

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

2010 yılında EPBD, yeni gerekliliklere göre revize edilmiştir. Bu revizyonla, mevcut direktifin zorunlu kıldığı yükümlülüklere açıklık getirilmekle birlikte, yeni hedefler de ortaya konmuştur. 2020 yılı için; sera gazı salımının 1990 yılı düzeyinin %20 altına çekilmesi, Avrupa Birliği'nin enerji tüketiminin %20 azaltılması, kullanılan enerjinin %20'sinin yenilenebilir kaynaklardan sağlanması ve tüm binaların neredeyse sıfır enerjili olması hedeflenmektedir. Bu direktifle, minimum enerji performans gereksinimlerine ilişkin optimum maliyet düzeyinin hesaplanması ve bu hesaplamanın ulusal bina enerji performansı hesap metotlarına entegre edilmesi tüm ülkeler için zorunlu kılınmıştır.

Avrupa Birliği ülkeleri, yeni direktifin getirdiği zorunluluklar üzerine, enerji performans gereksinimlerinin optimum maliyet düzeyleri ile ilgili çalışmaları sürdürmektedir. Enerjisinin yaklaşık %80'ini ithal eden Türkiye için de büyük öneme sahip olan maliyet etkin enerji verimliliği ile ilgili yasal prosedür ülkemizde henüz oluşturulmamıştır. Ancak bu çalışmanın en kısa sürede konusunda uzman kişilerce sürdürülmesi hem ekonomik hem de sosyal açıdan kritik bir konumdadır.

Bu tez çalışması kapsamında, Avrupa Birliği direktif ve yönetmeliklerinin öngördüğü şekliyle, minimum enerji performans gereksinimlerina ait optimum maliyet düzeylerinin nasıl hesaplanması gerektiği açıklanmış ve Türkiye için bina enerji performansı ulusal hesap metoduna adaptasyonunun önemine dikkat çekilmiştir. Alan çalışması olarak, mevcut olduğu kabul edilen bir ofis binası üzerine yapılabilecek enerji verimliliği için iyileştirme senaryolarının Türkiye koşullarında maliyet-optimum düzeyleri incelenmiştir.

Avrupa Komisyonu, yeni direktifle zorunlu hale getirilen optimum maliyet düzeyinin belirlenmesinde kullanılmak üzere bir metod oluşturmuş ve bu metodu 2012 yılı Ocak ayında yayınladığı bir yönetmelik ile detaylandırılmış, hesaplamalara açıklık getirmiştir. Bu yönetmeliğe göre, hesap metodu beş ana aşamadan oluşmaktadır. Bu aşamalar sırasıyla, referans binanın belirlenmesi, minimum enerji performans gereksinimlerinin tespit edilmesi, binada harcanan toplam enerjinin hesaplanması ve birincil enerjiye dönüştürülmesi, maliyetin hesaplanması ve son olarak da yapılmış olan enerji ve maliyet analizlerinin koordine edilerek maliyet-optimum enerji düzeyinin belirlenmesidir.

Referans binanın oluşturulması, hasaplamalar için temel adımı oluşturmaktadır. Enerji performansı gereksinimlerine ait optimum maliyet düzeylerini her bir bina için ayrı ayrı hesaplamak mümkün olamayacağından, belirlenen referans binalar, mevcut bina stoğunu ve inşa edilecek yeni binaların karakteristik özelliklerini en iyi temsil edecek binalar olmalıdırlar. Ancak, referans binaların belirlenebilmesi için gerekli bilgi ve istatistikler bir çok ülkede yetersiz durumdadır. Aynı şekilde, Türkiye'de de bu istatistikler yetersiz olduğundan, bu araştırma kapsamında kullanılmış olan ofis binası bir referans bina değil, daha önce Bep-Tr ile ilgili araştırma ve tez çalışmaları kapsamında kullanılan ofis binasından yararlanılarak türetilmiş bir sanal referans binadır. Bu bina üzerinde, iki farklı iklimde, çeşitli iyileştirme alternatifleri uygulanmış ve bu alternatiflerin etkisi enerji performansı ve maliyet açısından değerlendirilmiştir.

Örnek ofis binasına uygulanmak üzere belirlenen iyileştirme alternatifleri, hem tekil olarak analiz edilmiş, hem de birbirleri ile etkileşimleri değerlendirilmiştir. Enerji tüketimi ile ilgili hesaplarda, bir dinamik simülasyon aracı olan Energy Plus programı kullanılmıştır. Birincil enerji hesaplamaları için ise, Türkiye için belirlenen dönüşüm katsayıları uygulanmıştır.

Araştırmanın ana aşamalarından birini oluşturan maliyet hesaplamaları, ilgili direktif ve yönetmelikler ile belirtilen yönteme uygun olarak gerçekleştirilmişir. Ocak 2012'de yayımlanan AB yönetmeliğinde belirtildiği üzere, münferit faydayı göz önünde bulunduran yaklaşımlarla hesap yapmak mümkün olduğu gibi, sosyal faydayı göz önünde bulunduran makro-ekonomik yaklaşımlarla da maliyet hesaplaması yapılabilir.

Bu çalışma kapsamında, referans gösterilen EN 15459 standardı esas alınarak münferit perspektife göre hesaplama yapılmıştır. Bu hesaplamalarda, yalnızca planlanan değişiklik senaryosuna ilişkin maliyetler göz önünde bulundurulmuştur. Binanın ilk yapım maliyetleri değil, mevcut binaya uygulandığı varsayılan enerji iyileştirme senaryolarına ilişkin maliyetler hesaba katılmıştır.

İlgili fiyatlar, Bayındırlık ve İskan Bakanlığı, Yüksek Fen Kurulu Başkanlığı'nın yayımlamış olduğu, "2011 Yılı İnşaat ve Tesisat Birim Fiyatları" kitabından elde edilmiştir. Fiyatı bu dökümanda bulunmayan iyileştirmeler için ise, piyasadan elde edilen fiyatlar kullanılmıştır. Maliyet hesaplamalarında başlangıç yılı olarak 2011 yılı alınmıştır.

Yayımlanan son AB yönetmeliği ile, maliyet hesapları için esas alınması gereken hesaplama süresi; konutlar için 30 yıl, kamu binaları ve diğer konut işlevli olmayan binalar için ise 20 yıl olarak belirlenmiştir. Bu araştırma kapsamında, 5-30 yıl arasında çeşitli hesaplama süreleri analiz edilmiş ve sonuçları enerji performans düzeyleri ile birlikte karşılaştırılmıştır.

Yapılan hesaplamaların sonuçları, birincil enerji cinsinden tüketim – maliyet grafikleri ile sunulmuş; iklime, bina kabuğuna ve iklimlendirme sistemine ilişkin ölçütlerin enerji performansı ve maliyet üzerindeki etkileri ortaya konmuştur.

Sonuç olarak, minimum enerji performans gereksinimlerine ilişkin optimum maliyet düzeylerinin ulusal standartlarda belirlenmesi ile ilgili çalışmalarda, kullanılan verilerin ve yapılan kabullerin önemi açıkça görülmektedir. Bu nedenle, analizler yapılırken, gerek referans binaların, gerekse enerji performans parametrelerinin belirlenmesi aşamalarında oldukça detaylı ve uzun süreli araştırma çalışmaları gerekmektedir. Farklı özelliklerdeki çeşitli iklim bölgelerine sahip olan ülkemizde, özellikle iklim etkileri göz önünde bulundurulmak zorundadır. Maliyet bilgileri ve bu maliyetlerin geri ödeme süreleri ulusal koşullar dikkate alınarak araştırılmalı ve hesaplamalar titizlikle gerçekleştirilmelidir.

Bu tez çalışması ile, minimum enerji performans düzeylerine ilişkin optimum maliyet düzeylerinin belirlenmesinin, Türkiye için önemi ve bu hesaplamanın bina enerji performansı hesap metoduna adaptasyonun gerekliliği ortaya konmuş, bu adaptasyonun gerçekleştirilmesi için yapılması gereken çalışmalar ve yöntemin oluşturulması sırasında ortaya çıkabilecek sorunlar açıklanmıştır.

1. INTRODUCTION

Global warming, depletion of nonrenewable energy sources and correspondingly rising energy costs are current problems faced with the rapid increase in energy consumption within recent decades. Moreover, energy consumption in the world is expected to increase over the next half century [1]. Figure 1.1 shows the expected increment over the next years according to U.S. Energy Information Administration reports.

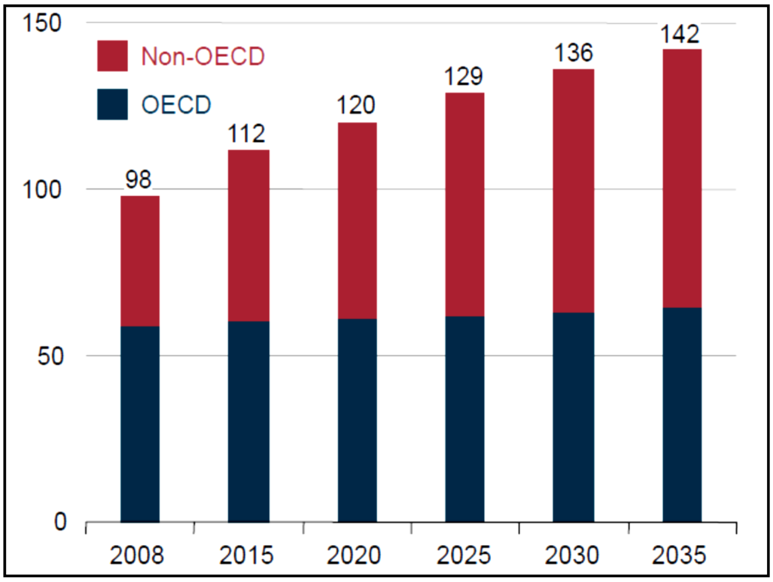


Figure 1.1 : Energy consumption projections [2].

Certainly, reducing emmissions 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 fosil fuels brings ever-increasing energy prices, world is forced to use less energy [3]. As given in Figure 1.2, energy prices are expected to rise in the near future according to projections.

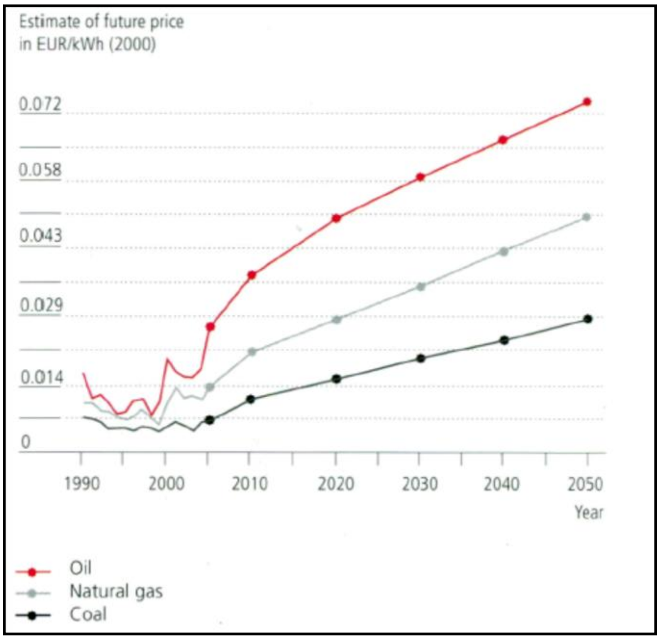


Figure 1.2 : Energy cost development [4].

Researchers and authorities put forward issues as utilization of alternative energy sources instead of fossil fuels and efficient use of energy in order to meet energy needs at the same time to decrease energy consumptions, CO_2 emmissions and solving environmental problems. However today recent energy technologies require significantly greater support and practical application [4]. For this reason, it is clear that efficient use of energy is the main source against alarming environmental aspects.

Energy efficiency is explained by International Energy Agency with following definition; something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input [2]. Energy efficiency is also a political, economical and environmental strategy in order to provide social and economical welfare. Therefore, energy use and CO_2 emmisions are ristricted and energy efficiency is supported by governments with legislations and subsidies. In policies, legislations and plans related with energy efficiency, buildings has an important key role in many countries.

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 CO_2 emmissions.

1.1 Energy Consumption of Buildings

On a global average, at least 40% of a country's energy is consumed by building-related acitivities such as construction, operation and maintenance, including power for heating, cooling, lighting and electrical plug loads. [4] Energy saving potential of buildings sector has a significant importance due to energy consumption precautions in buildings are both definite and practicable, also has remarkable saving outputs. Figure 1.3 shows the ratio of buildings sector in energy consumption.

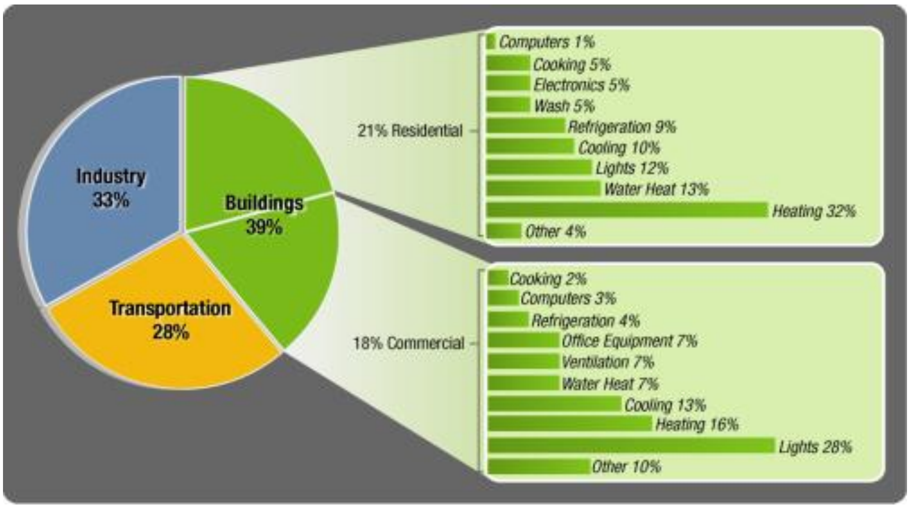


Figure 1.3 : Sectoral energy consumption [5].

According to researches in United States, in 2030 only residential buildings have 30% electricity saving potential with 1896 TWh and 28% natural gas saving potential with 5,47 quads and cost of these energy savings are 2,7 2007¢/kWh and 6,9 2007$/MBtu [6]. Considering other building typologies such as commercial buildings, educational buildings and health facilities energy saving potential of the whole buildings sector is infinitely increasing.

In Europe, also energy saving potential of buildings has a significant importance and there are studies on building energy consumption since 40% of energy consumption and 36% of EU CO_2 emissions occurs through buildings [7] Turkey performs studies by following events in Europe. According to Ministry of Energy and Natural Resources informations, Turkey has a great potential of energy savings in buildings sector with 30% and it is followed by industry with 20% and by transportation with 15% [8]. Consequently, it is clear that future energy savings in buildings sector is a key issue for Turkey in order to control and reduce consumptions.

However, providing energy savings during the operation of building can require additional investment costs. Due to there are many ways of designing energy efficient buildings or adopting efficiency measures to existing buildings, selection of the right alternative between these parameters depends on the energy consumption analyses and cost. Many lifecycle cost analyses of buildings have been done in order to evaluate investment and operational costs together. Recent legislative arrangements in Europe also requires to make the cost-optimal selection from the requirements of energy consumption in buildings.

During the operation of buildings, most of the energy is consumed for providing required temperature, humidity and illuminance level, in order to achieve thermal and visual comfort conditions for users by running mechanical end electrical systems. For this reason, identifying building energy consumption is not adequate for assessing efficiency of buildings. Energy consumed in buildings should be reduced without compromising thermal and visual comfort conditions. The main indicator which represents combination of standard comfort requirements and energy savings is, energy performance level of buildings.

1.2 Energy Performance of Buildings

Energy performance of a building means, the energy amount which is consumed or assessed to meet needs as heating, cooling, hot-water heating, ventilation and lighting with a standardized use of building [9].

For expressing the importance of energy performance of buildings, European Comission 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]. Therefore, by legal implementations about efficiency in building energy use, it is aimed to make significant percentage of savings in terms of both energy and economy in European Union.

Major driving force of legislation on building energy performance is Directive 2002/91/EC of the European Parliament. This European Directive aims to reduce energy consumption and CO_2 emmissions of buildings considering 2020 targets of European Union (EU) as 20% reduction in Greenhouse gases emmisions by 2020 and 20% energy savings. For this reason the directive requires Member States to ensure at least minimum energy performance requirements of new and existing buildings [7]. Directive 2002/91/EC is recast in 2010 with name of Directive 2010/31/EU. Recast Directive introduces requirements related with nearly zero-energy buildings and cost optimality.

Importance of energy performance of buildings for Turkey is definitely clear considering nearly 80% of required energy is met by import [10]. Therefore, in parallel with the recent process and researches in the world, Turkey enacted national legislations to provide energy efficiency in buildings. Energy Efficiency Law and Building Energy Performance Regulation are the main legislative instruments of this process.

1.3 Aim of the Thesis

In Europe, great energy saving potential of buildings is realised and national energy performance requirements are set within the context of Directive 2002/91/EC which is called as EPBD. National building energy performance methods are developed based on methodologies defined in the related standards and European countries started studies for mandatory certification of buildings. Following EPBD and its related standards, Turkey also set minimum energy performance requirements through Building Energy Performance Regulation and adopted a calculation methodology in national level as EU Member Countries [11].

Currently, EU countries are going ahead on the requirements of Directive 2010/31/EU, which is called recast EPBD. This recast directive requires to adopt cost-optimal calculations of minimum energy performance requirements into national methodologies which are established in accordance with EPBD. Several steps are defined for these calculations with a framework document and Member States are obliged to follow these steps.

In Turkey, not any legal procedure yet to adopt cost-optimality calculations into national building energy performance calculation methodology. However, especially in some climatic regions, cost-optimal levels of minimum energy performance requirements are crucial for Turkey. Adopting a methodology for calculating cost-optimal levels shall be one of the initial steps of further necessary studies in Turkey.

In this thesis research, it is aimed to introduce requirements of cost-optimal calculation methodology recommended by EU Comission and to provide awareness about essentials for Turkey’s national building energy performance methodology regarding recast EPBD.

After this introduction, in the second chapter, legal instruments and standards related with building energy performance calculations are introduced. EU obligations and requirements in Turkey are explained in detail including EPBD requirements. Calculation methodologies are described and Turkish National Building Energy Performance Calculation Methodology (Bep-Tr) is explained.

Then, concept of cost-optimality is clearly defined and all steps and requirements of calculating cost optimal levels of minimum energy performance requirements are explained together with a case study. As case study, a notional office building is examined. Possible retrofit actions for Turkey are analysed on the office building. In order to determine cost effective and cost optimal retrofit actions, process recommended by European Commission is followed and calculations are made by means of energy efficiencies and cost values. Energy Plus simulation tool is used for the energy performance calculations and cost calculations are made according to referred standard.

At the end, energy efficiency and cost of the different retrofit actions are compared for the same office building but for different climates of Turkey and cost optimal levels are presented with graphs. Further necessary studies and recommendations are also introduced in accordance with the results of this research.

2. BUILDING ENERGY PERFORMANCE LEGISLATION

Since buildings have the greatest potential of energy savings, several plans and studies are ongoing in order to increase energy efficiency of buildings. Therefore, legislative limitations about building energy consumptions are also on the agenda including renovation of existing buildings and energy efficient design for new buildings. In this chapter, legislative processes in EU and Turkey are discussed.

2.1 Legislation in Europe

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’’ [12].

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 [13]. Kyoto Protocol entered into force in 2005 and binding for also European Union countries.

European Parliment and Council reported that, buildings sector reached some benefits with the Directive 93/76/EEC, however the sector has a great unrealised 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 [9]. EPBD aims to set minimum energy performance standards for new and existing buildings in different categories.

In 2010, European Parliment 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 [14].

2.1.1 Energy Performance of Buildings Directive (EPBD)

Energy Performance of Buildings Directive (EPBD) is the main legal tool of European Union which 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, adoptation of national metholodogies 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 [9].

With EPBD, Member States are obliged to set their building energy performance calculation methodologies at national or regional level. For this 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 enegy 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 [15].

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 neccessities, a recast procedure took place for EPBD and with the final agreement, recast EPBD came into force in July 2010.

2.1.1.1 Building energy performance certification

Energy performance certification of buildings is one of the main requirements of EPBD for EU countries. Energy performance certificate must display the energy performance level of the building which is calculated according to national calculation methodologies. The certificate shall also include minimum energy performance requirements for comparison and furthermore, recommendations about cost-effective or cost-optimal renovation posibilities are required in the energy performance certificates. Energy performance certificates has a validity period which is maximum 10 years.

Most of the EU countries developed national certification systems in accordance with EPBD requirements. Since 2003, different approaches have been established and different layouts for energy performance certificates are formed. Figure 2.1 shows layouts of the energy performance certificates of different EU countries.

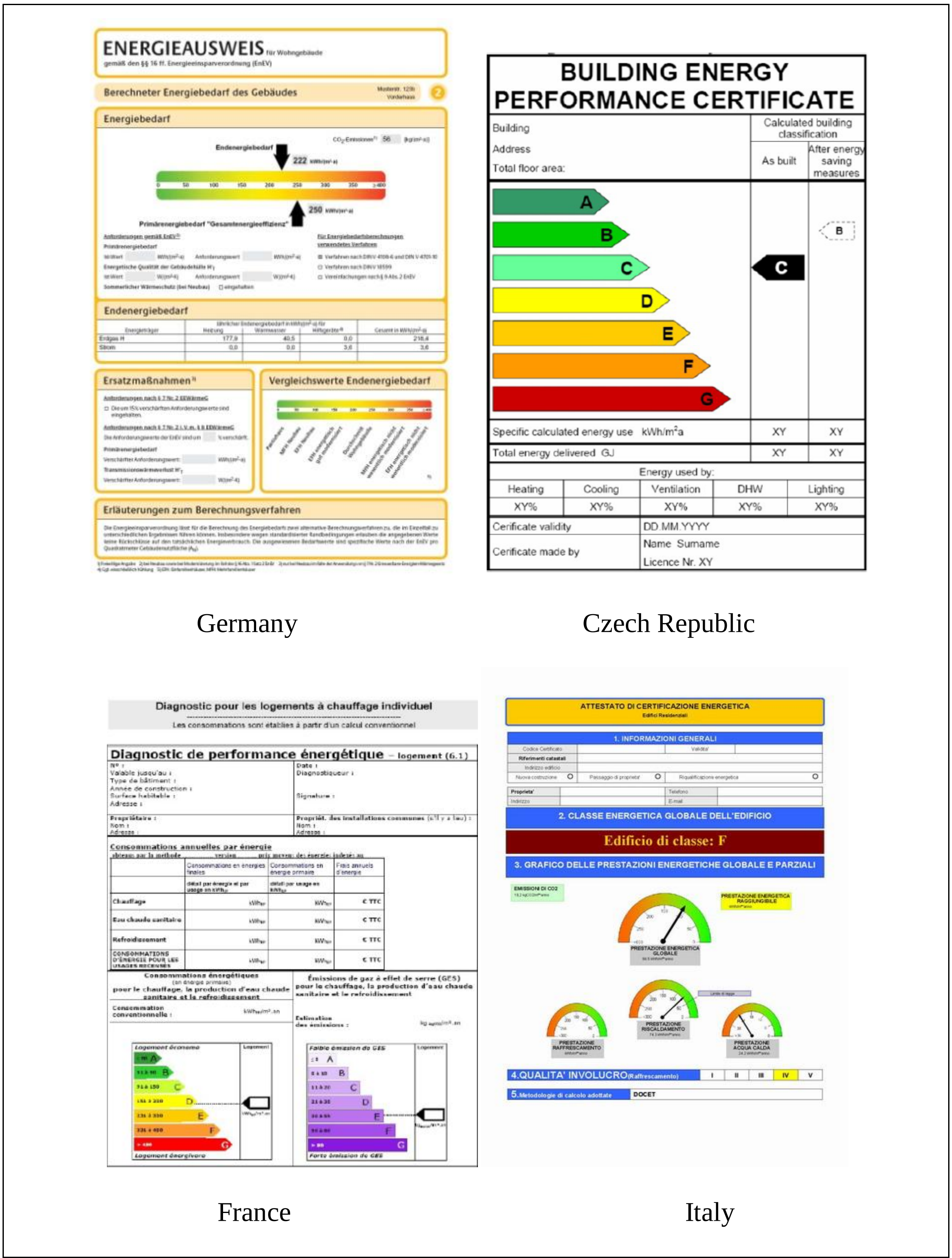


Figure 2.1 : Energy performance certificate layouts of some European Countries [16].

Proposed methods that used to assess energy performance ratings of buildings, ranges between ratings based on measured consumptions and calculated energy ratings by using dynamic energy performance simulation tools. All rating sytems have some advantages and disadvantages. Since energy measures of buildings are influenced by the occupant behaviours, in calculated rating systems which are using dynamic calculation method, energy performance of the building is assessed in a standardized use of the buildings however, these calculations need long-term processes and detailed information. On the other hand, measured ratings are cheaper and time saving but prevents to provide a comparative system independent from occupant behaviours and requires a method for adjustment [16].

A few European countries use measured ratings or combination of two sytems. However, in most of the European countries, calculated ratings are used for the building energy performance certifications. Different methods of energy performance calculations are explained in Chapter 3 in detail.

2.1.2 Recast EPBD

European Comission 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” [17].

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 [14].

Additionally, Article 5, “Calculation of cost-optimal levels of minimum energy performance requirements”, appeared with recast EPBD and obliges that cost-optimal levels of minimum energy performance requirements shall be calculated by using comparative methodology framework which should be established by the European Comisssion [14]. 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 4.

2.2 Legislation in Turkey

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.

TS 825 Turkish Standard named Thermal Insulation in Buildings came into force a few decades before and last revised version was published in 2009. TS 825 aims to limit heating energy of buildings thus to increase energy savings and also to adopt a calculation methodology for determining energy demand. TS 825 stated that, using the standard for determining optimum design decisions for new buildings and ideal improvements for existing buildings are also possible [18]. However, energy related calculations except heating energy demand are not included in this mandatory standard for buildings in Turkey.

Energy Efficiency Law is published in May 2007 with the aim of providing efficient use of energy, relief of financial burden and protection of environment. Scope of the law covers energy efficiency issues for buildings, transportation and industrial establishments and energy management. This law requires a regulation on building energy performance which includes norms and standards about design parameters, heating, cooling, heat insulation, hot water and lighting in buildings and obligations for energy certification [19].

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 CO_2 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 emmissions, to determine building energy performance measures and to protect environment [11].

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 which provides building energy certificates showing energy performance levels.

2.2.1.1 Building energy performance certification in Turkey

Through Building Energy Performance Regulation, Turkey started building energy certification using Bep-Tr calculation method. As most of the European countries, Turkey is using calculated energy ratings for building energy certification.

As shown with Figure 2.2, energy performance certificate displays building energy consumption, greenhouse gas emmissions, renewable energy use and energy performance of the building in terms of heating, domestic hot water, cooling, ventilation and lighting energy classes.

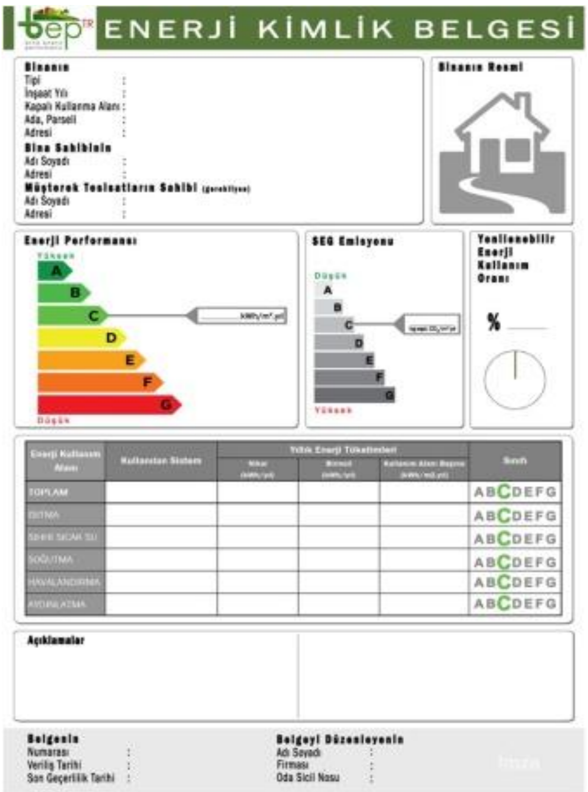


Figure 2.2 : Energy performance certificate of Turkey [20].

With the requirements of Recast EPBD, energy performance certificates shall provide recommendations about cost-effective or cost-optimal renovation posibilities. This shall also be the previous work for building energy performance certificates in Turkey.

3. BUILDING ENERGY PERFORMANCE CALCULATION METHODOLOGIES

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 setpoint temperatures. National building energy performance calculation methodology of Turkey is based on this method and explained in Chapter 3.2.

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.” [15].

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 is a long-term process and complicated, as well as requires specialized knowledge ; for this reason, using this method for mandatory certification of the whole building stock is not practical.

3.1 Building Energy Performance Calculation Methodologies in EU Countries

In European Countries, selection of the national building energy performance calculation metholodogy 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 endeavour 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.

Turkish national building energy performance calculation methodology, named Bep-Tr methodology, is developed based on national specifications and EN ISO 13790, using simple-hourly method.

3.2 National Building Energy Performance Calculation Methodology of Turkey

Bep-Tr is the national building energy performance calculation method of Turkey and developed in 2009, in parallell with EPBD requirements and the progress in Europe. The method is adopted in 2010 with the obligations of Ministry of Public Works and Settlement.

The calculation methodology was developed to assess impact of all parameters affecting energy consumptions of buildings on energy efficiency and to determine energy performance level. As stated in the report, it is possible to use this methodology for comparing performances of different alternatives for buildings at design stage and for assessing impacts of possible energy efficiency improvements in existing buildings. This chapter explains Bep-Tr calculation methodology and technical details.

Bep-Tr method can be used for residential buildings, office buildings, educational facilities, medical facilities, hotels, shopping malls and commercial building typologies of new and existing buildings [21].

The national calculation methodology uses simple-hourly method defined in EN ISO 13790. Simple-hourly method is a simplified dynamic simulation method based on resistance-capacitance (RC) model. As stated in EN 13790, "the calculation method is based on simplifications of the heat transfer between the internal and external environment". Resistance – capacitance model is defined in detail as five resistance one capacitance branches in EN 13790.

Simple hourly method uses hourly time-step, hourly input data and hourly schedules for calculations. Calculation of net energy amount required for thermal comfort conditions is enabled with this method, by using operative temperature calculations. Additionally, simple-hourly method provides to actualize heating and cooling calculations during the same period contrary to monthly/seasonal methods.

This methodology includes five main calculation parts:

- Calculation of net energy demand for heating and cooling in buildings
- Determining energy consumptions for heating and cooling considering efficiency of the system and energy losses of installed system
- Calculation of energy consumption for ventilation
- Calculation of energy demand and consumptions for lighting by taking daylighting effects into account
- Energy consumption required for hot-water

Net energy demand for heating and cooling is calculated by considering climatic data, building geometry definition, thermal characteristics and ventilation aspects, internal and solar gains, building material and construction definitions, internal comfort requirements and thermal zones. In this section, the methodology used in Bep-Tr for calculating net energy demand is explained, including building geometry, thermal zones, heat transfer and heat gains.

3.2.1 Building geometry

Altough the methodology has the capability of running calculations for all types of building geometries, basic sample building geometries were defined in the calculation methodology as a matter of convenience for possible software and user. Figure 3.1 shows defined building geometries and defined roof types for these geometries. Shading effects of these geometries and building parts are taken into consideration according to these sample geometries.

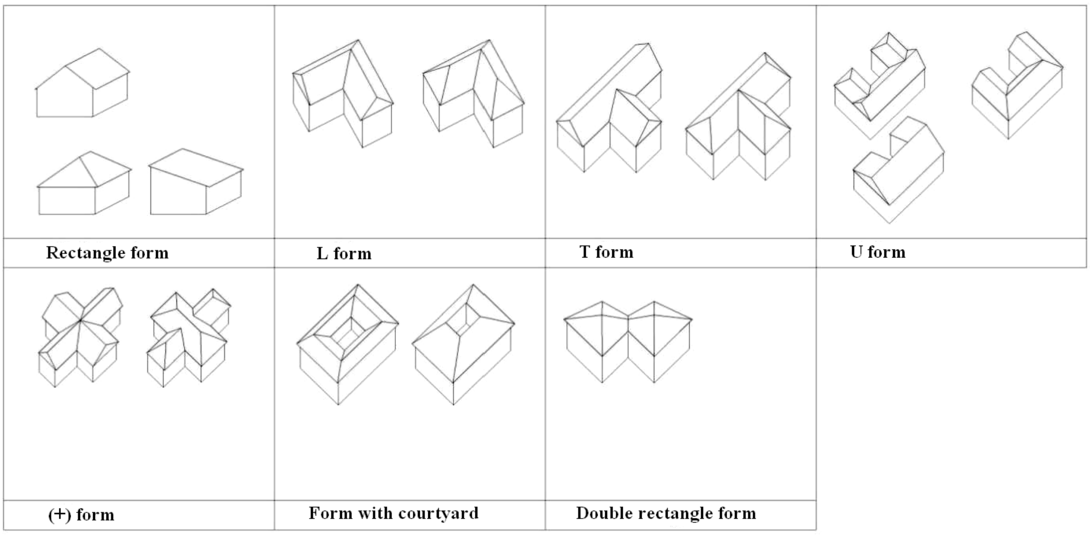


Figure 3.1 : Building geometries and roof forms of Bep-Tr [21].

3.2.2 Thermal zones

Units in buildings are divided into categories according to thermal characteristics as activity level, user profiles, properties of mechanical systems and internal gains. Group of units with similar thermal characteristics are named as thermal zone. Calculation for each zone is made within itself considering relationship with adjacent zone.

Thermal zoning system differs according to function of the building. In single family houses all conditioned spaces in a storey are assumed as a single zone, since heat transfer between the rooms are common. However, in apartment buildings each flat and each floor is assumed as a thermal zone and the core area is also considered as a single thermal zone in each storey. For office buildings, the external field, until 6m depth from the external windows, is assumed as external zone which is affected with solar heat gain, infiltration and other outside conditions, by means of windows and external walls. Internal parts are divided intozones according to function considering core zone and office zone.

In complex buildings as shopping malls, educational facilities, hotels and health care facilities, each floor is considered as a zone. However, for spaces which have different thermal characteristics as internal heat gains and thermal comfort requirements, the average internal gains and comfort temperatures are multiplied with the floor area in order to determine total weighted average of the floor.

3.2.3 Heat transfer through transmission

Thermal transmittance of building components are calculated with main equations given in EN ISO 13790 and related standards. However Bep-Tr introduces correction factors according to the building component types given in Figure 3.2 [21].These equations and correction factors are explained in detail in Bep-Tr technical report.

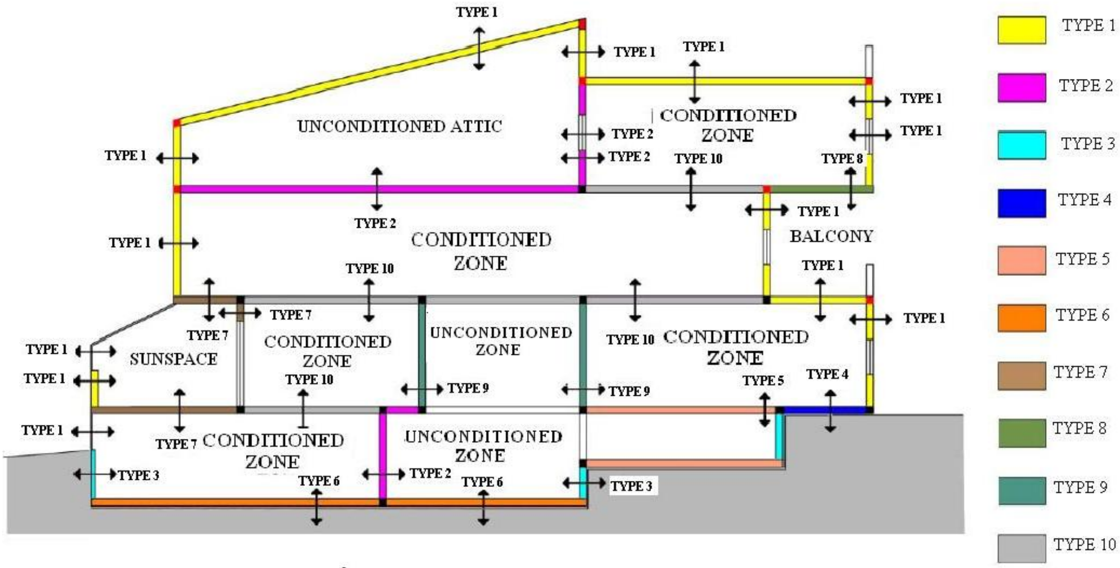


Figure 3.2 : Building component types based on heat transfer by conduction [21].

Since there are difficulties about gathering information about materials of existing buildings, assumptions on U values of these buildings are made according to year of their construction and existing standards for this year. For opaque components, heat brigdes are taken into account according to the method which ISO 14683:2007 standard explains.

Types and thermal transmittance of transparent components are listed in a table and are taken from this table automatically by simulation tool. U values of frames and night insulations are also taken into account in heat transfer calculations.

3.2.4 Heat transfer through ventilation and infiltration

Minimum ventilation requirements differs according to building use and typology. Ventilation heat transfer coefficients are calculated according to given equations in EN ISO 13790 and EN ISO 13789. Related Turkish standards are used for defining airtightness levels according to building typologies.

Natural ventilation from openings, infiltration from gaps and breaks on the building envelope, air flow from adjacent zone and the effect of mechanical ventilation systems are taken into account for the air flow calculations in Bep-Tr [22].

3.2.5 Internal heat gains

Internal gains differs not only according to function of the building and the zone, but also assumptions related with the schedules of the building use. Bep-Tr methodology calculates heat gains from internal sources including positive and negative heat gains.

Bep-Tr calculation methodology considers,

- Sensible and latent metabolic heat from occupants

- Dissipated sensible and latent heat from appliances,

- Heat dissipated from lighting devices.

As an exception for the residential buildings, heat gains from the hot water systems are also evaluated in Bep-Tr calculation methodology. Equations and schedules are explained in detail in Bep-Tr technical report [21].

3.2.6 Solar heat gains

Hence behaviors of the transparent and opaque components against solar effects are so different, Bep-Tr calculation mehodology analyses solar heat gains from opaque and transparent components seperately. Shading effects of external osbtacles and building parts, solar heat gains from the opaque and transparent components and heat losses to sky by radiation are taken into consideration in Bep-Tr calculation methodology.

Differently from the similar methodologies, Bep-Tr calculation methodology evaluates solar heat gains in detail by using hourly inputs for each orientation and for each slope value of the building component. Additionally, shading effects of external obstacles, building parts, solar control devices and external screens are taken into consideration, as addition to the method given in EN ISO 13790 [22].

After all of these calculations, in order to define heating/cooling energy demand of the zones of the building, operative temperature is calculated as the result of heat balance of each zone. If the calculated operative temperature is less than the heating set point temperature, there is heating need, if the calculated operative temperature is more than cooling set point temperature, there is cooling need in the considered zone.

4. CALCULATION OF COST OPTIMAL LEVELS OF MINIMUM ENERGY PERFORMANCE REQUIREMENTS: CASE STUDY FOR OFFICE BUILDING RETROFITS

One of the main objectives of EPBD was to set minimum energy performance requirements for buildings. With the renewals, recast EPBD requires to set these requirements "with a view to achieving cost-optimal levels". Cost optimal levels are defined in recast-EPBD as, "the energy performance level which leads to the lowest cost during the estimated economic lifecycle" [14]. According to Article 5 and Annex III of the recast Directive, calculation of cost-optimal levels complying with a comparative methodology is obliged and calculation procedure shall include following steps given in Annex III:

- *define reference buildings that are characterised by and representative of their functionality and geographic location, including indoor and outdoor climate conditions. The reference buildings shall cover residential and non-residential buildings, both new and existing ones,*
- *define energy efficiency measures to be assessed for the reference buildings. These may be measures for individual buildings as a whole, for individual building elements, or for a combination of building elements,*
- *assess the final and primary energy need of the reference buildings and the reference buildings with the defined energy efficiency measures applied,*
- *calculate the costs (i.e. the net present value) of the energy efficiency measures (as referred to in the second indent) during the expected economic lifecycle applied to the reference buildings (as referred to in the first indent) by applying the comparative methodology framework principles* [14].

The calculation procedure takes into account expenses and energy savings. After calculations using the main steps, for assessment, measures which optimizes profits and losses are determined as cost-optimal level.

On January 2012, European Comission adopted Regulation Supplementing Directive 2010/31/EU which includes the required comparative metholodogy framework.

Within the scope of the methodology framework, comparison procedure of energy efficiency measures and approaches of applying the comparison to reference buildings are clarified in order to identify cost-optimal levels [23].

In this chapter, this calculation and assessment procedure is explained step by step together with a case study. Case study of this thesis research, which is an example study on cost-optimal levels for Turkey, is also explained in detail in accordance with required process mentioned in EPBD and comparative methodology framework which is published by the European Commission.

4.1 Establishment of Reference Buildings

Due to making 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 which reflects most typical measures for building geometry and systems, energy performance for both building envelope and systems, functionality and cost structure of building stock and also represents climatic conditions and geographic location [23]. Reference building is required both for new and existing buildings to make cost optimal calculations at design stage of new buildings and calculations of major retrofits applied in existing buildings.

In this part of the study, EPBD requirements on establishing reference building are presented, reference building of Bep-Tr calculations is briefly explained and case study building used in this research is introduced.

4.1.1 Methodology of establishing reference building

Currently there is no any standard methodology on creating reference buildings, therefore processes which are followed by Member States range between detailed studies as lists with wide content and studies just includes defined reference buildings for a few building categories.

European Commission recommends two ways for establishing reference buildings. The first way is to select real buildings, which have the most typical characteristic parameters, as a representative of existing building stock. The other way is to create virtual buildings that enclose the most used materials and sytems for each building parameter. Required parameters for reference buildings are; building form including size and geometry, building envelope information such as U values, transparency ratio, compactness, materials and infiltration rate, technical systems and operation information such as occupancy and other schedules [24].

Selection of reference building by using one of the recommended ways requires statistical input data about the building stock, however it is not available in each European countries. In this case, a study about the database and also expert opinion is needed for establishing reference building. Most of the Member States are working on the problems about the lack of information on database and statistics. Some projects has been done such as IEE project TABULA (Typology approach for building stock energy assessment) which classifies European building stock as model buildings and mainly focuses on residential buildings. Utilizing these studies is suitable in European Countries in order to select reference building for cost optimal calculations.

Annex I of EU Comission Regulation on 16 January 2012 supplementing Directive 2010/31/EU, requires to establish at least one reference building for new buildings and at least two reference buildings for existing buildings for each of the following building categories [23]:

- single-family buildings
- apartment blocks and multi-family buildings
- office buildings

For non-residential buildings, Member States can make a selection between establishing a non-residential reference building which can also be used for other non-residential categories or establishing a reference building for each categories differently. This categorisation can include commercial buildings, hospitals, hotels, shopping centres, educational facilities, sports facilities and other multi function buildings.

In order to increase reality of calculations, sub-categorisation of reference buildings can be done based on age, size, climatic zone, construction material, construction structure or use pattern. Choice of the most appropriate sub-categorisation criteria must be done by experts according to properties of the building stock and conditions of the country.

Definition of reference buildings is a key issue for cost-optimal calculations of minimum energy performance requirements hence the outputs of the process is mainly based on these reference buildings. Correspondingly, national decisions on whole building stock are affected from the outputs and for this reason detailed studies are ongoing in Europe at national level.

4.1.2 Reference building for existing national calculation methodology – Bep-Tr reference building

In Turkey, reference buildings have been defined in existing Building Energy Performance Calculation Methodology for Turkey 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 certification considering minimum energy performance requirements at national level. Reference building of Bep-Tr is a virtual baseline building which is conformable to minimum energy performance requirements obliged by existing national standards and regulations. Characteristics of the reference building is explained in a report which is published in the official gazette on December 2010. These characteristics are explained below [21].

Each building has an individual reference building considered as 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 as same with the proposed building.

National building energy performance calculation methodologies have to be compatible with national standards. Therefore in Bep-Tr, building envelope properties of the reference buildings are determined mainly based on TS 825 mandatory standard.

TS 825 groupes all cities in Turkey according to heating degree days. There are four different degree day regions in TS 825 standard which are shown with a map in the Figure 4.1.

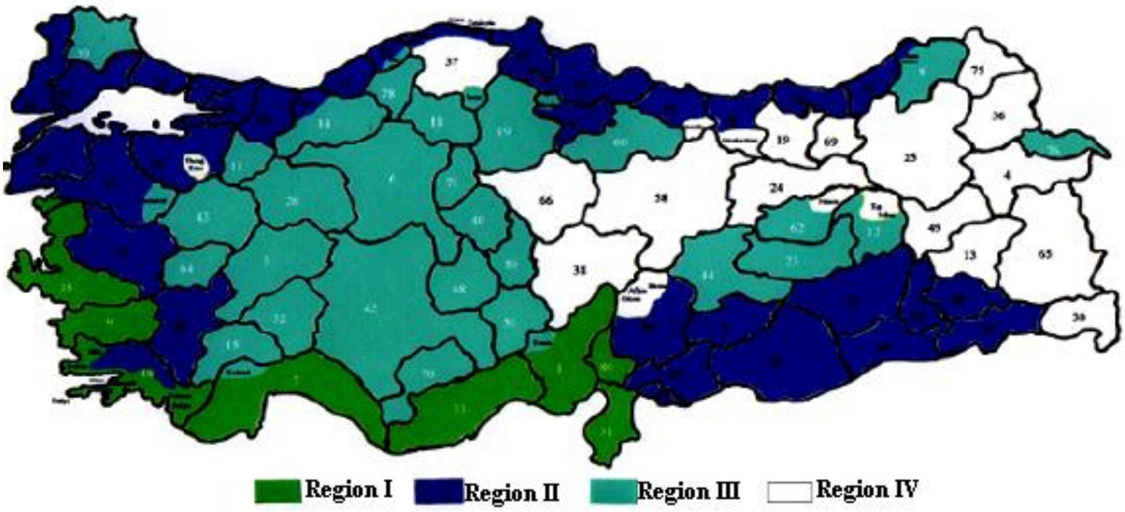


Figure 4.1 : Degree day regions of Turkey [18].

Requirements about maximum heat transfer coefficients (U values) of opaque and transparent surfaces of wall, ground floor and ceiling are given in the standard and these requirements differ for each region. Maximum U values are choosen for Bep-Tr reference building, in order to provide minimum requirements of national standard. As an addition to information gathered from TS 825 standard, solar heat gain coefficients (SHGC) of transparent components are determined for the reference building in accordance with the main characteristics of degree day regions. Building envelope properties of Bep-Tr reference building is given in Table 4.1. Properties of HVAC systems differs between residential and non residential reference buildings and are given in Table 4.2, together with lighting system properties.

Table 4.1 : Building envelope properties of Bep-Tr reference building [21].

	Region I	Region II	Region III	Region IV
Heat transfer coefficient of wall (U_{wall})	0,7 W/(m²K)	0,6 W/(m²K)	0,5 W/(m²K)	0,4 W/(m²K)
Heat transfer coefficient of ceiling ($U_{ceiling}$)	0,45 W/(m²K)	0,4 W/(m²K)	0,3 W/(m²K)	0,25 W/(m²K)
Heat transfer coefficient of ground floor (U_{floor})	0,7 W/(m²K)	0,6 W/(m²K)	0,45 W/(m²K)	0,40 W/(m²K)
Special cases*	*If transparency ratio of the building envelope is above 60%, U values of opaque components are decreased 25%			
Heat transfer coefficient of window (U_{win}) when transparency ratio is below 60%	2,4 W/(m²K)	2,4 W/(m²K)	2,4 W/(m²K)	2,4 W/(m²K)
Heat transfer coefficient of window (U_{win}) when transparency ratio is above 60%	2,1 W/(m²K)	2,1 W/(m²K)	2,1 W/(m²K)	2,1 W/(m²K)
Solar Heat Gain Coefficient (SHGC) of glazing (g_{gl})	0,75	0,75	0,3	0,3
Heat Bridges	All columns and beams are assumed without heat insulation.			
Night Insulation	No any night insulation.			
Shading devices and obstructions	No any shading devices or obstructions.			

Table 4.2 : Mechanical systems of Bep-Tr reference building [21].

	Residential Buildings	Non-residential Buildings
Heating System	Central Heating sytem using hot water circulation. Standard and athmospheric burner boiler using natural gas. Boiler working temperature is 90/70°C. Radiators are located under the window of the external wall. Thermostatic valve and pump frequency controller.	Same as residential building.
Cooling System	Air conditioner on the wall.	Fan Coil system with air cooling and on/off controlled.
Domestic Hot water system	Flash heater with natural gas.	Central system with natural gas boiler which is a standard and athmospheric burner boiler.
Ventilation system	Natural ventilation is assumed.	Mechanical ventilation with PI controlled air conditioning system.
Lighting system	There is no any defined lighting system.	Lighting system of the reference building is assumed as direct lighting. Light reflactances of the surfaces are, ρ_{wall} = 50%, $\rho_{ceiling}$ = 70%. Required illuminance level is defined according to function of the space and this level is met by 70% of the fluorescent, 30% incandescent lamps.
Renewable energy systems	There is no any defined renewable energy systems for reference building.	

All other measures and systems in reference building are assumed as same with proposed building design.

4.1.3 Case study building

This case study for Turkey requires a new reference office building desciption for the purpose of cost-optimal calculations which is the representative of the existing office building stock. However, there is no any comprehensive available information about the building stock in Turkey or any completed studies about the establishment of reference building as well. Therefore, building used in this case study is an office building which is neither a selected real representative building nor a virtual building composed from most common materials and systems but an example building which is derived based on the office building used in test studies of Bep-Tr calculation methodology and previous thesis researches related with this methodology.

Example case study building is a five floor office building with a square plan form. The building is a notional office which is considered as an existing building. Core area is at the middle and the rest of the floor area is used as open office. Total area of a floor is 900 m^2 and ceiling height is 4m.

The building is divided into zones considering thermopyhsical properties of different spaces. In each floor, there are six office zones and a core zone. Open office area is divided into zones according to location and orientation. Outer parts, which are 6m depth from the external surfaces, are assumed as external zones since this area is affected by outside conditions and solar effects from building envelope, while inner office areas are not affected from outside conditions. There are four external office zones in each floor which are oriented to four main directions and each external office zone is 144 m^2. Figure 4.2 shows the floor plan and the zones for a floor of the example office building.

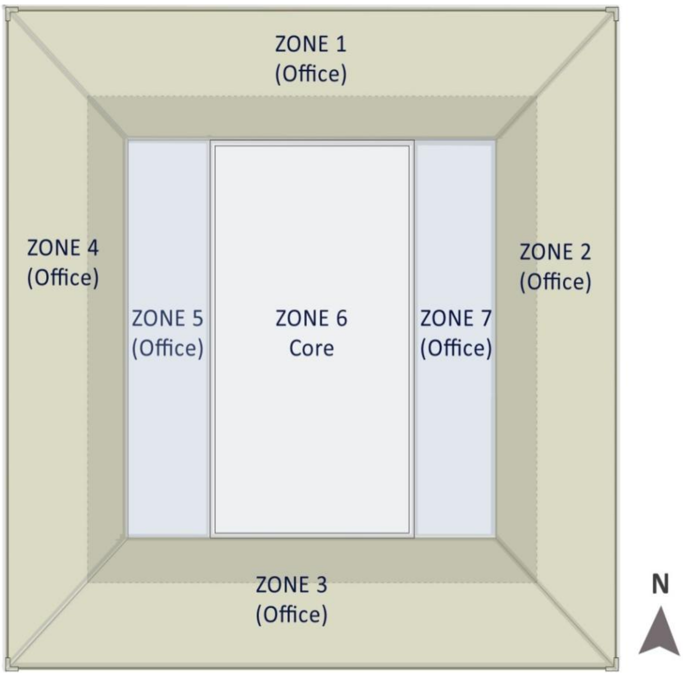


Figure 4.2 : Floor plan and zonning of case study office building.

Differently from four heating degree day regions of TS 825 standard, there are actual five different climatic zones in Turkey: Hot-humid region, hot-dry region, tempered humid region, tempered-dry region and cold region. Figure 4.3 shows the geography of five climatic regions on a map with different colors.

Figure 4.3 : Climatic regions of Turkey.

In this research, in order to view the outputs of climate effect, the example building is analysed in two different climatic zones of Turkey: tempered-dry climate and hot-humid climate. Ankara is the representative city of tempered-dry climate, where Antalya is the representative city of hot-humid climate.

The building has 50% transparency ratio and windows are located in each direction equally in a way which can be seen from Figure 4.9. It is considered that there is no any existing solar control devices on the facade.

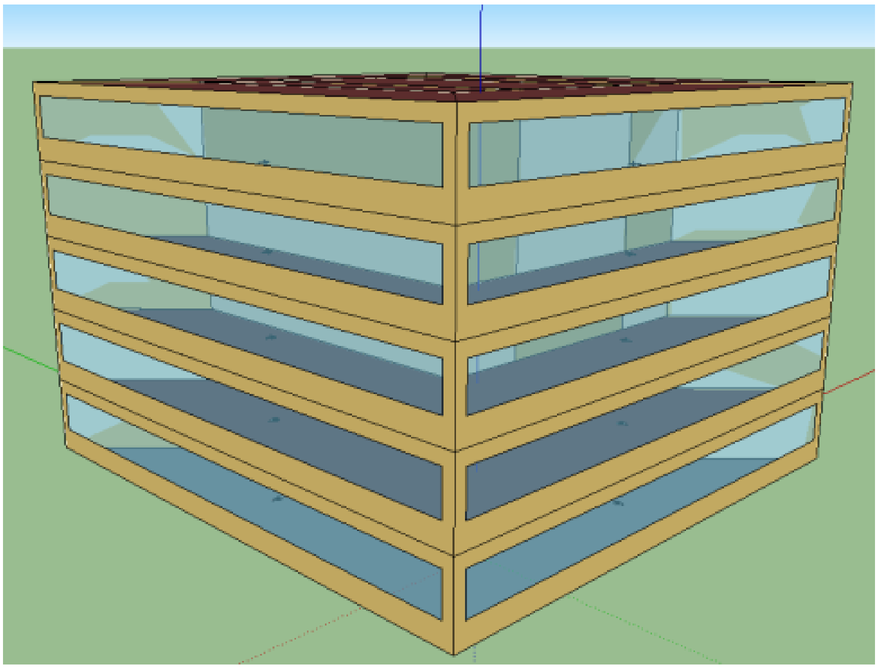
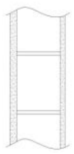
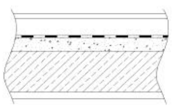
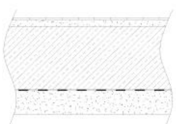


Figure 4.4 : Building geometry of the case study office building.

The building is assumed as constructed before TS 825 mandatory standard was published. Therefore there is no any existing heat insulation materials on the envelope of example office building. U values are determined by selecting most used materials in Turkey based on experience. U values and construction layers properties of the external opaque components are given in Table 4.3.

Table 4.3 : U values and layers of the opaque components for case study building.

Drawing	Component	Layers	Conductivity (λ)	Thickness (m)	U value
	External Wall	Plaster Lightweight brick Plaster	1,4 0,25 0,7	0,03 0,19 0,02	**1,02**
	Roof	Roof cover Air Gap Waterproofing Concrete Reinforced concrete Plaster	1,5 0,025 0,1 1,65 2,5 0,7	0,015 0,05 0,006 0,04 0,12 0,02	**1,78**
	Ground floor	Concrete Waterproofing Reinforced concrete Concrete Laminate flooring	1,65 0,1 2,5 1,65 0,2	0,15 0,006 0,04 0,04 0,015	**1,60**

Windows are considered with pvc frame and single glazing as 4mm clear glass, which has 0,89 visible transmittance value, 0,86 Solar Heat Gain Coefficient (SHGC) and 5,7 W/m^{2}K U value.

Case study office building is considered as an intensive office with 9,3m^2/person in open office areas. Working hours are, between 09:00 and 18:00 during weekdays. Air change per hour in the building is considered as 0,6 ach^{-1}.

The office building is mechanically conditioned. Input data for considered HVAC system is given with Table 4.4.

Table 4.4 : Input data for HVAC systems.

Parameter	Value
Heating Setpoint	21°C
Cooling Setpoint	26°C
HVAC Schedule	Weekdays 09:00-18:00
Heating System Generator	Hot water boiler
Cooling System Generator	Chiller with 1,5 COP
Emission	Fan coils

In lighting system in the example office building, 70% of the lamps in the office building are assumed as fluorescent, and 30% of the lamps are assumed as incandescent lamps. There is no any lighting control system for the base building.

4.2 Identification of Energy Efficiency Measures

EU Comission Regulation supplementing Directive 2010/31/EU, requires to define energy efficiency measures for new and existing buildings and for all parameters which have impact on energy performance of the building. High-efficiency alternative systems shall also be included such as decentralised energy supply systems based on renewable energy, cogeneration, district energy supply systems or heat pumps [23].

Due to efficiency measures are interdependent and one system can afftect the energy performance of the other, it is recommended by commission staff to assess packages of measures in order to reach results of synergy effects of meaningful combinations. Thus, cost-effective measures in the package enable to include other measures which are not cost-effective but have substantial benefits on primary energy and CO_2 savings [24].

Innumerable packages could be established including various measures related with building orientation, building envelope, solar control and daylighting, heating, cooling and ventilation systems, lighting systems and renewable energy systems. Therefore, most representative measures for the country would be initial selections for the calculations.

The Regulation also requires, “The selected energy efficiency measures and measures based on renewable energy sources, and packages/variants, shall also be compatible with air quality and indoor comfort levels according to CEN standard 15251 on indoor air quality or equivalent national standards.” Different air quality and comfort levels produced with different measures, shall be made transparent [23].

In this study, selected energy efficiency measures are applied to the case study building which is considered as an existing office building. Since it is not possible to include all energy efficiency measures; for this case study, most typical measures usually applied to office buildings in Turkey are selected. Applied energy efficiency measures include: retrofits on thermal insulation level, glazing, shading devices, lamp types, and daylight responsive automatic lighting control. These measures are both applied to the example office building as a single measure and together with the others as a package of measures. These measure packages and scenarios are shown in Table 4.5.

With the base situation 20 energy efficiency measures seen from Table 4.5 are applied to the example building for both tempered-dry climate and hot-humid climate as retrofit actions.

Additional thermal insulation is applied to the building in two levels. One is TS 825 level which represents maximum U values that national standard allows, while the other one represents the thermal insulation level which provides lower U values by increasing the insulation thickness on building envelope. According to degree day regions of TS 825, Ankara is in the III. Region, and Antalya is in the I. Region. TS 825 requirements for these regions and U values used in this research are given below with Table 4.6.

Table 4.5 : Case study scenarios.

		Thermal Insulation Level	Glazing Properties	Shading Device	Lamp Types	Lighting Control
0	**BASE 0:**	Without Thermal Insulation	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Without shading	%100 Incandescent	No lighting control
1	**BASE:**	**Without Thermal Insulation**	**SHGC: 0,85, T_{vis}: 0,89, U = 5,7**	**Without shading**	**%70 Fluorescent %30 Incandescent**	**No lighting control**
2	**CASE 1:**	Thermal Insulation = TS 825	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Without shading	%70 Fluorescent %30 Incandescent	No lighting control
3	**CASE 2:**	Thermal Insulation > TS 825	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Without shading	%70 Fluorescent %30 Incandescent	No lighting control
4	**CASE 3:**	Without Thermal Insulation	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Without shading	%70 Fluorescent %30 Incandescent	With lighting control
5	**CASE 4:**	Thermal Insulation = TS 825	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Without shading	%70 Fluorescent %30 Incandescent	With lighting control
6	**CASE 5:**	Thermal Insulation > TS 825	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Without shading	%70 Fluorescent %30 Incandescent	With lighting control
7	**CASE 6:**	Without Thermal Insulation	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Without shading	%70 Fluorescent %30 Incandescent	With lighting control
8	**CASE 7:**	Without Thermal Insulation	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Aluminium Fixed Shading	%70 Fluorescent %30 Incandescent	With lighting control
9	**CASE 8:**	Without Thermal Insulation	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Without shading	%100 Fluorescent	With lighting control
10	**CASE 9:**	Thermal Insulation = TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Without shading	%70 Fluorescent %30 Incandescent	With lighting control
11	**CASE 10:**	Thermal Insulation > TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Without shading	%70 Fluorescent %30 Incandescent	With lighting control
12	**CASE 11:**	Thermal Insulation = TS 825	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Aluminium Fixed Shading	%70 Fluorescent %30 Incandescent	With lighting control
13	**CASE 12:**	Thermal Insulation > TS 825	SHGC: 0,85, T_{vis}: 0,89, U = 5,7	Aluminium Fixed Shading	%70 Fluorescent %30 Incandescent	With lighting control
14	**CASE 13:**	Without Thermal Insulation	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Aluminium Fixed Shading	%70 Fluorescent %30 Incandescent	With lighting control
15	**CASE 14:**	Thermal Insulation = TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Aluminium Fixed Shading	%70 Fluorescent %30 Incandescent	With lighting control
16	**CASE 15:**	Thermal Insulation > TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Aluminium Fixed Shading	%70 Fluorescent %30 Incandescent	With lighting control
17	**CASE 16:**	Thermal Insulation = TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Aluminium Fixed Shading	%100 Fluorescent	No lighting control
18	**CASE 17:**	Thermal Insulation > TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Aluminium Fixed Shading	%100 Fluorescent	No lighting control
19	**CASE 18:**	Thermal Insulation = TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Aluminium Fixed Shading	%100 Fluorescent	With lighting control
20	**CASE 19:**	Thermal Insulation > TS 825	SHGC: 0,44, T_{vis}: 0,71, U = 1,6	Aluminium Fixed Shading	%100 Fluorescent	With lighting control

Table 4.6 : Different thermal insulation levels applied to example office building.

	TS 825 Requirements			Thermal Insulation Retrofits Applied to Example Office Building					
				= TS 825 Level			> TS 825 Level		
	U_{walls}	U_{roof}	U_{floor}	U_{walls}	U_{roof}	U_{floor}	U_{walls}	U_{roof}	U_{floor}
Ankara III. Region	0,5 W/m²K	0,3 W/m²K	0,45 W/m²K	0,47 W/m²K	0,27 W/m²K	0,43 W/m²K	0,37 W/m²K	0,23 W/m²K	0,3 W/m²K
Antalya I. Region	0,7 W/m²K	0,45 W/m²K	0,7 W/m²K	0,68 W/m²K	0,45 W/m²K	0,7 W/m²K	0,45 W/m²K	0,32 W/m²K	0,52 W/m²K

After defined energy efficiency measures are applied on the example office building, improvements on cooling system is carried out, since cooling energy consumption of office building is substantial with the existing old chiller system. All other energy efficiency measures are also applied together with the chiller retrofit which includes increment of COP value of the chiller from 1,5 to 4,5.

4.3 Assessment of Net Primary Energy Demand

Third step for calculating cost optimal levels of minimum energy performance requirements is to determine energy use in terms of primary energy. According to Annex I of EU Regulation No 244/2012, Member States shall calculate energy measures with an order: from the energy needed for space heating, space cooling and hot water energy to net primary energy [23].

Energy performance calculation may be done according to recommendations of the Comisssion using the approach including following steps [24]:

- Calculation of net thermal energy needs
- Subtraction of thermal energy from renewable energy sources from net thermal energy needs
- Calculation of the energy uses for space heating and cooling, hot water, lighting, ventilation.
- Subtraction of electricity from renewable energy sources from electricity use
- Delivered energy calculation

- Primary energy calculation
- Calculation of primary energy associated with energy exported to the market
- Subtraction from primary energy of primary energy associated with energy exported to the market in order to reach net primary energy.

Calculation scheme including these steps from net energy needs to primary energy use is given in Figure 4.5.

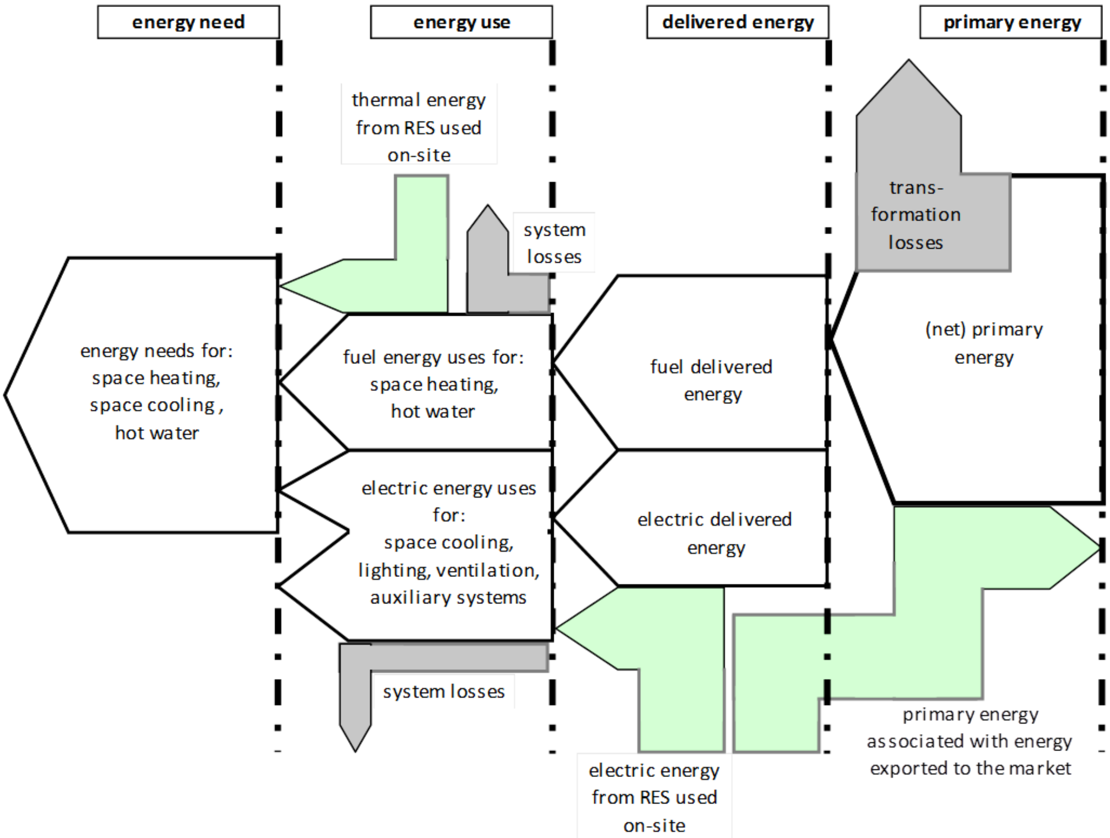


Figure 4.5 : Calculation scheme for energy use [24].

Related CEN standards or national building energy performance calculation methodologies that are established according to EPBD are allowed to use for energy performance calculations. However, using a dynamic method is recommended by Comission in order to reach reliable results at the first stage.

In calculations, Member States are required to use primary energy conversion factors that are established at national level and the results shall be expressed in square meters.

In this study, calculations are made according to recommended process with EPBD and related standards. First of all, energy demands were calculated in order to check building energy models and results. Then, end use consumptions of energy systems, subsequently primary energy amounts are calculated for the example office building including heating, cooling and lighting electricity by taking daylighting effects into account. Energy from renewable energy sources are not included in this research.

National primary energy conversion factors for Turkey are used for primary energy calculations. Natural gas conversion factor is 1 and electricity conversion factor is 2,36 for Turkey.

Energy performance calculations are done by detailed dynamic method using dynamic simulation tool Energy Plus and geometric model is done by Open Studio plugin for SketchUp software.

4.4 Calculation of Cost

Member States shall calculate the cost of the energy efficiency measures in accordance with Recast EPBD and EU Regulation No 244/2012. The methodology of cost calculation is based on ‘global cost’ which includes different cost categories such as, initial investment costs, running costs, replacement costs (referred to the starting year), energy costs and disposal costs if applicable. These cost categories are based on EN 15459 standard and defined in the regulation as follows [23]:

- Initial investment cost is, “all costs incurred up to the point when the building or the building element is delivered to the customer, ready to use. These costs include design, purchase of building elements, connection to suppliers, installation and commissioning processes”;
- Energy cost is defined as “annual costs and fixed and peak charges for energy including national taxes”;
- Running cost means “annual maintenance costs, operational costs and energy costs”;
- Disposal cost is “the costs for deconstruction at the end- of-life of a building or building element and include deconstruction, removal of building elements that have not yet come to the end of their lifetime, transport and recycling”;

- Replacement cost is defined as "a substitute investment for a building element, according to the estimated economic lifecycle during the calculation period";

Figure 4.6 shows the cost categorisation and relationship between the cost categories within the approach to global cost [24].

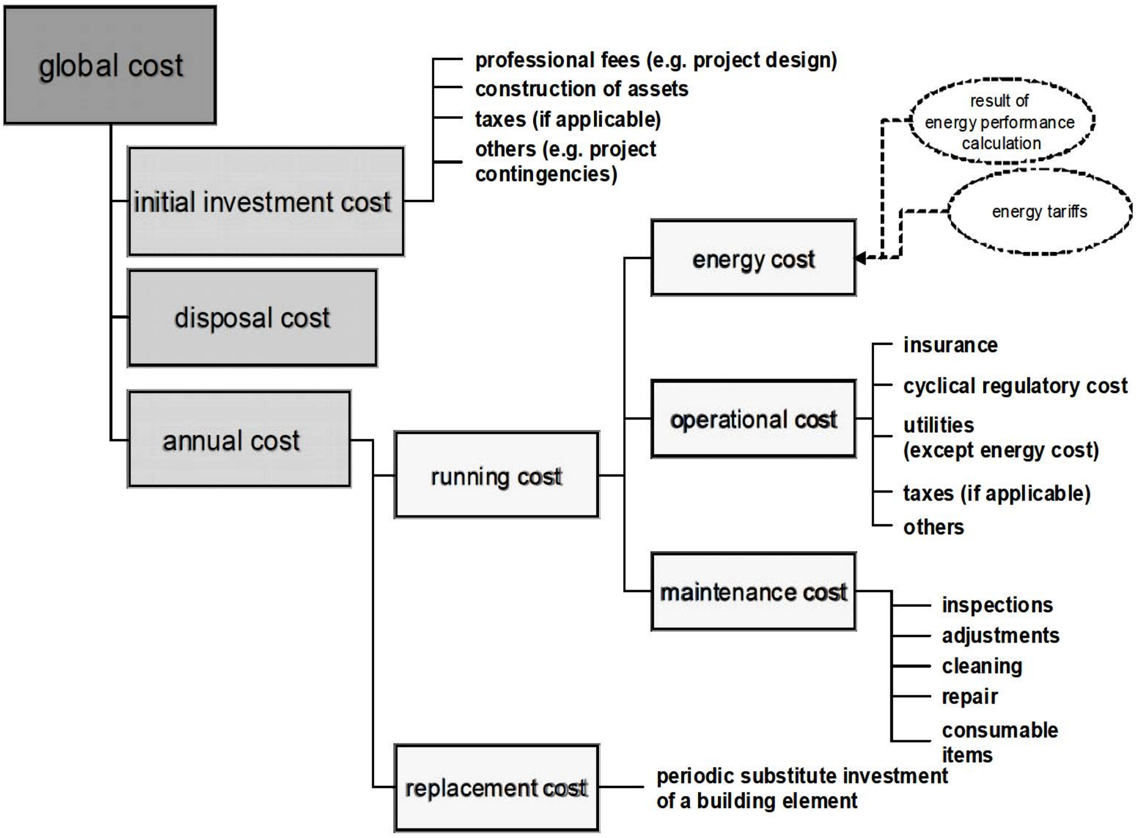


Figure 4.6 : Cost categorisation [24].

Main principles of global cost calculation using the cost categories is explained in Chapter 4.4.3 in detail.

4.4.1 Cost calculation perspectives

Determination of cost optimal levels of minimum energy performance requirements can be performed from three different perspectives according to Concerted Action report of EPBD [25]:

- Societal "macro" economic perspective which includes societal benefits such as climate change and CO_2 emmissions but ignored taxes and subsidies.

- Individual end user perspective which includes costs and benefits from owner’s and occupant’s point of view which includes taxes and subsidies.
- Idealised end-user “micro” economic perspective which is a basic version of individual end user perspective which includes a typical user definition in order to prevent different effects of different end-users and ignores market barriers.

Different perspectives require different calculation procedure and result in a different way regarding the served purpose. EU Regulation supplementing recast EPBD introduces both macroeconomic perspective and financial viewpoint but the decision on the final national benchmarks is left to discretion of Member States.

In this study, the cost is calculated according to individual perspective which includes costs belongs to the owner and the tenant in accrodance with the Regulation and EN 15459 standard.

4.4.2 Global cost calculation procedure

Calculation period has influence on the results based on the relation between investment cost and annual costs. In the recent regulation of EU, global cost calculation period is defined as 30 years for residential and public buildings, and 20 years for commercial, nonresidential buildings [23].

All costs, except costs that are same for all assessed measures and costs related to building elements which do not affects energy performance of building, must be included in the cost calculation.

In this study different calculation periods such as 30 years, 20 years, 10 years and 5 years are used in order to analyse the effect of calculation period on results. Since the office building is assumed as an existing building, just costs of retrofits are taken into account for investment costs. In example, for a heat insulation retrofit on the walls, cost for constructing scaffolding, cost for removing the existing wall covering, cost for the heat insulation, and cost for reconstructing the wall covering is included in investment cost.

Global Cost calculation is explained in EN 15459 by following steps:

- Gathering financial data

- Gathering project data
- Costs regarding components and systems (investment, replacement)
- Energy Costs
- Global cost calculation

4.4.2.1 Gathering financial data and project data

Duration of calculation, inflation rate, market interest rate, rate of development of human operation costs and rate of development of energy prices are the financial data required for the global cost calculation.

For EU countries, information on energy price developments for oil gas coal and electricity may be provided from Annex II of EU Regulation No 244/2012. For other energy carriers, national and local forecasts shall be provided.

Cost data is required to be market-based and coherent as regards location and time and to expressed as real costs at country level. According to explanations of European Commission in Guidelines document, the cost data can be gathered from market-based cost databases, offers of construction companies or evaluation of projects constructed recently [24].

Estimated lifespan of some building components and products are available in Annex A of EN 15459 standard.

In this study, cost data is taken from unit price book published by Ministry of Public Works and Settlement. The book includes material, construction and installation costs based on year 2011 [26]. However, costs of all measures analysed in this study are not available in the mentioned book. In this case, missing cost data is taken from the market and offers of construction companies. Lifespan of the components are provided from EN 15459. Financial data such as inflation rate, discount rate and exchange rate for market prices are provided from the central bank data which are available from the official website [27].

Location, climate, type of the building and other general data are necessay project data for cost calculations. For the example building in this case study, the building is assumed as an office building operated by owner and used by a tenant, and the case study building is analysed in two different climates as mentioned in previous sections.

4.4.2.2 Costs regarding components and systems

This step includes calculation of replacement costs, running costs and investment costs which consist of building construction costs and energy system costs.

Investment cost for space heating, space cooling and domestic hot water systems include generation, storage, distribution, emission and control units. Investment cost for ventilation systems include air supply, distribution, emission and control units and investment cost for lighting system includes type of lighting system, associated control system and solar control system.

Replacement costs are based on lifetime of the component expressed in Annex A of EN 15459 and at the end of the lifetime replacement cost is added to global cost. The lifetime of the component can be different from calculation period of global cost. In this case, residual value of the component at the end of the calculation period (also called as final value) has to be subtracted from global cost.

Running costs consist operational costs, maintenance and repair costs and added costs. This cost is calculated annually.

In accordance with the scope of this thesis research, costs which are taken into account differs based on case study retrofit requirements. For cost calculations of scenarios, including just envelope retrofits such as thermal insulation, glazing or shading, investment costs related with building construction are taken into account with replacement costs. However, for other cases which are including also retrofits on lighting and cooling systems, both building construction costs, energy system costs, replacement costs and running costs are taken into account based on national 2011 prices.

4.4.2.3 Energy costs

Energy costs are obtained mainly by coupling between calculated consumptions of the building and energy tariff. Energy cost also includes a fixed part, such as subscription costs or rental payment for energy systems (e.g. gas tank, electricity transformation). Additionally, environmental costs are also included in energy costs and energy sales are required to count as negative costs [28].

In this study, energy cost calculation is based on natural gas and electricity consumptions of the office building including heating, cooling and lighting and energy tariffs which is calculated relative to 2011 starting year prices for Ankara and Antalya.

4.4.2.4 Global cost calculation

There are two different perspectives and calculation procedures explained in EU Regulation: financial calculation and macroeconomic calculation [23].

In financial calculation, all costs that have influence on customer including all applicable taxes and charges are taken into consideration. The global cost for financial calculation considering different types of costs **(4.1)** and discount rate are calculated with the equations **(4.2)** given below.

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right] \qquad \textbf{(4.1)}$$

τ : calculation period

$C_g(\tau)$: global cost over the calculation period

C_I : initial investment cost for measure or set of measures *j*

$C_{a,i}(j)$: annual cost during year *i* for measure or set of measures *j*

$V_{f,\tau}(j)$: residual value at the end of calculation period of measure or set of measures *j*

$R_d(i)$: discount factor for year *i* calculated with the given equation **(4.2).**

$$R_d(p) = \left(\frac{1}{1 + r/100}\right)^p \qquad \textbf{(4.2)}$$

r : real discount rate

p : number of years from the starting period

In macroeconomic calculation, all prices are taken into consideration excluding all applicable taxes, VAT, charges and subsidies in order to determine societal benefits. Additionally in this approach, cost of greenhouse gas emmissions are also considered as shown in the given equation (4.3).

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i) + C_{c,i}(j)) - V_{f,\tau}(j) \right] \qquad \textbf{(4.1)}$$

$C_{c,i}(j)$: carbon cost for measure or set of measures *j* during year *i*

For both calculation perspectives, sensitivity analyses are required in EU Regulation in order to determine the discount rate.

In this thesis research, financial calculation is used by following the process mentioned in EN 15459. Expenses of the investor and occupant are determined individually and then summed to get the total global cost with discounted residual value at the end of the calculation period. EN 15459 summarises the common calculation process with Figure 4.7.

Duration of calculation (τ)		Years	Rate of development of operation cost		%	
Inflation rate		%	Rate of development of cost for energy type 1		%	
Market interest rate		%	Rate of development of cost for energy type 2		%	
Rate of development of cost for products		%	Rate of development of cost for electricity		%	(for auxiliary components)

		Total, incl. VAT year 0	Inflation rate	Present value factor		Cost due to owner		Costs due to occupancy
1 – INITIAL COSTS								
Investment costs for HVAC and DHW systems				1,0000				
Investment costs for part of building construction related to energy savings and losses				1,0000				
2 – PERIODIC COSTS				Calculated for any year				
Costs for year 2								
Costs for year i								
Final value reduction					-			
3 – RUNNING COSTS (except energy)				Consider τ years				
Annual costs (for operation, insurance, etc.)								
4 – ANNUAL COSTS FOR ENERGY				Consider τ years				
Annual costs energy 1	(to be multiplied by τ)							
Annual costs energy 2	(to be multiplied by (τ)							
Annual costs auxiliary energy (electricity)	(to be multiplied by (τ)							
		GLOBAL COST						
		TOTAL GLOBAL COST						

Figure 4.7 : Calculation sheet for global cost calculation [28].

4.5 Determination of Cost Optimal Levels of Minimum Energy Performance Requirements

The last step of the cost optimal analyses is to derive cost optimal energy performance level for each reference building. Recast EPBD specifies that, identification of cost-optimal levels consists “a balance between the investments involved and the energy costs saved throughout the lifecycle of the building”. Therefore, recast EPBD requires a comparison between minimum energy performance requirements and calculated cost optimal levels of minimum energy performance requirements. Differences exceeding %15 shall be reported and planned to reduce [14].

As stated in Concerted Action reports of EU on cost optimal levels, cost optimality is related with cost effectiveness which can be achieved when the cost of the action is lower than the value of the benefits that result, until the end of the expected life of the measure. In other words, if the net present value reached at the end of the calculation is positive, the action is cost-effective. Cost optimal level is a special case of cost-effective level which maximizes the net present value [25]. Figure 4.8 presents cost optimality and cost effectiveness with a schematic illustration.

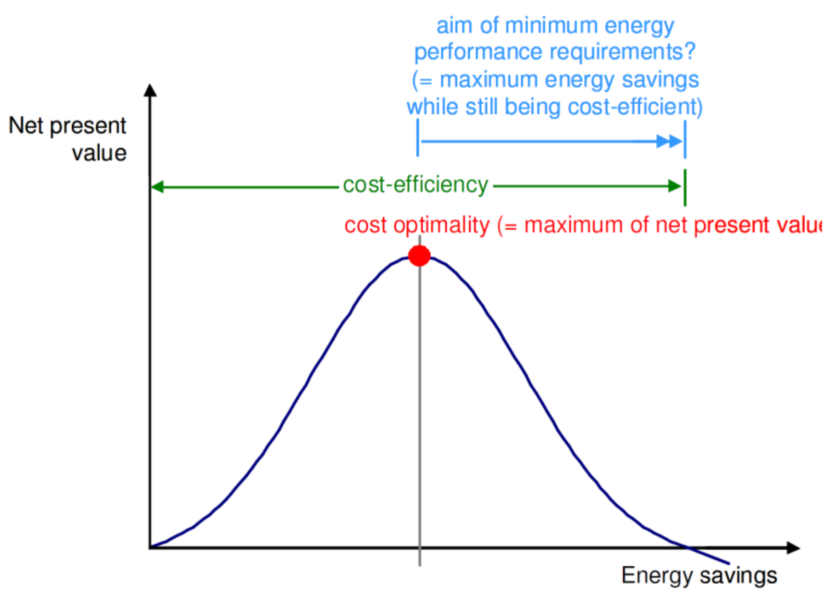


Figure 4.8 : Relationship between cost-effectiveness and cost-optimality [25].

For making the derivation of cost optimal levels for a reference building, graphs can be drawn based on primary energy calculations and global costs of different efficiency measures which are defined in the previous stage. An example graph is shown by Figure 4.9 where the x-axis shows primary energy in kWh/m2a and y-axis shows the global costs in €/m2.

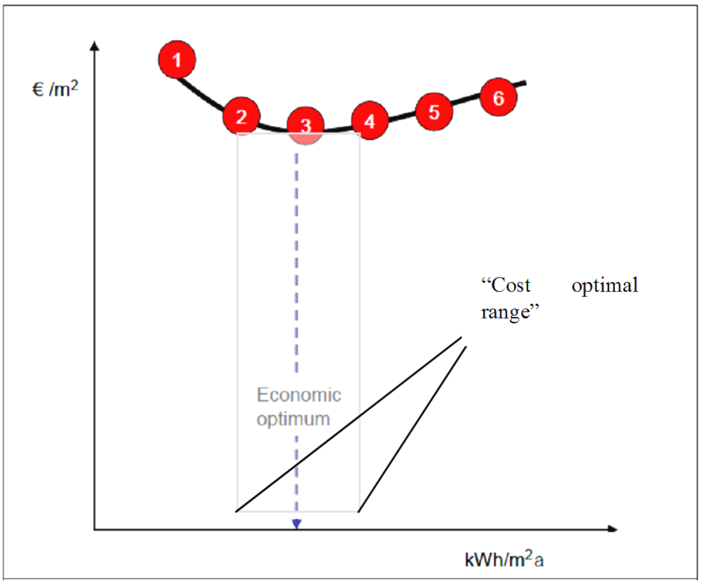


Figure 4.9 : Sample graph for cost optimal range [24].

Points with different numbers in the graph represents different measures and the lowest cost corresponds number 3 which is the measure optimizing global cost and primary energy. This point is named 'cost optimal level' of energy performance measures for the reference building. However, as stated by Wittchen and Thomsen, "in reality the distribution may not be uni-modal (it may have several local optima)" [29].

The cost-optimal levels shall be determined for each reference building individually. In calculations, for cases which has different energy performance levels but same global costs, MS are encouraged by the EU Regulation "to use the requirements resulting in lower use of primary energy as the basis for comparison with the existing minimum energy performance requirements." [23].

In this thesis study, cost-optimal levels are defined for the example office building using the recommended way, in order to assess the effect of different retrofit actions applied on the building. Package of measures with cooling system retrofits are displayed seperately from other packages which include just building component retrofits.

5. RESULTS

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 case study 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 case study office building, heating energy is met with natural gas, while cooling and lighting energy is met with electricity. The office building is analysed in two different cities: Ankara as the city in tempered-dry climatic region and Antalya as the city in hot-humid climate.

Figure 5.1 reports the results of end use consumptions of the office building in Ankara and Figure 5.2 shows the primary energy amounts which are converted from consumptions using conversion factors for Turkey. Correspondingly, end use consumptions and primary energy amounts of the same office building in Antalya are shown with Figure 5.3 and 5.4. Each bar represents energy use of a retrofit scenario and the numbers of the scenarios are written under the bars which are explained in Chapter 4.2.

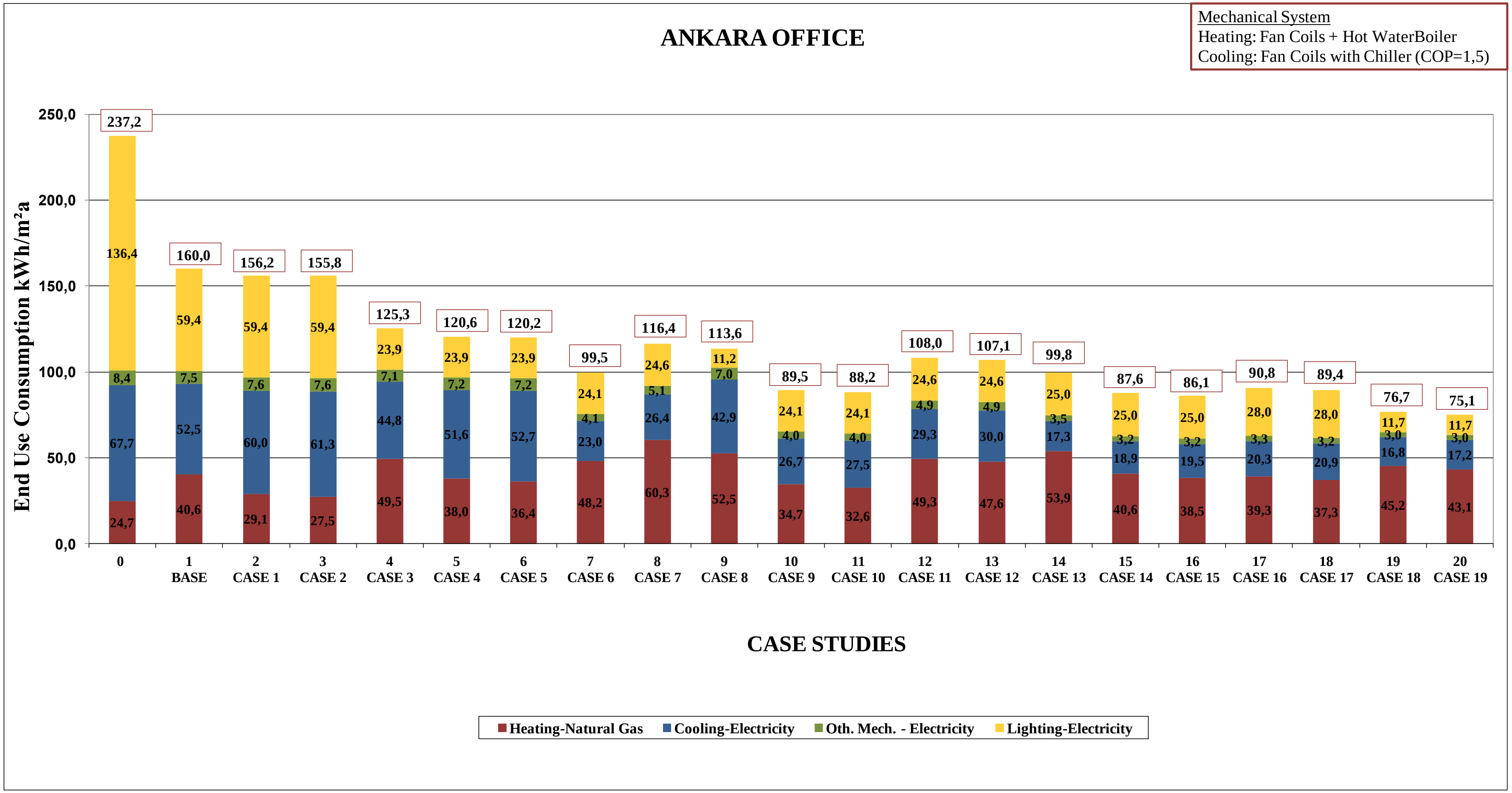


Figure 5.1 : End use consumptions in Ankara office.

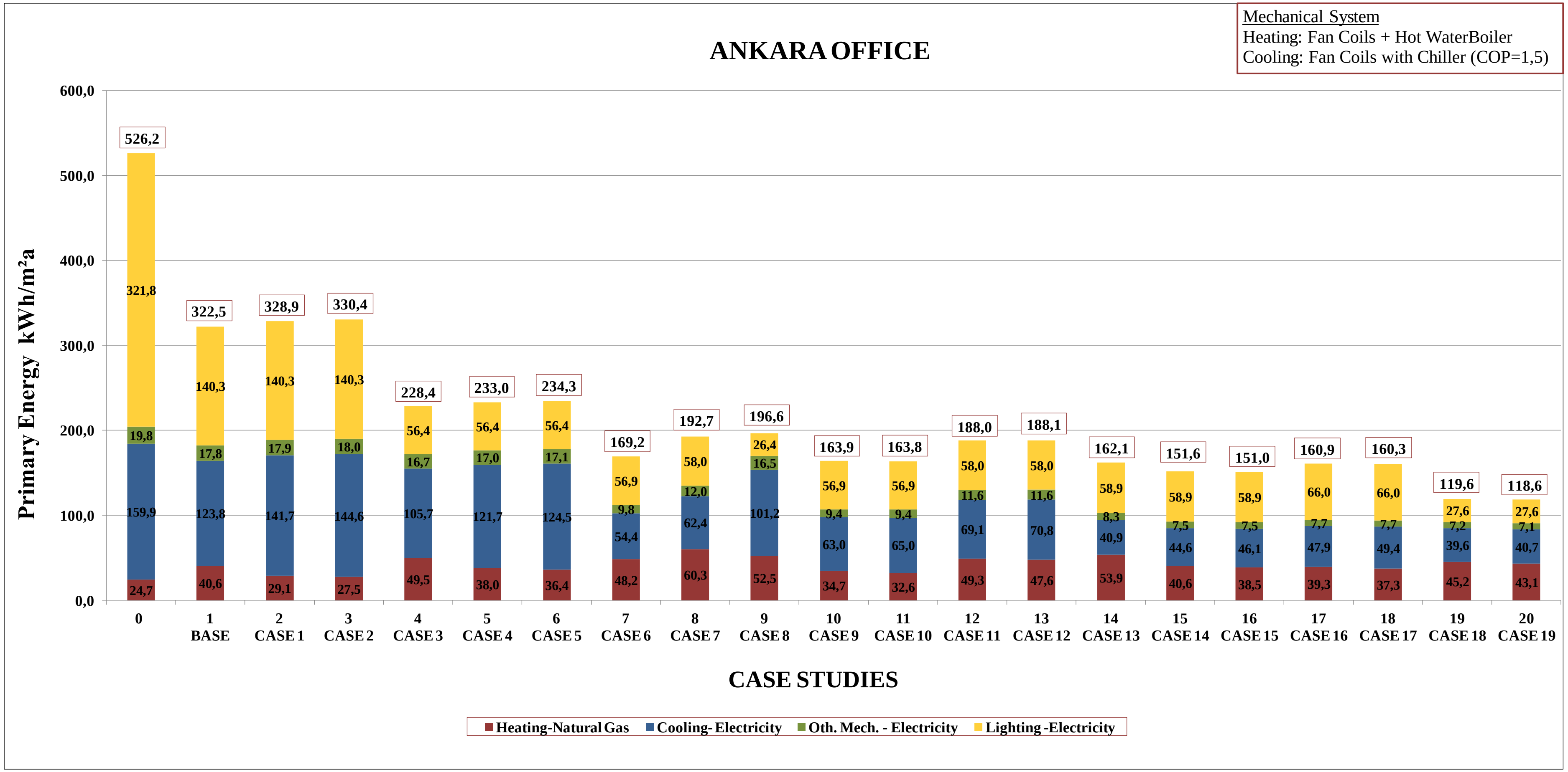


Figure 5.2 : Primary energy amounts in Ankara office.

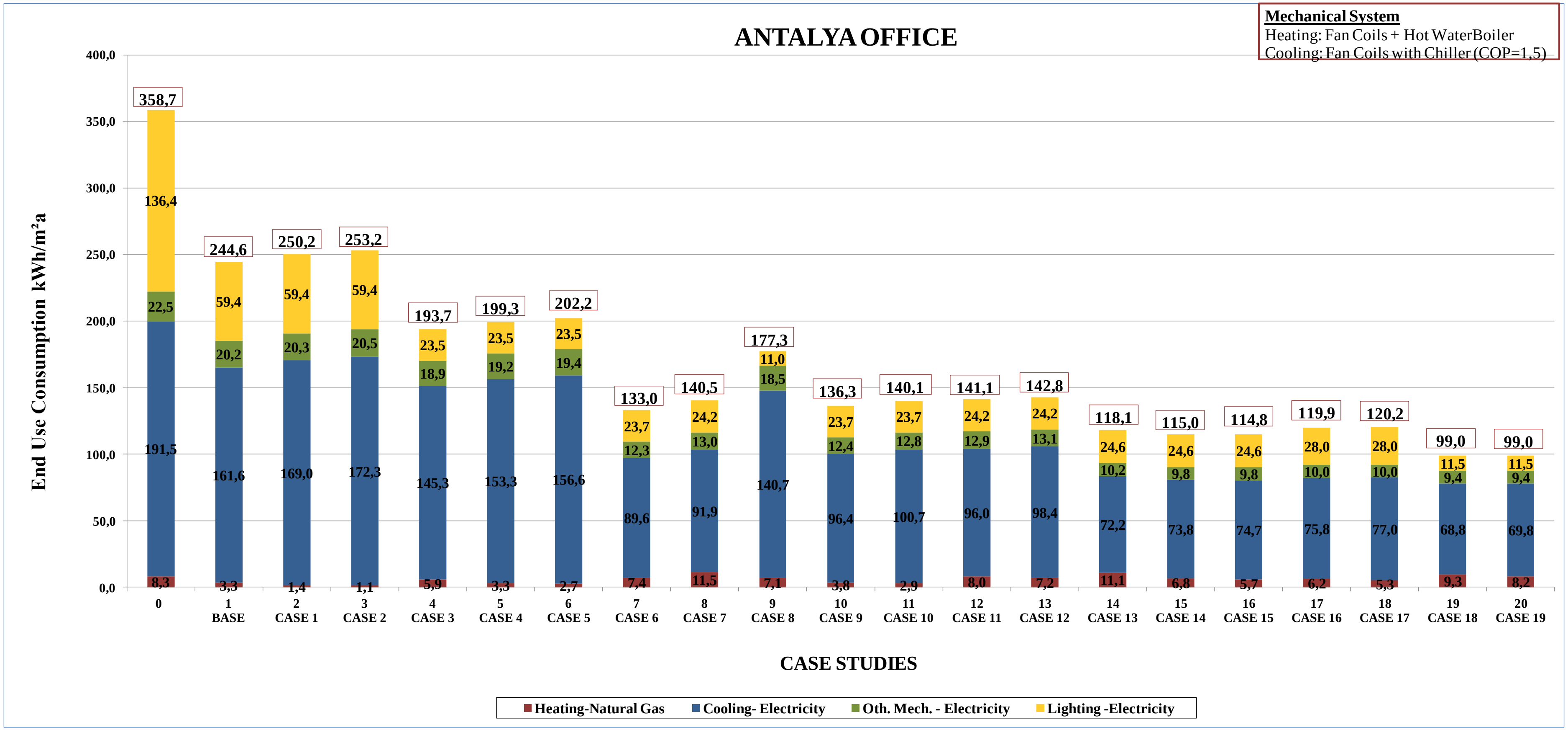


Figure 5.3 : End use consumptions in Antalya office.

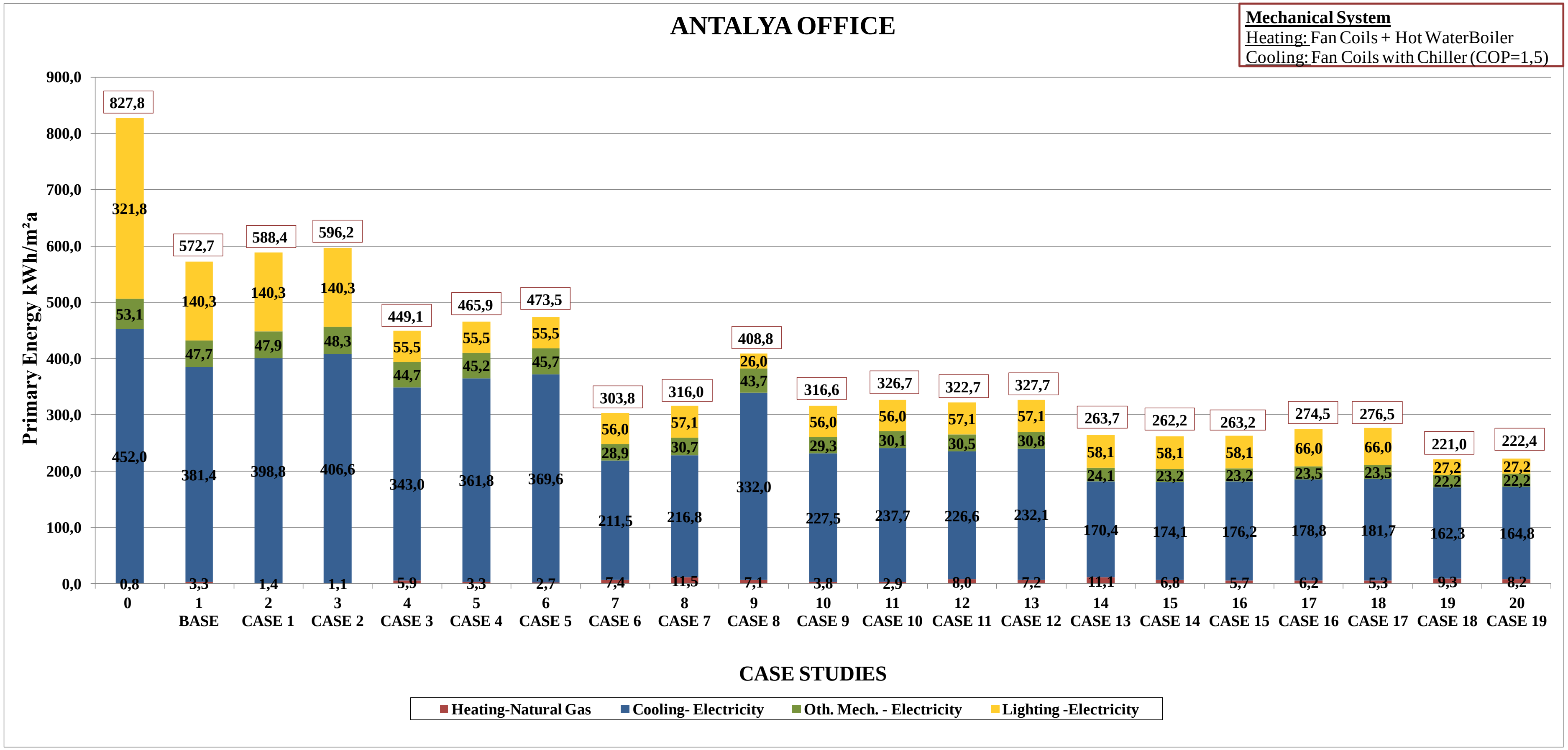


Figure 5.4 : Primary energy amounts in Antalya office.

As seen from the end use consumption graphs, heating consumption of the office building is almost zero in Antalya in comparison to Ankara. However, even in tempered-dry climate, the building has remarkable cooling energy consumptions. The reason is that, office bildings has substantial amount of internal heat gains result from occupants, equipments and lighting devices during office hours and also has high transparency ratio of the building which causes high cooling load.

Primary energy graphs make clear the load and effect of cooling energy on this example office building because the energy conversion factor of electricity is 2,5 times greater than the conversion factor of natural gas. Retrofit actions including heat insulation, results with higher primary energy than the cases without heat insulation on the building envelope. According to the results of Base scenario, Case 1 and Case 2, thermal insulation levels required by TS 825 mandatory standard, diminish the building enegy performance level by preventing to cool the example office building against internal heat gains even in tempered dry climate.

Retrofit actions which are individually effective on decreasing cooling loads, such as shading, automatic lighting control and better glazing, result with better energy performance level for the case study office building. In both climates, case 18 and 19 are the most energy efficient retrofits for the office building. These scenarios include retrofits on thermal insulation, glazing, shading, lamps and daylight responsive automatic lighting control together.

Energy performance levels of the retrofit scenarios on the office building are also calculated for both climates. Total energy classes are determined according to national building energy performance methodology, Bep-Tr. Base scenario is considered as baseline building for energy performance comparisons. Calculated energy classes are given with Table 5.1. As seen from the table, improving the energy efficiency level of example office building from D to A is possible with proper retrofit actions. However, energy efficiency of retrofit scenarios should be analysed in accordance with building typology and characteristics before decisions.

Table 5.1 : Energy performance levels of case study retrofit scenarios.

	Retrofit Scenarios	Energy Class in Ankara	Energy Class in Antalya
1	BASE	D	D
2	CASE 1	D	D
3	CASE 2	D	D
4	CASE 3	B	B
5	CASE 4	B	C
6	CASE 5	B	C
7	CASE 6	B	B
8	CASE 7	B	B
9	CASE 8	B	B
10	CASE 9	B	B
11	CASE 10	B	B
12	CASE 11	B	B
13	CASE 12	B	B
14	CASE 13	B	B
15	CASE 14	B	B
16	CASE 15	B	B
17	CASE 16	B	B
18	CASE 17	B	B
19	CASE 18	A	A
20	CASE 19	A	A

It can be seen from the analyses that, this example office building needs a high efficiency cooling system. However, the cooling system of this example office building has very low efficiency since installed system is considered to include an old chiller. For this reason, a small-scale retrofit action in cooling system has been tested by replacing the chiller. In order to analyse the effect of cooling system efficiency together with retrofit scenarios, existing chiller is replaced with a new one which has 4,5 COP value. All retrofit scenarios are tested with renewed chiller system as well.

Figure 5.5 shows the end use consumptions and Figure 5.6 shows the primary energy amounts of the office building in Ankara with the replaced chiller. Correspondingly, Figure 5.7 and 5.8 display end use consumptions and primary energy amounts of the same office building located in Antalya.

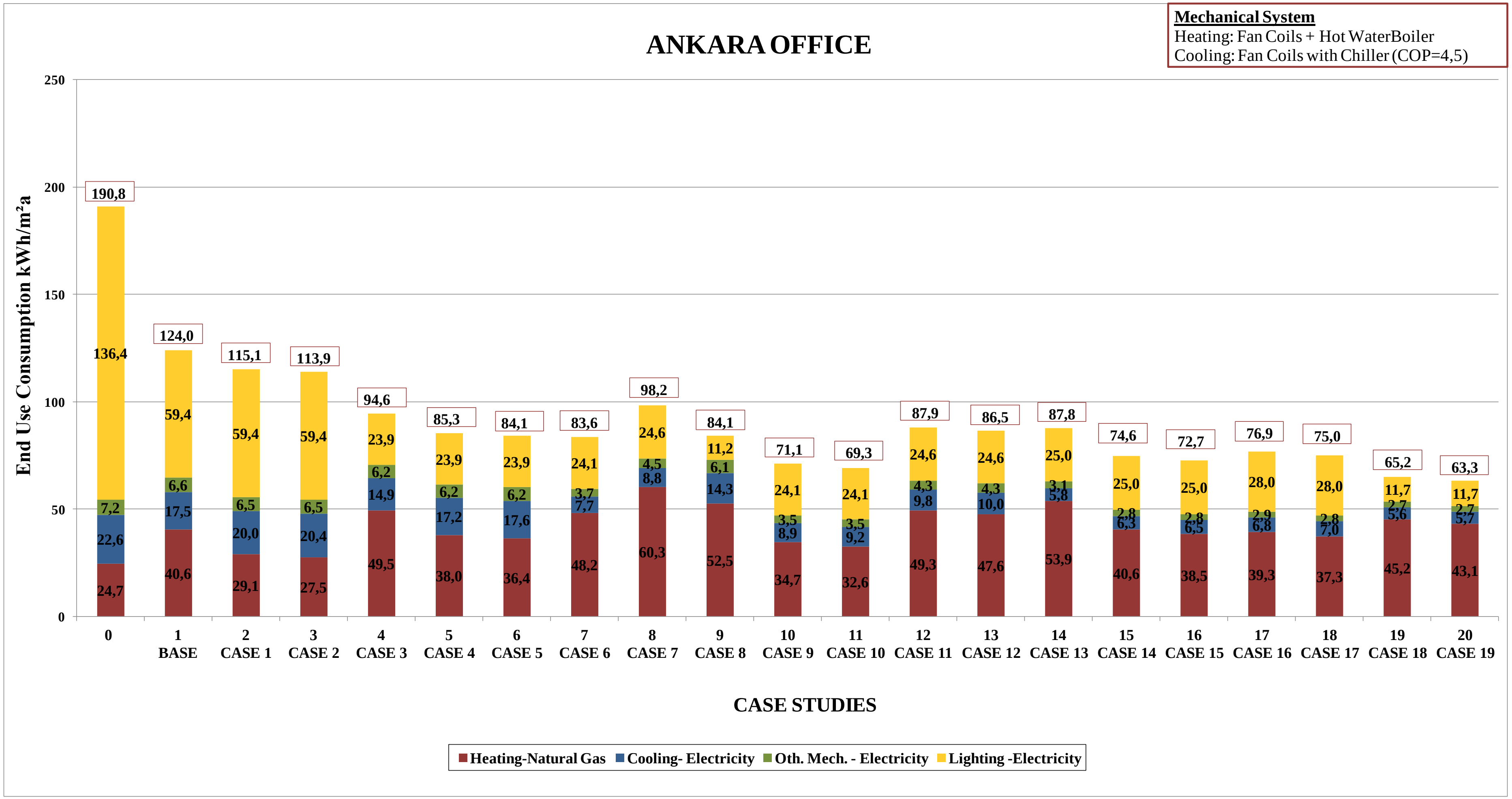


Figure 5.5 : End use consumptions in Ankara office with better chiller COP value.

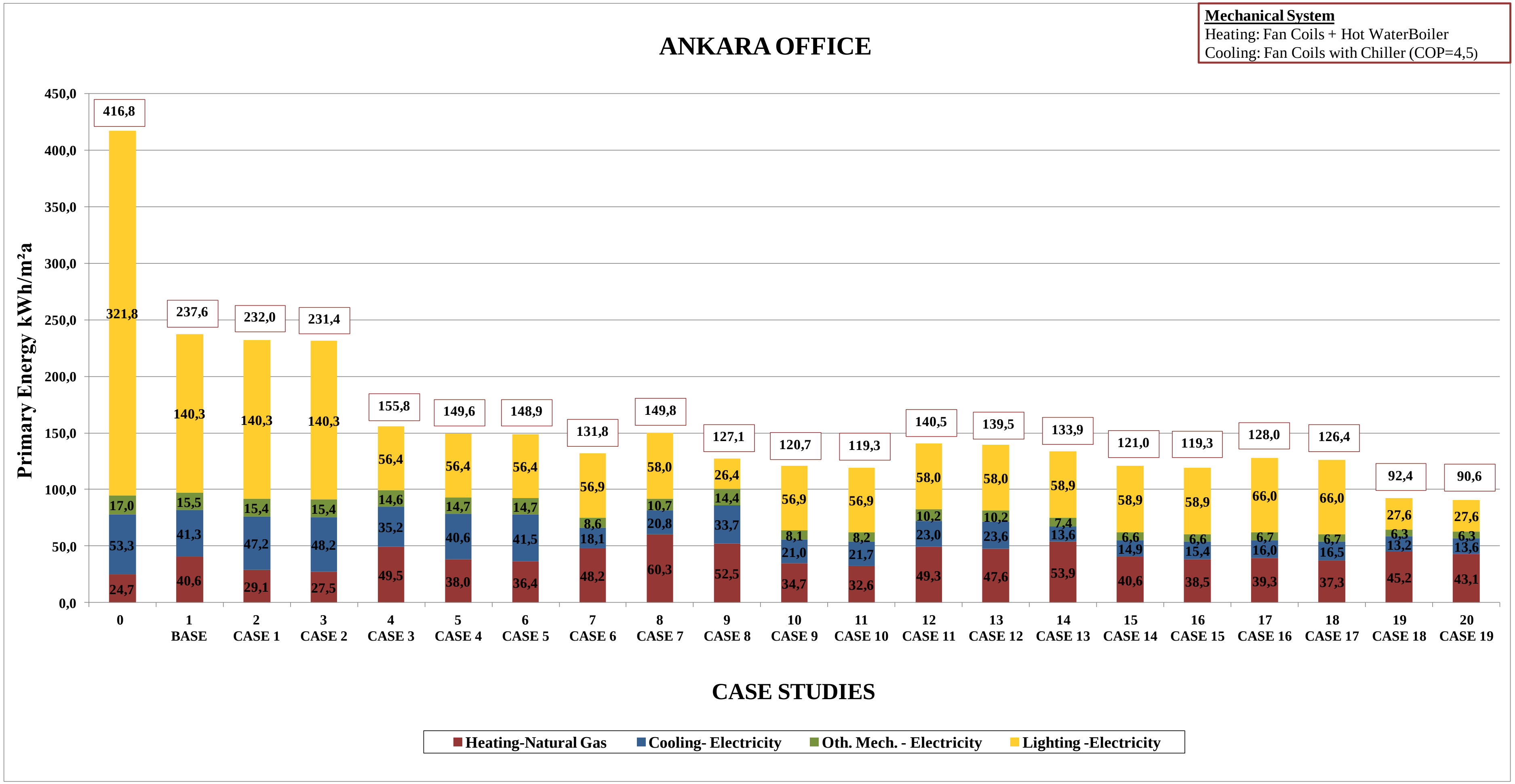
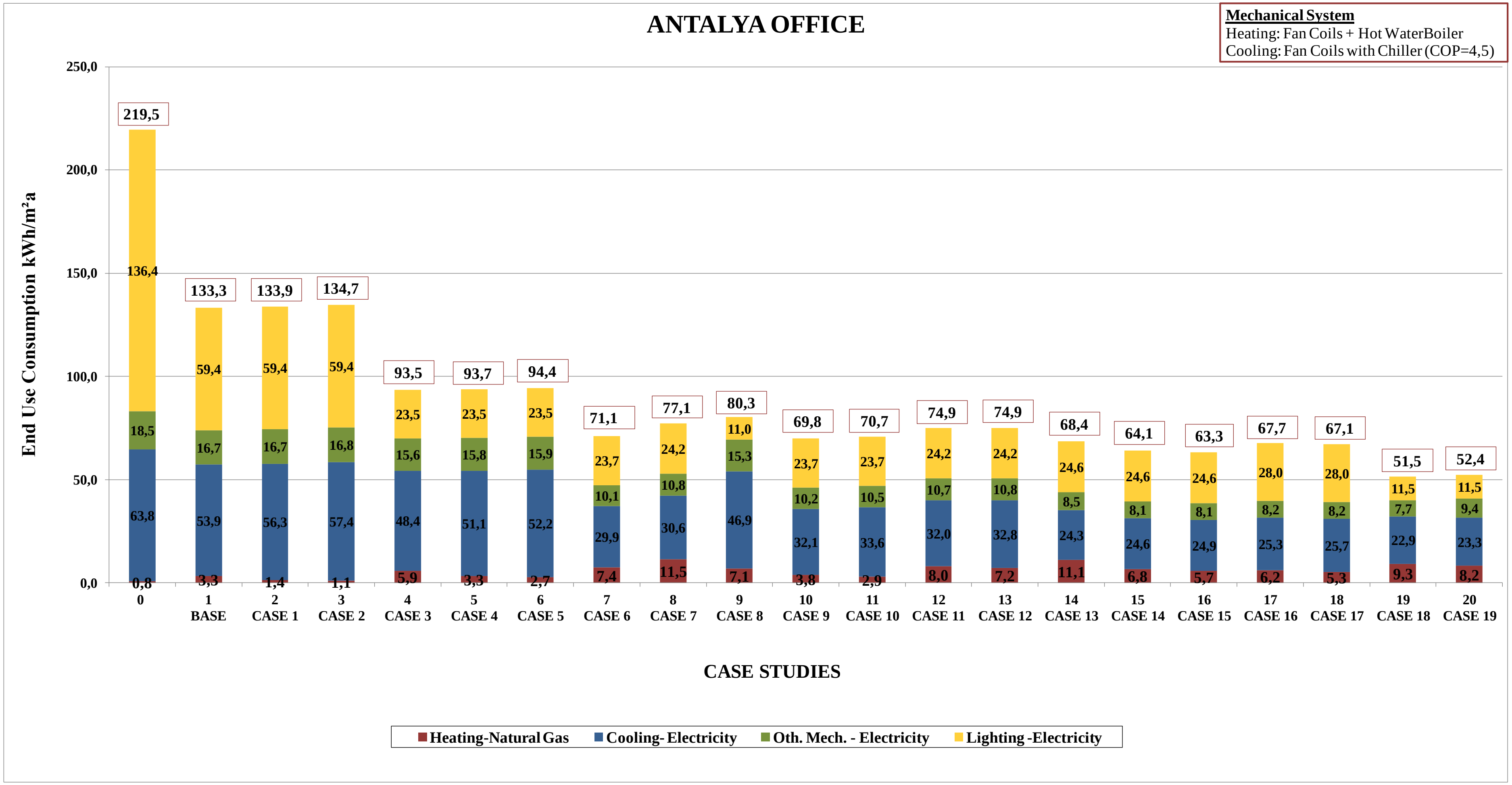


Figure 5.6 : Primary energy amounts in Ankara office with better chiller COP value.



	0	BASE	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8	CASE 9	CASE 10	CASE 11	CASE 12	CASE 13	CASE 14	CASE 15	CASE 16	CASE 17	CASE 18	CASE 19
Heating-Natural Gas	0,8	3,3	1,4	1,1	5,9	3,3	2,7	7,4	11,5	7,1	3,8	2,9	8,0	7,2	11,1	6,8	5,7	6,2	5,3	9,3	8,2
Cooling- Electricity	63,8	53,9	56,3	57,4	48,4	51,1	52,2	29,9	30,6	46,9	32,1	33,6	32,0	32,8	24,3	24,6	24,9	25,3	25,7	22,9	23,3
Oth. Mech. - Electricity	18,5	16,7	16,7	16,8	15,6	15,8	15,9	10,1	10,8	15,3	10,2	10,5	10,7	10,8	8,5	8,1	8,1	8,2	8,2	7,7	9,4
Lighting -Electricity	136,4	59,4	59,4	59,4	23,5	23,5	23,5	23,7	24,2	11,0	23,7	23,7	24,2	24,2	24,6	24,6	24,6	28,0	28,0	11,5	11,5
Total	219,5	133,3	133,9	134,7	93,5	93,7	94,4	71,1	77,1	80,3	69,8	70,7	74,9	74,9	68,4	64,1	63,3	67,7	67,1	51,5	52,4

Figure 5.7 : End use consumptions in Antalya office with better chiller COP value.

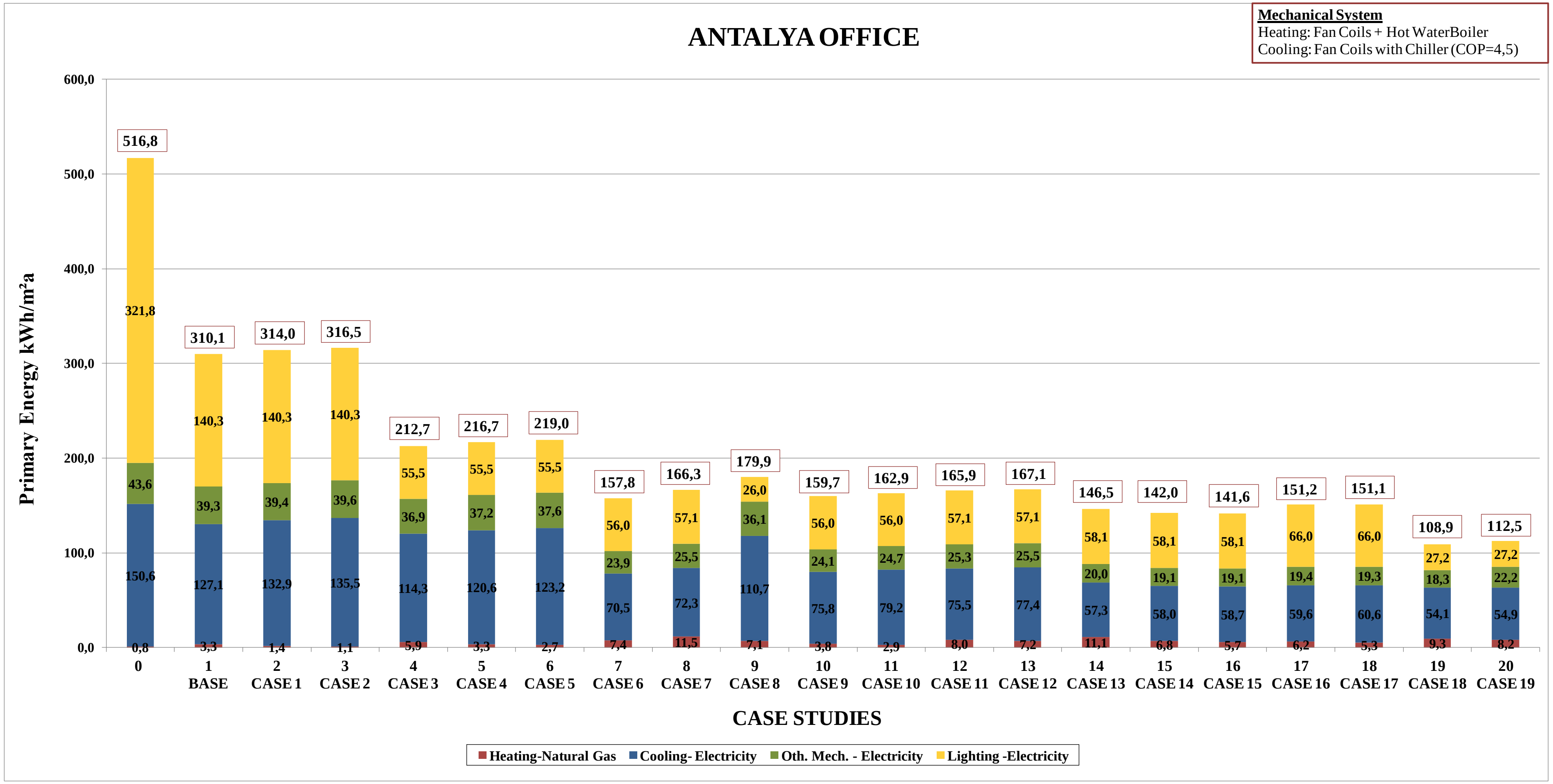


Figure 5.8 : Primary energy amounts in Antalya office with better chiller COP value.

Results of end use consumptions and primary energy amounts indicates the effect of mechanical system efficiency on building envelope retrofits and total energy efficiency. As seen from the graphs, when COP value of the chiller increased, benefits of retrofit actions also show a great increment in case study building. In Ankara, differently from office buildings with lower efficiency chiller, thermal insulation level required by TS 825 results with higher energy performance level with the higher efficiency chiller and heating loads become dominant as expected in this tempered-dry climate.

Since cooling loads are main driving force of energy consumption in Antalya, improvement in the cooling system of the office building decrease energy consumption for all scenarios remarkably. Considering the graphs shows the energy consumption per m^2, energy saving potential of the office buildings in hot-humid climatic region is very clear, however using this potential requires comprehensive standards on building energy performance with detailed studies including passive and active energy systems of buildings.

Energy performance levels of these retrofit scenarios with cooling system retrofit are given with Table 5.2 below. These energy performance levels are calculated according to Bep-Tr methodology and base scenario with 1,5 COP is defined as the baseline building for energy performance comparisons. It can easily seen that, influence of mechanical system efficiency on building energy performance with building energy retrofits is significant. In comparison to the cooling system with low efficiency chiller, especially in hot-humid climate, energy rating of the office building is remarkably improved. Since cooling is the main energy load of the example office building, envelope retrofits which are effective on decreasing the cooling load with the efficient cooling system provides high energy efficiency together.

Table 5.3 shows energy performance ratings of retrofit scenarios with cooling system as well. However, values in this table are calculated by considering base scenario with 4,5 COP is the baseline building for the comparison. From the difference between Table 5.2 and 5.3, it can easily seen that reference building defitnition is the main determining factor for energy classification and cost optimal analyses.

Table 5.2 : Energy performance levels of case study retrofit scenarios with cooling system retrofit according to baseline building with 1,5 COP.

	Retrofit Scenarios	Energy Class in Ankara	Energy Class in Antalya
	BASE (with 1,5 COP)	D	D
1	BASE (with 4,5 COP)	B	B
2	CASE 1	B	B
3	CASE 2	B	B
4	CASE 3	B	A
5	CASE 4	B	A
6	CASE 5	B	A
7	CASE 6	B	A
8	CASE 7	B	A
9	CASE 8	A	A
10	CASE 9	A	A
11	CASE 10	A	A
12	CASE 11	B	A
13	CASE 12	B	A
14	CASE 13	B	A
15	CASE 14	B	A
16	CASE 15	B	A
17	CASE 16	B	A
18	CASE 17	B	A
19	CASE 18	A	A
20	CASE 19	A	A

Table 5.3 : Energy performance levels of case study retrofit scenarios with cooling system retrofit according to baseline building with 4,5 COP.

	Retrofit Scenarios	Energy Class in Ankara	Energy Class in Antalya
1	BASE	D	D
2	CASE 1	D	D
3	CASE 2	D	D
4	CASE 3	B	B
5	CASE 4	B	C
6	CASE 5	B	C
7	CASE 6	B	B
8	CASE 7	B	B
9	CASE 8	B	B
10	CASE 9	B	B
11	CASE 10	B	B
12	CASE 11	B	B
13	CASE 12	B	B
14	CASE 13	B	B
15	CASE 14	B	B
16	CASE 15	B	B
17	CASE 16	B	B
18	CASE 17	B	B
19	CASE 18	A	A
20	CASE 19	A	A

According to EPBD requirements, cost of these retrofit actions are also calculated in order to assess the primary energy amounts together with the global costs. Global cost calculations are made for each retrofit action and for different calculation periods which are 30, 20, 10 and 5 years. Results for each city with each chiller efficiency given seperately in figures including global costs for all calculation periods. Deriving cost optimal levels of several retrofit actions is possible by using global cost - primary energy balance.

Figure 5.9 includes the global cost and primary energy varibles for the office building in Ankara with 1,5 COP value and for each calculation period. Figure 5.10 displays the same analyses for the office building in Antalya. Figure 5.11 and 5.12 shows global cost – primary energy analyses for the office building respectively in Ankara and Antalya with 4,5 COP value. In the graphs, each point represents cost calculation and primary energy calculation of a retrofit scenario and numbers of the scenarios are written near the points.

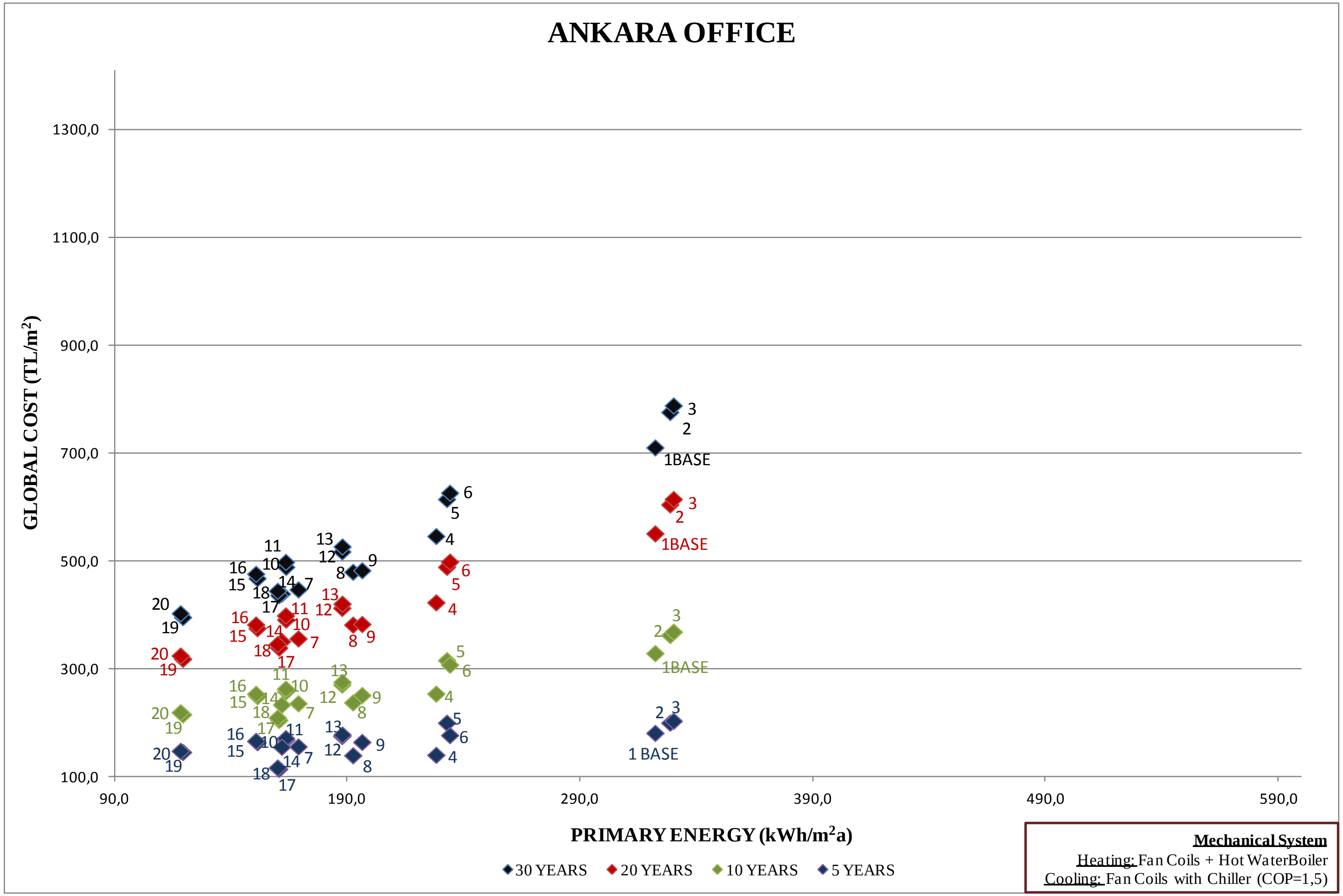


Figure 5.9 : Global costs of retrofit actions on Ankara office.

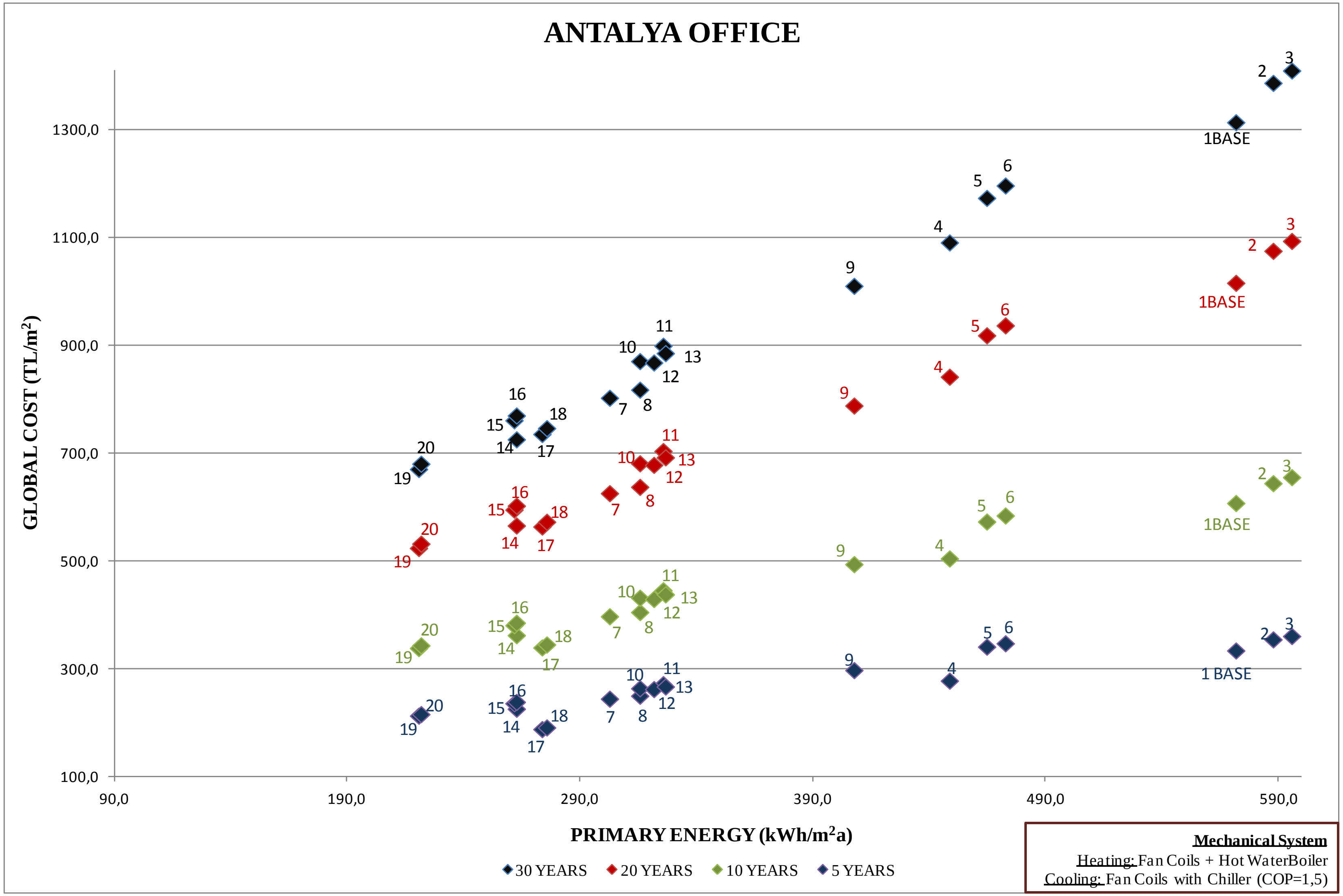


Figure 5.10 : Global costs of retrofit actions on Antalya office.

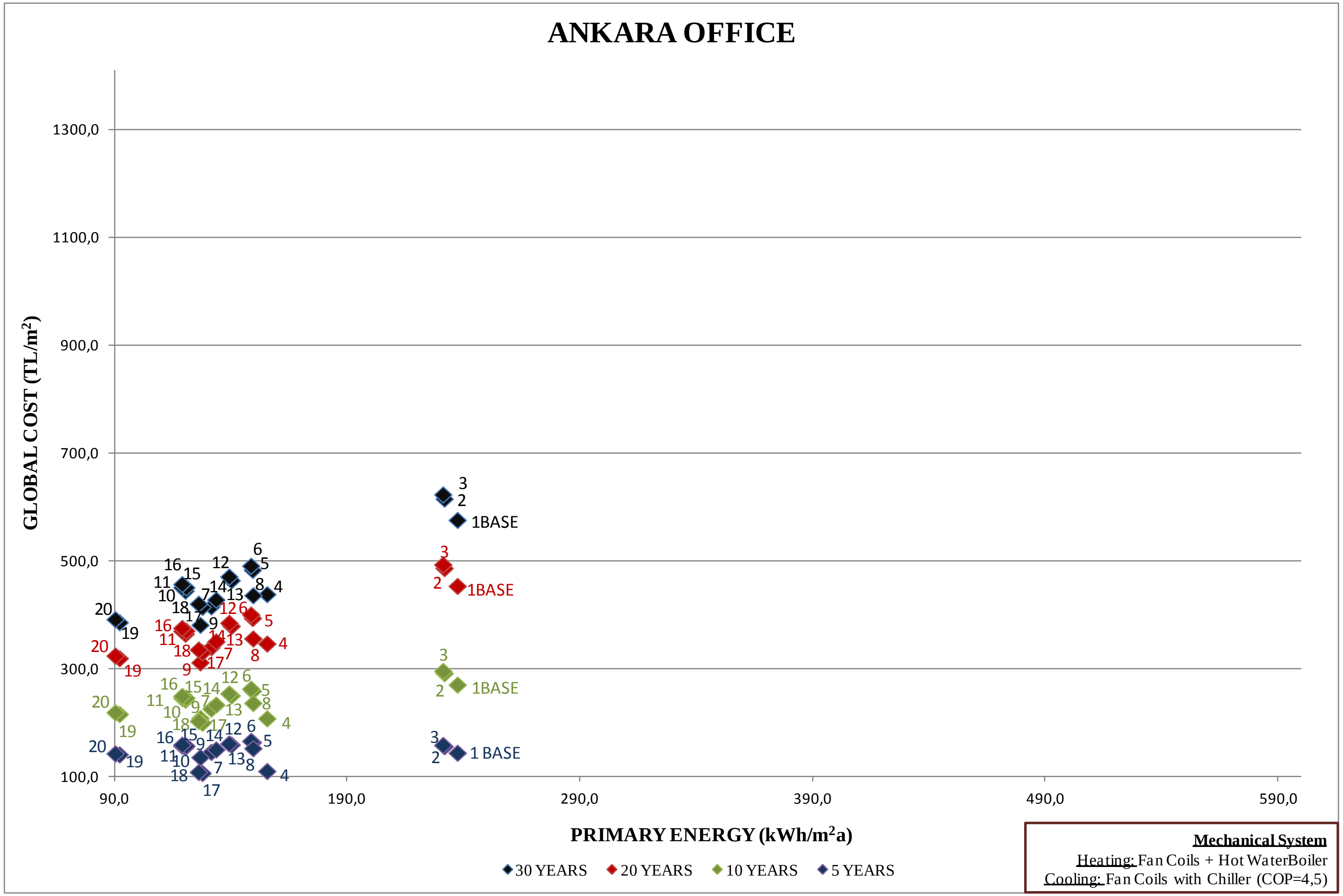


Figure 5.11 : Global costs of retrofit actions on Ankara office with better chiller COP value.

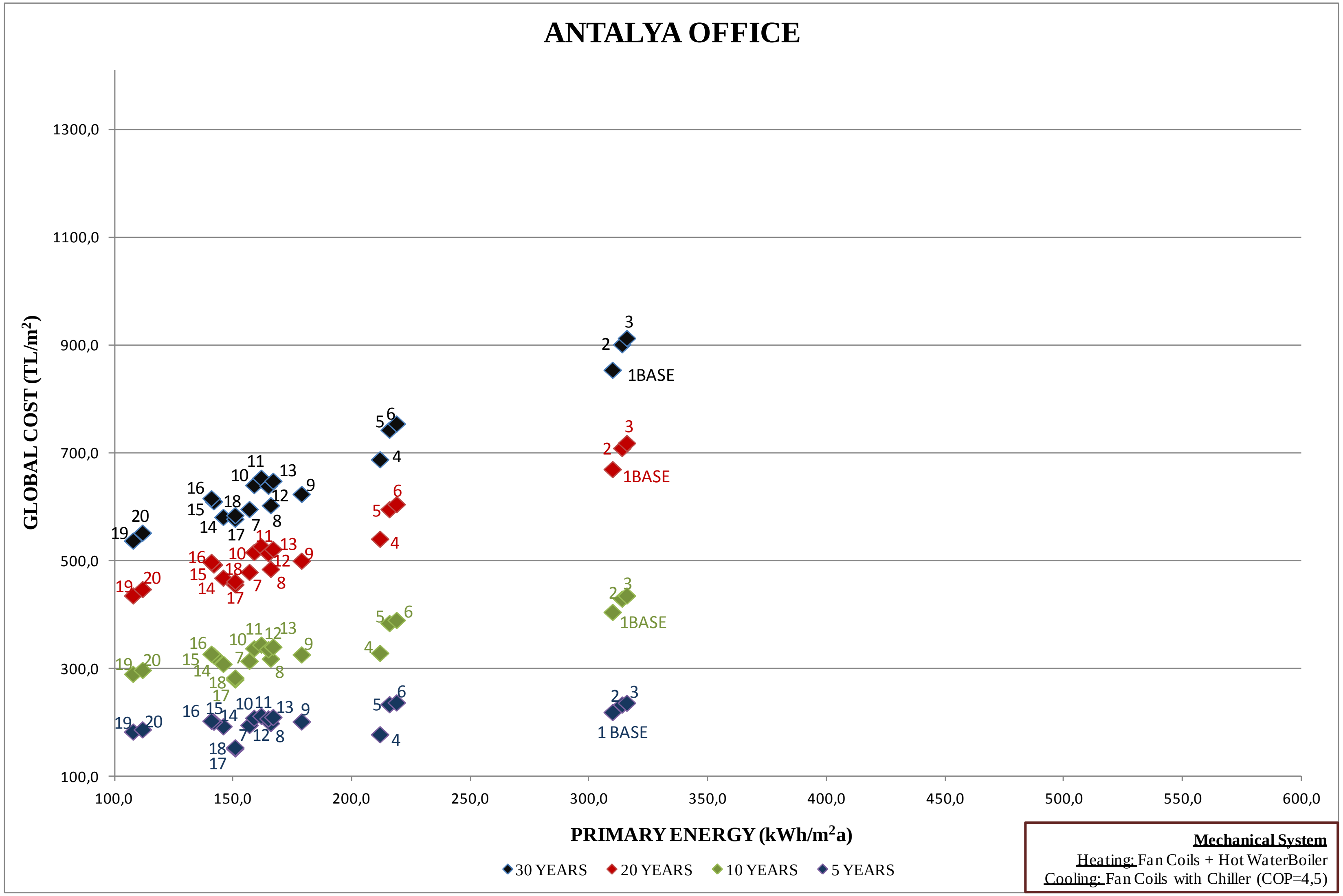


Figure 5.12 : Global costs of retrofit actions on Antalya office with better chiller COP value.

Results display different local cost-optimum points through retrofit actions. Both in Antalya and Ankara, results change in a similar way according to calculation periods. Due to labour costs are lower and are decreasing the global cost with national conditions, annual energy costs are very effective on global cost calculations. Therefore, cost optimal levels in analyses of longer periods such as 20 and 30 years differs from the shorter calculation periods as 5 and 10 years. In longer calculation periods, annual costs are dominant factors and although initial investment cost increases with new investments, global cost is not affected from the increment and all positive investments result with cost optimal energy efficiency in the example office building. However in shorter calculation periods, portion of the investment cost increase and some investments with greater costs move away from cost-optimal point.

There are also differences in results depending on the climate and cooling system efficiency. Coordinates of some scenarios, such as scenario 9 with 20 and 30 years calculation period, differs according to the climate, however the cost-optimal points are the same retrofit scenarios in Ankara and Antalya in the analyses with the 1,5 COP value of chiller and with 5 and 10 years calculation periods. Because, the cooling load is the determining factor in both cities. Analyses with 4,5 COP value of chiller shows some differences between two city, where cost optimum point differs between scenario 14, 17 and 19. The reason is that, the office building in Ankara needs precautions against both heating and cooling loads while in Antalya, office building needs precautions mostly based on cooling loads. Cost savings of cost-optimal retrofit acitons are also remarkable, especially when both passive architectural parameters and active energy systems are taken into consideration together. While considering longer payback periods, most of the investments are feasible with positive effects on energy and cost savings.

As a result of these analyses, it is possible to mention that, free cooling and natural ventilation strategies can be used in the office buildings which have a similar design with this case study office building in Antalya.

6. CONCLUSION

Requirements of recast EPBD are analysed in this thesis research and especially essential cost-optimality calculations of energy performance requirements are highlighted. Specifically, different retrofit scenarios for an example office building are studied in terms of cost optimality that is described in recast EPBD. For the case study, the office building is considered as located in Antalya and Ankara. Tested cost calculation periods range between 5 and 30 years.

As explained within this study, establishment of reference building is a very important base for cost optimality calculations and shall be defined for both new and existing buildings. Because of the lack of information in Turkey about the characteristics of buildings and building components, especially for the existing building stock, defining the reference building is a big challenge and it is not possible without comprehensive investigations and studies. Assumptions on reference building definition have significant impact on results.

In this study, cost optimal levels of minimum energy performance requirements are studied through a sample office building retrofit only. However, the cost optimality should be studied in detail for each building typology such as single family houses, apartment blocks, offices and other non-residential building typologies including new and existing ones separately. Additionally, results of this research show that, each different climatic zone of Turkey requires different reference building definitions for cost-optimality calculations. Reference building studies are also needed for revising minimum energy performance requirements for all climatic regions in Turkey.

Defining energy efficiency measures, which are used in the cost optimality analyses, is also an important phase. Innumerable measures or packages of measures can be defined for the buildings, however making the selection between these is related with detailed analyses and experience. National results can be affected from the wrong decisions. In this study, several measures are examined, but in national studies, number of these should be increase in order to define most appropriate cost optimal range.

Results of the analyses points out the necessity of coherence between the minimum energy performance requirements and national mandatory standards. Especially in hot-humid climatic region as Antalya, precautions against heating loads, such as thermal insulation requirements of TS 825 standard, increase cooling energy consumption of the example office building. The reason is that, heating degree day regions of TS 825 is not coherent with real climatic regions of Turkey. As an example, in II. degree day region, both cities in tempered humid climate and in hot dry climate are included. For these cities, same thermal requirements are obliged with the standard which is focusing on just heating energy conservation. Therefore, national standards have to be examined in terms of recast-EPBD and to be revised considering climatic regions of Turkey and cooling loads of the buildings. Not only energy points of view but also from cost point of view, requirement of this mandatory standard is not a realistic objective considering the obligations of recast EPBD on cost optimal levels of energy performance requirements. Therefore, for Turkey, cost-optimality analyses of different energy efficiency measures shall be done individually for different climatic zones and also legislative requirements shall be examined in terms of recast EPBD.

When cost optimality analyses of different retrofit investments are assessed with longer calculation periods such as 20 and 30 years, additional investments mostly result with lower global costs against expectations due to lower labor cost in comparison to EU level and the effect of the annual energy costs is the main driver in Turkey. Therefore, analyses with shorter calculation periods such as 10 and 5 years have been also carried out in the study considering perspective of the prospective investors are not open to long term payback period. The calculation period of the global cost is a critical issue for national calculations and has to be decided according to national interests.

Another point is that, the cost analyses in this research are done according to individual perspective. However, making calculations from macro-economic perspective is another alternative if societal benefits dominate. Selection of the calculation perspective has to be decided before analyses.

Convincing is also a key issue for cost optimum retrofits in terms of investor and designer. National investors avoid the investments with long term benefits even analyses show considerable savings during long term such as 25 or 30 years. Since energy retrofits of buildings also have influence on architectural design of the building and the envelope, convincing the designer is another important aspect as well. Thus, cost effective retrofits shall be obliged with national legal arrangements.

The importance of cost optimality studies for Turkey is clear and also compulsory in order to prevent financial losses and waste of time. Therefore, further investigations on several steps of this calculation procedures has to be performed by experts to finalize the solution for cost optimal of minimum energy performance requirements for Turkey.

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