ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A NEW APPROACH TO IDENTIFY ACHIEVABLE NEARLY-ZERO ENERGY BUILDING TARGETS FOR EXISTING BUILDING RETROFITS

Ph.D. THESIS

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

MEVCUT BİNA İYİLEŞTİRMELERİNDE ULAŞILABİLİR YAKLAŞIK SIFIR ENERJİ HEDEFLERİNİN BELİRLENMESİ İÇİN YENİ BİR YAKLAŞIM

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KASIM 2017

Neşe GANİÇ SAĞLAM, a Ph.D. student of ITU Graduate School of Science Engineering and Technology student ID 502122066, successfully defended the dissertation entitled "A NEW APPROACH TO IDENTIFY ACHIEVABLE NEARLY-ZERO ENERGY BUILDING TARGETS FOR EXISTING BUILDING RETROFITS", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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October 2017 Neşe GANİÇ SAĞLAM
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ABBREVIATIONS

AC	**:** Abbreviation of Split Type Air Conditioners Retrofit
ASHRAE	**:** American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEP-TR	**:** National Building Energy Performance Calculation Methodology of Turkey
BPIE	**:** Building Performance Institute Europe
BOI	**:** Abbreviation of Boiler Retrofit
CBRT	**:** Central Bank of the Republic of Turkey
CEN	**:** European Committee for Standardization
CHW	**:** Abbreviation of Central Domestic Hot Water System Retrofit
COP	**:** Coefficient of Performance
DHW	**:** Domestic Hot Water
EC	**:** European Commission
EN	**:** European Standards
EPBD recast	**:** Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings
EPS	**:** Expanded Polystrene
EU	**:** European Union
GL	**:** Abbreviation of Glazing Retrofit
HVAC	**:** Heating, Ventilation and Air Conditioning
IEA	**:** International Energy Agency
IESNA	**:** The Illuminating Engineering Society of North America
IN	**:** Abbreviation of Heat ınsulation Retrofit
IWEC	**:** International Weather for Energy Calculations
LED	**:** Lighting Emitting Diode
LPD	**:** Lighting Power Density
MS	**:** Member States
NPV	**:** Net Present Value
NZEB	**:** Nearly Zero Energy Building
PV	**:** Photovoltaic
R&D	**:** Research and Development
RB	**:** Reference Building
REHVA	**:** Federation of European Heating, Ventilation and Air Conditioning Associations
RF	**:** Abbreviation of Raidant Floor Heating System Retrofit
SEER	**:** Seasonal Energy Efficiency Ratio
SHGC	**:** Solar Heat Gain Coefficient
SP	**:** Solar Thermal System
TL	**:** Turkish Lira
TS	**:** Turkish Standard
TSE	**:** Turkish Standards Institution
TUBITAK	**:** The Scientific and Technological Research Council of Turkey

TURKSTAT : Turkish Statistical Institute
VRV : Variable Refrigerant Volume System
XPS : Extruded Polystrene

SYMBOLS

$C_g\,(\tau)$	**:** Global cost over the calculation period
C_I	**:** Initial investment cost
$C_{a,i}\,(j)$	**:** Annual cost during yera i for measure j
$C_{s,a}$	**:** Annual energy cost savings
f_{pv}	**:** Present value factor
PP	**:** Simple payback period
$R_d\,(i)$	**:** Discount factor of year i
R_R	**:** Real discount rate
R	**:** Market interest rate
R_i	**:** Inflation rate
T_{vis}	**:** Visible transmittance
U	**:** Heat transfer coefficient
$V_{f,\tau}\,(j)$	**:** Residual value at the end of calculation period
λ	**:** Thermal conductivity

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A NEW APPROACH TO IDENTIFY ACHIEVABLE NEARLY-ZERO ENERGY BUILDING TARGETS FOR EXISTING BUILDING RETROFTIS

SUMMARY

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings aims to improve energy performance of buildings since the building sector represents 40% of the energy consumption. Nearly-zero energy building (NZEB) concept was also introduced with this directive called EPBD recast.

NZEB is described in EPBD recast as a building with a very high energy performance. It is also expected that the required energy is mainly met by the renewable energy sources. As seen from this definition, a certain energy performance level has not been identified for NZEBs, thus the NZEB level should be identified at national level. The target of the Directive related to NZEBs points at year 2021 as the deadline for ensuring all new buildings are constructed as NZEBs. This requirement directly links the NZEB concept with the cost-optimality concept by expecting that starting from 2021 NZEB level will be the minimum energy performance requirement for buildings.

Besides the new buildings, EPBD recast includes NZEB requirements for existing building retrofits as well. Cost-effective transformation of the existing buildings into NZEBs is obliged and correspondingly increasing number of NZEBs is targeted. However, any deadline has not yet been specified for these requirements related to retrofitted NZEBs.

This dissertation presents an approach to identify achievable NZEB targets for existing building retrofits. The approach regards the NZEB level as future cost-optimal level and adopts the comparative methodology framework introduced by the European Commission for cost-optimality calculations as the first phase for investigating potential NZEB levels. This phase of the approach extends the cost-optimality calculations by integrating the analyses related to the effect of occupant behaviour on the cost-optimal levels. The second phase offers the sensitivity analyses as the main tool to investigate potential NZEB levels and determine the financial gap between existing cost-optimal levels and the NZEB level. At the end of this phase proposals are prepared for bridging these gaps. Finally, the third phase focus on the national decision making procedure on NZEB definitions. Although the policy-makers are in charge of this phase, this approach proposes a general frame to present the relation between decision-making process and the previous analyses.

A sample implementation of the proposed approach is also presented in this dissertation. It was applied on a reference residential building in Turkey. Results obtained from this sample implementation emphasize the necessity of following a comprehensive approach in order to achieve promising cost-optimal levels for building retrofits. Moreover, this implementation displays the significant effect of conscious occupant behaviour on the results and points at the importance of awareness-raising activities for building occupants in terms of achieving improved NZEB levels.

The approach proposed in this dissertation provides a whole approach for identifying national targets for retrofitted NZEBs. It brings a new perspective by moving from scientific point of view to enforcement and presents an improved approach by integrating the occupant behaviour effect into the calculations. Moreover, by regarding the sensitivity analyses as the main tool for investigating NZEB levels, the approach is expected to guide further research activities. Through sample implementation, coherence between the obtained results and the European NZEB targets is also demonstrated.

This approach also encourages further studies related to cost-optimality and NZEB concepts. The further studies can also be adapt the proposed approach to new buildings in order to be used in periodic assessment and revisions of NZEB definitions. Moreover, the approach can also be exended by integrating thermal comfort related calculations.

MEVCUT BİNA İYİLEŞTİRMELERİNDE ULAŞILABİLİR YAKLAŞIK SIFIR ENERJİ HEDEFLERİNİN BELİRLENMESİ İÇİN YENİ BİR YAKLAŞIM

ÖZET

Artmakta olan enerji tüketiminin dünyada yol açtığı çevresel ve ekonomik etkiler, bu konudaki kaygıların yükselmesine sebep olmuş ve enerji tüketiminin azaltılmasına yönelik planlama yapılması ihtiyacını ortaya çıkarmıştır. Enerji tüketiminde en büyük payın bina sektörüne ait olması sebebiyle, binalarda enerji verimliliğinin arttırılması, birçok ülkenin enerji tüketimini azaltmaya yönelik planında ana hedefler arasındadır. Avrupa Komisyonu tarafından da, bina sektöründeki enerji tasarrufu potansyelinden yararlanma konusunda hedeflerin belirlenmesi ve yaptırımların gerçekleştirilmesi amacıyla Binalarda Enerji Performansı Revize Direktifi (2010/31/EU) yayımlanmıştır. Yaklaşık sıfır enerji bina kavramı kısaca EPBD recast olarak adlandırılan bu direktifle ortaya çıkmıştır.

Yaklaşık sıfır enerji bina, EPBD recast tarafından çok yüksek enerji performanslı bina olarak tanımlanmaktadır. Binanın ihtiyaç duyduğu az miktardaki enerjinin ise çoğunlukla yenilenebilir enerji kaynakları kullanılarak karşılanması beklenmektedir. Bu açıklamadan anlaşıldığı gibi, binalarda yaklaşık sıfır enerji seviyesi için standart bir enerji tüketimi seviyesinden veya izlenmesi gereken bir hesaplama yönteminden bahsedilmemektedir. Ancak, EPBD recast, 2021 yılından itibaren inşa edilecek tüm yeni binaların yaklaşık sıfır enerji bina olmasını şart koşmaktadır ve bu nedenle her ülkenin kendi koşullarına uygun yaklaşık sıfır enerji hedefini belirlemesi gerekmektedir. 2021 yılını hedefleyen bu koşul, yaklaşık sıfır enerji seviyesini önümüzdeki yılların minimum enerji performansı gereksinimi haline getirmektedir ve aynı direktifle getirilen enerji verimliliğinde optimum maliyet kavramı ile doğrudan ilişkilendirmektedir. Bu açıdan bakıldığında, 2021 yılından itibaren binalarda yaklaşık sıfır enerji seviyesinin aynı zamanda uzun dönemde en düşük maliyetle sonuçlanan enerji performansı seviyesi olması beklenmektedir. Direktife göre, yeni bilanaların yanı sıra mevcut binalarda da maliyet etkin iyileştirmeler yapılarak, binaların yaklaşık sıfır enerji seviyesine ulaştırılması istenmektedir. Bu doğrultuda ulusal planların hem yeni binaları hem de mevcut binaların iyileştirilmesi dikkate alarak, yaklaşık sıfır enerji bina sayısını arttırma yönünde hazırlanması beklenmektedir.

Bu tezde, mevcut bina iyileştirmelerinde yaklaşık sıfır enerji seviyesine yönelik ulaşılabilir hedeflerin belirlenebilmesi için bir yaklaşım önerilmektedir. Yaklaşım, binalarda yaklaşık sıfır enerji seviyesi ile optimum maliyet seviyesi arasındaki ilişki üzerine kurulmuştur ve potansiyel yaklaşık sıfır enerji seviyelerinin belirlenmesinde, gelecekte optimum maliyet seviyesine erişebilecek en yüksek enerji performansı düzeyleri dikkate alınmaktadır.

Önerilen yaklaşım, üç aşamadan oluşmaktadır. İlk aşama, Avrupa Komisyonu tarafından binalarda enerji performansı seviyelerinin optimum maliyet düzeyinin belirlenmesi amacıyla yayımlanan çerçeve yöntemin ulusal koşullara uyarlamasıdır.

Ancak bu aşamada, Avrupa Komisyonu tarafından önerilen çerçeve yönteme kullanıcı davranışlarının etkisi de entegre edilerek yöntemin kapsamı genişletilmiştir. Böylelikle, bina enerji performansı üzerinde etkili olan kullanıcı davranışlarının optimum maliyet seviyesine etkisi de dikkate alınmaktadır.

Yaklaşımın ikinci aşaması, potansiyel yaklaşık sıfır enerji seviyelerinin duyarlılık analizleri aracılığıyla belirlenmesidir. Duyarlılık analizleri, hâlihazırda Avrupa Komisyonu tarafından yayımlanan çerçeve yöntemin bir adımıdır ancak bina enerji performansında optimum maliyet seviyesinin özellikle ekonomik değişkenlere karşı duyarlılığını analiz etmede kullanılmaktadır. Bu yaklaşımda ise duyarlılık analizlerine farklı bir işlev yüklenmiştir. Bu analizler binalar için potansiyel yaklaşık sıfır enerji seviyelerinin belirlenmesinde temel araç olarak kullanılmakta ve yaklaşımın en önemli aşamasını oluşturmaktadır. İkinci aşamanın sonucunda, bina enerji performansı konusunda karar vericiler için potansiyel yaklaşık sıfır enerji seviyeleri ve seviyenin ulaşılabilir olması için gerekli koşullar sunulabilmektedir.

Yöntemin üçüncü aşaması, önceki iki aşamada elde edilen sonuçların karar verici yetkililer tarafından değerlendirilmesi, buna bağlı olarak mevcut binalar için yaklaşık sıfır enerji seviyelerinin belirlenmesi ve belirli aralıklarla takip edilerek güncellenmesini içermektedir. Her ne kadar bu aşamada izlenecek yöntem karar vericilerin tercihine bağlı olsa da, hem yaklaşımın bütüncül olarak ifade edilmesi, hem de yetkililere yol yostermesi açısından bu aşama için de öneri getirilmiştir.

Yukarıda özetlenmiş olan yaklaşım açıklandıktan sonra, yaklaşımın örnek uygulaması da gerçekleştirilmiştir. Bu uygulama, Türkiye'deki çok katlı apartman binalarını temsil eden bir referans bina üzerinde ve üç farklı iklim bölgesi dikkate alınarak yapılmıştır. Sıcak nemli iklim bölgesini temsilen Antalya ili, ılımlı menli iklim bölgesini temsilen İstanbul ili ve soğuk iklim bölgesini temsilen Erzurum ili iklim verileri kullanılmıştır.

Örnek uygulamada öncelikle, ele alınan referans binanın enerji performansı seviyeleri için optimum maliyet düzeyi tespit edilmiştir. İlk hesaplamalarda, istatistiklere bağlı olarak belirlenen referans kullanıcı davranışları dikkate alınmıştır. Daha sonra, kullanıcıların binanın enerji performansına etki eden davranışlarında değişiklik olması durumu için hesaplamalar tekrarlanmıştır. Bu analizler için örnek olarak pencere açıklıklarının kullanıcılar tarafından bilinçli kontrolüyle doğal havalandırmadan yararlanılarak, binanın soğutma ihtiyacının azaltılması ele alınmıştır.

Önerilen yaklaşımın ilk aşamasının seçilen referans bina için uygulanması sonucunda, Türkiye'deki çok katlı apartman binalarında maliyet etkin enerji tasarrufu potansiyelinin %70'in üzerinde olduğu görülmüştür. Kullanıcıların pencere açıklıklarının kontrolüne yönelik bilinçli davranışları ise enerji tüketimini ve bu tüketimden kaynaklı enerji giderlerini azaltarak maliyet etkin enerji tasarrufu potansiyelini %80'in üzerine çıkarmaktadır. İlk aşamanın sonucunda ayrıca, iklim özelliklerinin beklenildiği gibi hem ulaşılan enerji performansı seviyeleri açısından hem de etkin iyileştirme tedbirleri açısından etkili olduğu görülmüştür. Elde edilen sonuçlar, analiz edilen enerji verimliliği tedbirlerinin tekil olarak uygulanmasının yerine bir araya getirilerek tedbir paketleri halinde uygulanmasının hem enerji performansı hem de uzun dönem maliyet açısından daha etkili olduğunu göstermiştir.

Seçilen referans bina ve iklim koşulları için optimum maliyet seviyesinin belirlenmesinin ardından önerilen yaklaşımın ikinci aşaması uygulanmıştır. Bu aşamada öncelikle uygulanacak duyarlılık analizi senaryoları belirlenmiştir. Seçilen senaryolar indirim oranı ve enerji fiyat artışı gibi ekonomik değişkenlerin yanı sıra yardım ve teşvikler veya araştırma geliştirme faaliyetleri sonucunda meydana gelebilecek potansiyel ilk yatırım maliyeti azaltımları ve maliyet hesaplama sürelerini de kapsamaktadır. Analizler sonucunda, referans konut binası için her üç iklim koşulu altındaki potansiyel yaklaşık sıfır enerji seviyeleri belirlenmiştir. Potansiyel yaklaşık sıfır enerji seviyelerinin mevcut optimum maliyet seviyesi ile arasındaki finansal açık tespit edilerek, bu açığın kapatılmasına yönelik öneriler geliştirilmiştir. Öneri geliştirme aşamasında enerji verimliliği iyileştirme yatırımlarının geri ödeme süreleri hesaplanmış ve teşvik amaçlı sunulabilecek düşük faizli kredi seçeneği için sağlanması gereken kredi miktarları ve geri ödeme süreleri belirlenmiştir. Ayrıca, Türkiye'deki kentsel dönüşüm süreci göz önünde bulundurularak kredi ödeme süreleriyle mevcut binanın kalan ömrü arasında kurulması gereken bağlantı da açıklanmıştır.

Önerilen yaklaşımın üçüncü aşaması karar verici ve kanun koyucu yetkililer tarafından uygulanacağından bu bölümün örnek uygulaması gerçekleştirilmemiştir. Ancak hem yaklaşımın ikinci aşamasının sonunda hem de tartışma bölümünde bu aşamaya yönelik öneriler bulunmaktadır.

Literatürdeki yaklaşık sıfır enerji binalar ile ilgili çalışmalar, konuya çoğunlukla bu binaların çok yüksek enerji performansı seviyesine sahip olması yönünden yaklaşmakta ancak optimum maliyet düzeyi ile ilişkilendirmemektedir. Mevcut binaların maliyet etkin iyileştirilmesiyle ilgili bazı çalışmalar ise yalnızca ulaşılan sonuçları tartışırken elde edilen bulguları yaklaşık sıfır enerji hedefleriyle ilişkilendirmektedir. Mevcut bina iyileştirmeleri için hem yüksek enerji performansı seviyesini, hem de bu seviyenin optimum maliyet seviyesiyle ilişkisini dikkate alan az sayıda araştırma bulunmaktadır. Ancak bu çalışmalarda da karar vericilere öneri sunulmasını hedefleyen ve potansiyel yaklaşık sıfır enerji seviyelerinin belirlenmesine yönelik kapsamlı bir yaklaşım sunulmamaktadır. Bu açıdan bakıldığında, tezde önerilen yaklaşım, konuya yeni bir bakış açısı kazandırmaktadır. Ayrıca, kullanıcı davranışlarının optimum maliyet seviyesi hesaplarına dahil edilmesi ve duyarlılık analizlerinin yaklaşık sıfır enerji seviyelerinin araştırılmasında bir araç olarak kullanılması gibi yeni yaklaşımlar gelecek araştırmalara yol gösterici olacaktır.

Tezde önerilen yaklaşım kullanılarak elde edilen sonuçlara göre, Türkiye'deki mevcut çok katlı konut binalarındaki iyileştirmeler için potansiyel yaklaşık sıfır enerji seviyeleri arasında ulaşılabilir en düşük enerji tüketimi seviyesi, analiz edilen iklim bölgesine bağlı olarak, yıllık 41.8 kWh/m^2y ve 63.2 kWh/m^2y arasında değişmektedir. Bu değer Avrupa Birliği ülkelerinin belirlemiş oldukları yaklaşık sıfır enerji seviyeleriyle kıyaslandığında benzerlik göstermektedir.

Elde edilen sonuçlar kullanıcı davranışlarının maliyet optimum enerji seviyesi üzerinde etkili olduğunu ve kullanıcıların bina enerji tüketimi konusunda bilinçlendirilmesinin hem enerji kaynakları açısından hem de ekonomik açıdan tasarrufla sonuçlanacağını göstermektedir.

Yaklaşımın örnek uygulamasına ait sonuçlar ayrıca bina enerji perofrmansında optimum maliyet düzeyinin belirlenebilmesi için yapılan çalışmalarda, bina kabuğuna, bina servis sistemlerine ve yenilenebilir enerji kullanımına yönelik enerji verimliliği iyileştirmelerinin birlikte değerlendirildiği kapsamlı yöntemlerin izlenmesi gerektiğini göstermektedir.

Duyarlılık analizlerinin, potansiyel yaklaşık sıfır enerji hedeflerinin belirlenmesinde yararlı bir araç olduğu görülmüştür. Bu nedenle, önerilen yaklaşımın yeni binalar için uyarlanması önerilmektedir. Ayrıca, bu uyarlamanın yanı sıra, referans konut binası için uygulanmış olan bu yaklaşımın diğer mevcut bina tipleri için de uygulanması önerilen bu yaklaşımı güçlendirecektir. Ek olarak, önerilen yaklaşım, ilerideki araştırmalarda ısıl konfor analizlerinin de adapte edilmesiyle detaylandırılarak geliştirilmeye açıktır.

1. INTRODUCTION

Energy consumption in the world has been increased in recent years. The report of International Energy Agency (IEA) declares that world's total final energy consumption increased from 4661 Mtoe to 9425 Mtoe in forty-one years between 1973 and 2014 (International Energy Agency, 2016). The report also demonstrates that, although energy generation from renewable energy sources showed an increase in this period, non-renewable energy sources still constitute the majority. Therefore, depletion of energy sources is a critical problem and moreover, environmental problems also occurred as a consequence of increasing energy consumption. These problems have raised deep environmental concerns about future and necessity of taking precautions appeared.

Precautions against the increase in energy consumption are primarily directed at the sectors consuming the highest amount of energy which constitute the largest energy saving potential accordingly. The sector consuming the highest amount of energy in the world was declared as buildings sector by IEA as shown in Figure 1.1 below (International Energy Agency, 2013). Therefore, buildings sector is seen as one of the key fields to introduce actions targeting energy efficiency.

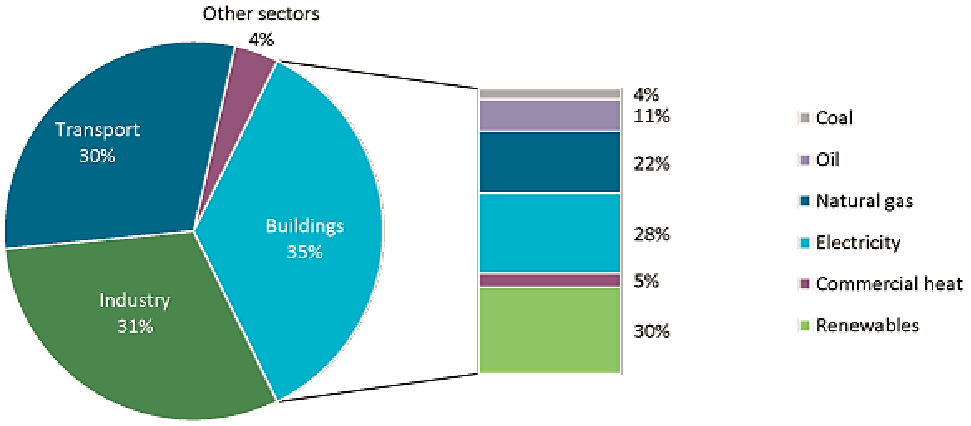


Figure 1.1 : Final energy consumption by sector and buildings energy mix, 2010 (International Energy Agency, 2013).

In order to utilize energy saving potential lying on the building sector in practice, governments have been establishing different mechanisms based on specific laws, regulations, standards, incentives, subsidies and other various promoting activities. European Union (EU) has also focused on utilizing this potential and has given consequence to building energy performance upgrades in recent years. In this context, the European Commission brought forward targets and policies to increase buildings' energy efficiency.

The main instrument of European Commission related to the energy performance of buildings is Directive 2010/31/EU (The European Parliament and The Council of The European Union, 2010). This directive is also called as EPBD recast and promotes improvement of energy performance of buildings considering cost effectiveness. In order to emphasize cost effectiveness for building energy performance improvements, EPBD recast introduced two new concepts: cost optimal levels of building energy performance and nearly zero energy buildings (NZEB). As explained in detail in Chapter 2, these two concepts are tightly linked with each other and both aim to keep expenses under control while increasing energy efficiency in buildings.

EPBD recast defines cost optimal level as the building energy performance level that results with the lowest cost for the considered calculation period and obliges EU Member States to identify national cost optimal levels. Existing requirements for minimum energy performance levels are needed to be revised if these are weaker than the cost optimal level.

NZEB, on the other hand, is a further target that points future and was defined in the Directive as "a building that has a very high energy performance". Briefly, NZEB level is assumed as not cost-optimal presently but represents a better energy performance level which is expected to be converged with the cost-optimal level in the future. The clarification of both the definition and numerical indicators for NZEB were left to the national decisions. These national definitions and targets are required to be approachable and realistic since all new buildings in EU are obliged to be NZEBs by 2021.

EPBD recast specifically address existing buildings as well and obliges Member States to provide cost effective transformation of existing buildings to NZEB. This transformation is crucial to ensure energy saving since Energy Efficiency Directive

2012/27/EU indicates that the highest energy saving potential is represented by existing building stock and therefore increasing the building renovation rate is essential to achieve future targets (The European Parliament and The Council of The European Union, 2012). Therefore EPBD recast also requires to present national plans for increasing the number of nearly zero energy buildings.

In order to achieve the targets set by European Commission, Member States are initially required to identify cost optimal and NZEB levels by following a national approach. The Commission intended to guide these national approaches and published a methodology framework to be adapted at national level (The European Commission, 2012a). The methodology framework is based on comparative assessment of expenses and savings within a long term period. In this way, it provides opportunity to select appropriate actions for increasing building energy performance and leads to the path for deriving cost-optimal levels. Since the cost-optimal and NZEB concepts are interrelated, this methodology framework also guides the national approaches for NZEB level definitions. However, a certain calculation method or an approach was not identified for NZEB level. Since NZEB definitions are required to be reasonable and achievable in terms of energy and economy and also required to be revised periodically, a convenient approach to identify achievable NZEB targets is necessary.

This PhD dissertation concentrates on the NZEB concept considering the deficiency in this area. Since the energy saving potential lying on the existing building stock is significant and the NZEB definitions for building retrofits are incomplete (BPIE, 2016), cost effective transformation of existing buildings to NZEBs is the main focus of the research.

Objective of the dissertation is to propose a new approach to identify achievable NZEB levels for retrofit of existing buildings by adapting the EU methodology framework at national level. The study regards NZEB level as the “future cost optimal level” and principally uses the sensitivity analyses as a tool to investigate the relevance of different energy performance levels as the future target. Although the last stage of the proposed approach refers directly to the policy, it mainly deals with the scientific approach that should be lied behind the decision. Therefore the study guides to develop solutions for bridging the financial gap between cost optimal and NZEB levels by determining the favourable fields which have priority to be supported for the national interests.

The approach introduced in this dissertation has three main phases. The first one is related to adaptation of the cost-optimal methodology framework with an innovative perspective incorporating the effect of occupant behaviour in cost-optimality analyses. The second phase is the main phase of the approach which utilises the sensitivity analyses as a tool to obtain potential NZEB levels which represent future cost-optimal levels. The third phase is related to decision-making on NZEB level that is in policy-makers' charge. Therefore only the main frame is put forward for this step in order to present the general context and relation with the previous phases. A sample implementation is also presented to demonstrate the proposed approach.

Regarding the target, the study first introduces the nearly zero energy building concept and the relation between cost-optimal and NZEB concepts within the frame of EU legislation in Chapter 2 and presents related literature on this recent notion. After this chapter was concluded with the recent progress in EU countries, building energy performance issue in Turkey was discussed in Chapter 3 since the sample implementation of the proposed approach was applied in Turkey as presented in the following chapters. The existing legislation in Turkey was examined in detail and up to date status is presented. Chapter 4 is the essence of the dissertation where the proposed approach is described in. In this chapter, proposed approach to identify achievable NZEB levels for renovation of existing buildings is explained in detail together with the conceptual context. In order to demonstrate the approach, it is implemented to a reference building representing existing high rise residential buildings in Turkey as presented in Chapter 5. The study is finalized with Chapter 6 and Chapter 7 where discussion and conclusion are introduced to discuss the main outcomes of this research activity, to explain concluding remarks and to display future research areas that have been opened after this dissertation.

With this context and structure, this research represents a global point of view on the NZEB concept. The procedure followed to propose solutions to bridge the gap between cost optimal and NZEB levels, which is based on an extended perspective of sensitivity analyses, can be followed in different countries to shape their national policy. Moreover, since the approach supports the decision making procedure for the national future plans, outcomes open new research areas for the near future.

2. NEARLY ZERO ENERGY BUILDING CONCEPT

Nearly zero energy building (NZEB) concept takes its origin from European Union (EU) legislation related to the building energy performance (The European Parliament and The Council of The European Union, 2010). Therefore, this chapter initially presents the significance of building energy performance within the whole energy strategy of EU in order to clarify the necessity of NZEBs. Afterwards, the chapter explains the NZEB concept within the legislative frame by providing information on definition, basis and requirements of the concept. Subsequently, a literature review on the concept and the recent progress in EU countries are illustrated.

2.1 Buildings as a Part of European Energy Strategy

In Europe, the largest share of the final energy consumption belongs to the building sector with 40% (The European Commission, 2011a). Therefore, maximizing energy performance of buildings is one of the key tools to achieve energy targets and is referred in future plans of EU.

In 2010, strategical targets were introduced with 2020 Energy Strategy of EU which are known as 20-20-20 targets (The European Commission, 2010). These targets aim to achieve 20% reduction in greenhouse gas emissions, 20% increase in energy efficiency and 20% share of renewable energy. This strategy regards buildings and transport as prior sectors for the following actions related to energy efficiency. Moreover, Energy Efficiency Plan 2011 of the European Commission (EC) indicates that buildings carry the biggest energy saving potential and correspondingly the plan focuses on the strategies to activate energy efficient renovation procedure for existing buildings (The European Commission, 2011a).

Beyond 2020, Energy Roadmap 2050 also puts particular emphasis on building energy performance in terms of both new buildings and existing building renovations and declares that NZEB should be the standard criteria to provide higher energy efficiency in buildings (The European Commission, 2011b).

In order to utilise the existing energy saving potential which lies in buildings, EC enacted specific legislation focusing on the energy performance of buildings. The recast of Energy Performance of Buildings Directive, Directive 2010/31/EU, is currently the main legal tool that leads EU Member States (MS) to set up minimum requirements for the energy performance of buildings (The European Parliament and The Council of The European Union, 2010). The NZEB concept was introduced within this directive which is also called EPBD recast. The Directive is explained in the following section.

2.2 Directive 2010/31/EU

Directive 2010/31/EU on the energy performance of buildings, also called EPBD recast (The European Parliament and The Council of The European Union, 2010), was established in 2010 to amend Directive 2002/91/EC (The European Parliament and The Council of The European Union, 2003). The aim of this Directive is to upgrade energy performance of buildings in EU considering indoor climatic conditions and cost-effectiveness. Although the previous directive (Directive 2002/91/EC) was also addressing the cost effectiveness of building energy performance measures, economic evaluation of the energy efficiency measures became more apparent with the new articles introduced in EPBD recast.

Specific to the economic evaluation of building energy performance levels, EPBD recast introduced the cost-optimality and NZEB concepts. These two interrelated concepts and relationship between them are explained below.

2.2.1 Relation between cost-optimality and NZEB concepts

Cost-optimality and NZEB are two concepts associated with each other. Cost optimal level definition provided in Article 2 of EPBD recast refers to the building energy performance level that results with the lowest cost for the considered calculation period. Article 5 of EPBD recast obliges Member States (MSs) to calculate cost optimal levels of building energy performance levels and to compare obtained results with the present national requirements for minimum energy performance of buildings. The national requirements are needed to be revised if these are less ambitious than the calculated cost optimal levels. The comparison and revisions are expected to be performed periodically.

In order to clarify the cost optimal calculation for MSs, the basis of the method is explained in Annex III and the European Commission was obliged and authorized to constitute a methodology framework in line with this basis. This expected framework was published in 2012 by EU Regulation No 244/2012 which supplements EPBD recast (The European Commission, 2012a). MSs are required to adapt this method to their national conditions and calculate the cost-optimal levels of energy performance requirements using the method.

Nearly zero energy building, instead, is defined in EPBD recast as “a building that has a very high energy performance” and the greater part of the energy demand is expected to be supplied by renewable energy sources. However, the absolute definition is left to the decision of national authorities. Article 9 of EPBD recast requires MS to identify NZEB levels since by 2021 all new buildings are expected to be NZEB while the deadline is 2019 specifically for public buildings. The European Parliament and the Council of the European Union (2010) sets the deadline as 2021 for new NZEBs while a certain deadline is not referred for existing buildings. However, MSs are obliged to draw national plans with the aim of increasing number of NZEBs considering both new and existing buildings. New buildings shall be designed and constructed as NZEB while existing buildings are required to be converted to NZEBs through a cost effective retrofit procedure. Therefore, MSs should propose a plan for cost effective transformation of the existing buildings into NZEBs in their national plans that are reported to European Commission.

Accordingly, while cost-optimality is a criteria for the existing actions, NZEB concept may be described as being a model for 2021. NZEB concept refers to a very high energy performance level which is not certain yet but known as more ambitious than cost-optimal level. Based on the requirements of EPBD recast regarding the regular review of national building energy performance requirements and the expectations related to NZEB, it is expected that by 2021 cost-optimal and NZEB concepts are needed to be converged (The European Commission, 2016). Therefore, cost-optimal methodology framework may also be used for investigating supportive tools and actions for achieving NZEB level (Buildings Performance Institute Europe, 2011).

2.2.2 Cost-optimal methodology framework

In order to supplement EPBD recast and provide a methodology framework for the cost optimal calculations, European Commission issued the EU Regulation No 244/2012 (The European Commission, 2012a). Annex I of this Regulation introduces the cost-optimal methodology framework which complies with Annex III of EPBD recast. In order to derive cost optimal energy efficiency levels for buildings, MS are obliged to adopt this framework in their national context. Moreover, national calculation approach, obtained results and comparison with the existing requirements in force are required to be reported to the Commission by MSs.

The cost optimal methodology framework, introduced with Annex I of the Regulation, is based on the following six stages (The European Commission, 2012a):

1) Definition of reference buildings representing the characters and energy performance related properties of national building stock,
2) Identification of energy efficiency measures and packages combining the measures to be analysed for reference buildings,
3) Calculation of reference buildings' net primary energy consumptions under the effect of energy efficiency measures and packages of measures applied,
4) Evaluating the global cost of the reference buildings that occur as a result of different energy efficiency measures and packages of measures,
5) Sensitivity analyses on the input data used in global cost calculations,
6) Derivation of cost optimal levels of energy performance requirements based on an assessment through coupling primary energy consumption and global cost results for each reference building.

As seen from the above-mentioned calculation steps, the cost-optimal methodology framework is based on the comparative analyses of the energy performance and economic provisions of different energy efficiency actions through an investigation on the representative buildings. Therefore each step of the methodology requires expertise and needed to be supported by research activities.

Due to the fact that climatic and economic circumstances are different in each country, the cost-optimal approach is required to be contextualized at national level. In order to guide MSs to adapt this framework into their national frame, European Commission published accompanying Guidelines for EU Regulation No 244/2012 (The European

Commission, 2012b) and EPBD recast (The European Parliament and The Council of The European Union, 2010). Guidelines is not a legally binding document however, it aims to provide extended explanations for the national applications in the structure of cost optimal methodology framework. Based on the EU Regulation No244/2012 and the Guidelines, requirements for the above-mentioned stages of the cost-optimal methodology framework are explained below.

As the first stage of cost-optimal methodology, national reference building establishment procedure requires specific attention since all of the following calculations and analyses are developed on established reference buildings and correspondingly obtained results through these representative buildings affect the main decisions at larger scales.

Reference building definition procedure mentioned in Regulation 244/2012 refers to a building which is representative of typical national building characteristics related to geometry, systems, energy performance, functionality, cost structure, climatic conditions and geographic location. These representative buildings should allow generalisation of the obtained results for the represented building stock since it is not possible to perform individual cost-optimal analyses for every single building.

The Regulation requires establishment of reference buildings for at least single-family houses, multifamily buildings, office buildings and other non-residential buildings with particular energy performance requirements. This procedure should cover both new and existing buildings. Although minimum numbers of reference buildings for each category are indicated as one for new buildings and two for existing building retrofits in the Regulation, Guidelines recommends having also sub-categories in order to represent the stock in a realistic way.

In order to ensure that reference buildings are definitely representative of the existing buildings, available data related to the existing building stock should be regarded as the main input to be analysed by the experts.

In order to define reference buildings with all properties affecting their energy performance, the required data refers to at least followings:

- the general information about building age, function, location and climatic condition
- architectural properties (i.e. building geometry, form, orientation, facades)

- thermo-physical properties of the building envelope (i.e. thermal transmittance (U value) and solar heat gain coefficients of the components, thermal bridges)
- building energy systems and their properties (i.e. system types, component efficiency and capacity, control systems)
- operation and occupancy patterns (i.e. schedules related to operating hours, internal heat gains, power densities, ventilation rates)

In accordance with the reference building definition in the Regulation, a reference building may be a hypothetical or a real building. Based on this, three different reference building definition methods are described in the literature (Corgnati et al., 2013):

1. Selection of real reference buildings
2. Establishment of hypothetical reference buildings
3. Establishment of example reference buildings

As a result of examination based on the above-mentioned statistical data; a real building, which represents typical characteristics of the building stock, may be selected if the real building is likely to represent these typical features (second method). Another method is to establish a theoretical reference building by combining typical building characteristics (third method). Considering that detailed data about the building stock may not be entirely available in every case, Corgnati et. al. (2013) refers to the TABULA project (Loga and Diefenbach, 2010) and recommends to use the first method to identify example reference buildings. This method is only acceptable in case of lack of data and requires substantial expertise to have convenient assumptions.

In order to analyse cost-optimal energy performance levels for the reference buildings, the second stage is the identification of the energy efficiency measures. The energy efficiency measures should be identified for each reference building considering the parameters affecting energy performance of buildings. Besides analysing the energy efficiency measures individually, The European Commission (2012b) recommends to analyse them as combined within energy efficiency packages. Moreover, the Regulation requires to include measures needed for achieving existing minimum energy performance requirements and measures needed for meeting NZEB levels. Indeed, single measures are insufficient to achieve NZEB level since a comprehensive renovation approach is required as shown in Figure 2.1 (The European Commission, 2014).

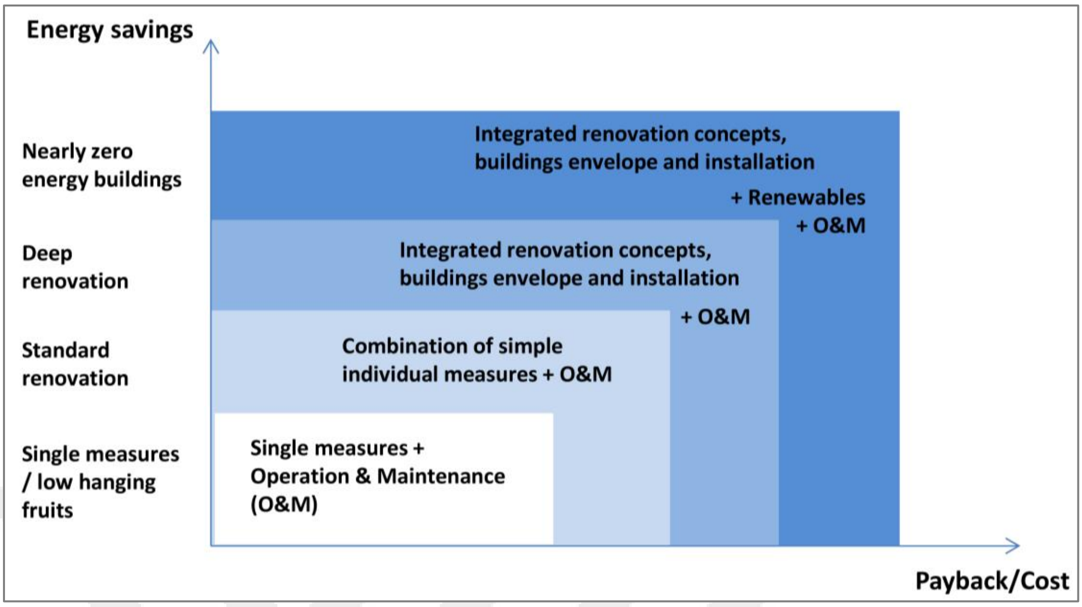


Figure 2.1 : Retrofit Categories (The European Commission, 2014).

The third stage of the cost-optimal methodology framework is the calculation of primary energy use achieved by means of identified energy efficiency measures and packages of measures applied to the reference buildings. In this step, according to the European Commission (2012a), energy consumptions for space heating and cooling, ventilation, domestic hot water (DHW) and lighting systems are required to be included in the calculations considering the whole year. The calculation procedure is based on the calculation of building energy use and conversion of the results to primary energy using primary energy conversion factors for each energy carrier. Energy produced by on-site renewable energy systems should also be calculated and subtracted from energy use and primary energy. The results should be expressed as net primary energy demand per unit useful floor area. MSs are independent to follow relevant CEN standards or to use their national calculation methods, however, Guidelines recommends to use a dynamic method in order to achieve reliable results. With the aim of ensuring reliable NZEB calculations, Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) published a book in cooperation with CEN, which clarifies the energy balance calculations for NZEB definitions (REHVA, 2013).

Since the methodology framework is based on comparative analyses of energy performance and economic assessment of different measures, the next stage of the method is calculating the global cost of energy efficiency measures. EU Regulation 244/2012 requires calculating global cost of different energy efficiency scenarios in terms of net present value. Net present value (NPV) is one of the tools used for investment decisions and considers the changes in the worth of money within time (Warnacut, 2016). In order to reflect time value of the money in NPV calculations, present value of future cash flows are calculated by using a discount rate and the evaluation considers the sum of these present values of cash flows (Rist and Pizzica, 2015).

The global cost calculation method introduced with EU Regulation 244/2012 relies on EN 15459 Standard (CEN, 2007) however, it offers two options for the calculation perspective. The first option is financial perspective which is also called individual end user perspective. This perspective regards the global cost as the sum of initial investment cost, annual costs and the residual value at the end of the calculation period. The financial perspective includes the taxes, charges and subsidies within the related cost categories and is calculated with Equation 2.1.

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right] \tag{2.1}$$

In Equation 2.1, τ indicates calculation period, in years. $C_g(\tau)$ is global cost over the calculation period, C_I is initial investment cost for the measure, $C_{a,i}(j)$ is annual cost during year i for measure j, $V_{f,\tau}(j)$ is residual value at the end of calculation period and $R_d(i)$ is discount factor of year i. The discount factor is calculated using Equation 2.2. given below.

$$R_d(p) = \left(\frac{1}{1 + R_R} \right)^p \tag{2.2}$$

In Equation 2.2, p is number of years and R_R is real discount rate. Real discount rate was calculated using Equation 3.

$$R_R = \frac{R - R_i}{1 + R_i} \tag{2.3}$$

In the formula R is the market interest rate and R_i is the inflation rate.

The second option for global cost calculation is macroeconomic perspective where the taxes, charges and subsidies are excluded while the cost of greenhouse gas emission are taken into consideration under another cost category which is called carbon cost.

Both options attempt to provide a comparative economic evaluation related to the energy performance of buildings. Therefore, the fixed expenses and the costs related to the building elements that does not affect the energy performance of the building are not included in the global cost calculations (The European Commission, 2012a).

As equations express, the calculation of the global cost in terms of present value is directly linked with the financial data such as market interest rate and inflation rate. Therefore a financial data gathering step is initially required. The financial data is mainly used for calculating the present value of annual costs.

After financial data gathering, calculation for each cost category should be made depending on the calculation perspective. Detailed descriptions and the calculation methods for the cost categories included in global cost calculation are explained below within the frame of existing building retrofits.

In order to calculate the initial investment cost (C_I) of retrofit measures, market cost based data should be collected. As identified by the European Commission (2012b), cost data gathering sources are construction projects, offers of companies and the databases based on market costs. It is important to include the taxes and charges when following financial perspective and exclude these in case of following macroeconomic perspective.

Annual cost ($C_{a,i}$) includes both replacement cost and running costs such as maintenance, operation and energy costs. The costs related to these cost categories should be calculated separately and be converted to the present value by using the calculated discount factor for their realization year.

Replacement cost represents periodic cost of a building component that occurs at the end of the lifespan as a result of change or repair. Accordingly, replacement cost calculation requires the investment cost and the lifespan of the component as the inputs. Information related to building envelope components are required to be derived from the manufacturers and/or related literature while the lifespan of the energy system components are provided within Annex A of EN 15459 standard (CEN, 2007).

Disposal costs at the end of the lifespan may also be included in the calculations however, it is not mandatory in accordance with the Regulation (The European Commission, 2012a).

Together with the lifespan of the components, maintenance costs including operation, repair and service costs are also expressed as the percentage initial investment cost within Annex A of EN 15459. Maintenance costs should be calculated using these percentages and investment costs of the components or systems.

Energy costs are one of the main input data of the global cost calculation. This cost category is classified separately from other operational costs since energy costs correspond to the annual energy consumption and related charges. Therefore energy costs calculation procedure has a direct connection with the outputs of third step where the energy consumption calculations are performed. Results related to the delivered energy, not covered by renewable energy systems, should be used for the calculation of energy costs. Moreover, data related to energy prices and tariffs should also be gathered for this cost category to obtain the annual energy cost. In order to calculate the present value of the energy costs, energy price development rates are needed. Information related to the energy prices development rates for EU Member States is provided within Annex II of the Regulation and the Guidelines of the European Commission (2012a, 2012b).

In order to calculate the periodic annual costs for certain number of years or for the whole calculation period, such as energy costs, present value factor may be used as an alternative simple approach instead of calculating the sum of the discounted costs for each year. Present value factor is calculated using Equation 2.4 [CEN, 2007].

$$f_{pv} = \frac{1 - (1 + R_R)^{-n}}{R_R} \tag{2.4}$$

Residual value ($V_{f,\tau}$) is the total remaining value of the building components based on their remaining lifespan at the end of the cost calculation period. The cost calculation period is indicated in the Regulation as 30 years for residential and public buildings while it is given as 20 years for other non-residential buildings. Present value of the residual value should also be calculated using the discount factor.

If the cost calculation considers macroeconomic perspective, carbon cost should be calculated based on annual greenhouse gas emissions and their prices provided in the

Regulation. The carbon price developments are also provided within Annex II of this Regulation.

Based on the calculation perspective, global cost of the energy performance scenarios are needed to be calculated for the reference buildings considering the above-mentioned cost categories.

After the completion of initial four stages, primary energy consumption and the global cost results are required to be assessed comparatively in order to obtain cost-optimal energy performance levels for reference buildings. For this assessment, primary energy consumption and the global cost results of different energy performance measures or packages of measures should be expressed on a cost-optimal graph. As shown in Figure 2.2 cost-optimal graph ensures to make a comparison between energy efficiency measures and packages by consisting of the horizontal axis showing the primary energy uses and the vertical axis showing the global costs of them. In the graph, the energy efficiency measure or package of measures which correspond to the lowest cost represents the cost optimal level for the analysed reference building.

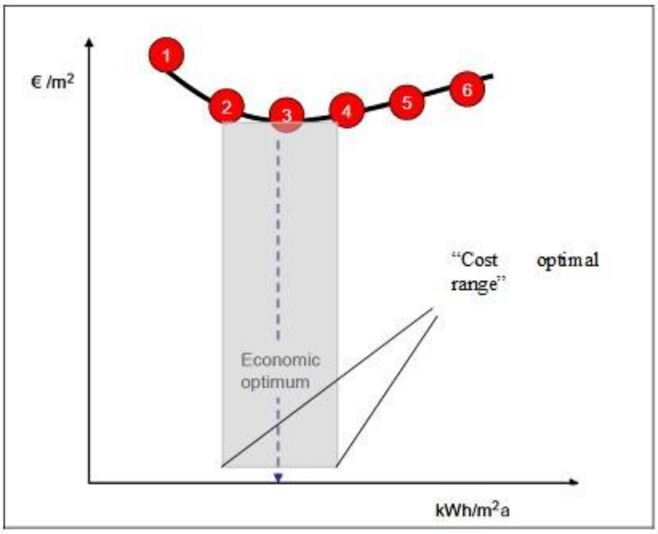


Figure 2.2 :A sample cost-optimal graph (The European Commission, 2012b).

The cost-optimal methodology framework requires sensitivity analyses on the global cost calculation inputs. Aim of these sensitivity analyses is to analyse the effect of main parameters which have an influence on the cost-optimal results. The requirements of EU Regulation are mainly related to the sensitivity analyses on economic indicators. For instance, it requires analysing at least two discount factors where one of them is 3%. Moreover, the Regulation requires to consider different energy price development scenarios within sensitivity analyses.

The obtained results of cost-optimal calculations should also be compared with the existing national requirements for minimum energy performance levels of buildings since the Regulation obliges to revise the regulations in case of a significant difference between cost-optimal levels and existing requirements.

2.3 Latest Research Activities on NZEB Concept

The number of studies related with NZEB concept is limited because this concept is almost recent. Since the calculation methodology explained by EPBD recast and complementary instruments is only an instructive framework and left the national definitions of NZEBs to national assessment of MS, research activities related directly with NZEB are commonly at national or regional level. The focus of these studies vary from NZEB requirements to policy implications related to NZEB definitions.

Szalay and Zöld (2014) proposed a method for setting NZEB requirements based on a large building sample and demonstrated this method for residential buildings in Hungary. The results are justified considering future projections and the suggested method is validated by comparing the results with European targets. Their research shows that primary energy consumption of potential NZEB levels are higher than the EU target, however, according to future projections the target level can be achieved in Hungary. The NZEB concept pointed at this research mainly focuses on achieving a very high energy performance level and does not apparently link the cost-optimal level with the NZEB concept.

Oliveira Panão et al. (2013) also explored NZEB requirements but focused on Mediterranean residential buildings. For the residential buildings in Lisbon, considerations about NZEB level is presented. According to the obtained results, they indicated that, primary energy consumption for heating, cooling and domestic hot water can be decreased until 60 kWh/m²y excluding the effect of renewable energy systems. Unlike Szalay and Zöld (2014), Oliveira Panão et al. (2013) regarded the relation between cost-optimal and NZEB levels and search for a NZEB definition beyond the cost-optimal level. Although they provided the critical analysis of the results in terms of different assessment criteria, such as EN standard or national codes, the variations of the NZEB definitions and the boundary conditions which affect their achievability in the future were not described.

Schimschar et al. (2011) investigated previous and current energy policy and also provided future scenarios based on transition potential of residential buildings in Germany towards NZEB. The research shows that the highest potential share of nearly zero energy dwellings by 2020 is 6% in Germany. This study also does not point at the cost-effectiveness of NZEB level.

The studies mentioned above are directed at residential buildings since these buildings represent the majority. However, there are also studies focusing on NZEB targets for non-residential building stock. E. Pikas et. al. (2014) investigated design solutions for an office building in Estonian climate within the frame of cost-optimal and NZEB concepts. The paper follows a three stage approach to determine economically feasible solutions for cost optimal and nearly zero-energy levels. This approach involves parameters such as wall insulation thickness, window/wall ratio and electricity generation with PV. The study considers the relation between the cost-optimal and NZEB levels. The effect of façade construction costs, PV costs and cost of exported electricity was analysed but the sensitivity analyses were not addressed in this paper. As the result, it is mentioned that NZEB level, which is defined as ≤100 kWh/m², is not cost optimal for the office building in Estonian climate yet but it is possible to become cost optimal with the reduction of PV cost in the near future.

As mentioned in the previous subchapter, cost optimal and NZEB concepts refer not only to new constructions but also to existing building renovations since cost effective evolution of those buildings into NZEB is subsequently binding. Moreover, Energy Efficiency Directive 2012/27/EU indicates that the highest energy saving potential is represented by existing building stock and therefore increasing the building renovation rate is crucial to achieve 2050 targets (The European Parliament and the Council of the European Union, 2012). With this inspiration, a large number of research activities in MS focused on cost optimal renovations of existing buildings from the viewpoint of EPBD recast.

Research of Brown et al. (2013) analyses residential building stock in Sweden and proposes to include national environmental ratings in the building energy retrofit analyses to integrate indoor environmental quality assessment. Another study in

Sweden deals with the future targets on building energy retrofits and declares that by 2050, 50% energy saving potential exists in Swedish multi-family buildings despite the challenges (Liu et al., 2014). Bonakdar et al. (2014) compares different financial scenarios and assesses the national building codes of Sweden and accordingly introduces a method for cost optimal analysis of multifamily building retrofits. These studies all show that a significant energy saving potential lies behind the Swedish residential building stock and put forward different methods for transformation of these buildings.

In another country at northern Europe, Estonia, Arumägi and Kalamees (2014) reveal that building envelope retrofits are required to be supported by service systems retrofits to provide cost-effective transformation of wooden apartment buildings. Brick apartments, on the other hand, analysed by Kuusk et al. (2014) and similarly, the essentiality of a deep renovation perspective and financial support for the retrofit of these buildings is emphasized. These research activities result with Estonian energy roadmap as explained by Kurnitski et al. (2014) and Pikas et al. (2015).

Another series of research activities which resulted with proposals for policy-makers can be recognized in Portugal. Research activities of Brandão de Vasconcelos et al. (2015) move from reference building definition process for the residential building stock to a comprehensive cost-optimal approach for Portuguese residential buildings (Brandão de Vasconcelos et al., 2016a). Based on the sensitivity analyses, the authors introduce policy implications (Brandão de Vasconcelos et al., 2016b). They reveal that the energy efficiency measures should be combined within retrofit packages to enhance the advantages and discount rates are effective on cost-optimal calculation results.

Studies in Italy focused on the cost-optimal approach for transformation of existing buildings. While Corrado et al. (2014) introduced a new optimization approach for residential buildings, Becchio et al (2015) offer the cost-optimal methodology as an architectural decision-making tool for single family building retrofits.

These studies mainly present analyses reaching cost-optimal levels and make proposals on NZEB concept based on their outcomes. The shared outcomes of these research activities point at importance of cost-effectiveness in building energy retrofits to reach related future targets and also the necessity to consider retrofit packages supported by both envelope and system retrofits instead of considering only single retrofit measures. Despite this, passive energy strategies for buildings are the most commonly addressed measures in studies related to cost-effective energy retrofit of residential buildings (Pombo et al., 2016). Although the studies in the literature specify that a comprehensive approach is required to be followed for the cost-effective transformation of the existing buildings to NZEB, it is not the common approach. Therefore there should be a method guiding the further research activities on NZEB definitions for existing buildings.

Meanwhile, different perspectives were developed on the cost-optimality concept. Barthelmes et al. (2016) and Becchio at al. (2016) emphasize the significance of the occupant behaviour effect on building energy performance which is more than 150%. They reveal that it is important to extend the frame of cost-optimal analyses to include occupant behaviour effect in order to achieve future targets such as post-carbon cities.

2.4 Progress in EU Countries

Requirements of EPBD recast related to NZEB concept consist of providing all new buildings after 2020 are NZEB and transforming the existing buildings towards NZEB. Within the recent years, the MSs have been studying on NZEB definitions and to prepare their national plans for increasing the number of NZEBs. Their progress has been followed by the reports sent to the European Commission (Url-1).

In accordance with the Report from the Commission to the European Parliament and the Council on Progress by Member States towards Nearly Zero-Energy Buildings (2013), 14 MS submitted their progress report by 2012. Eight of them were considered in the report since the other lately arrived. Among this eight MS, only four of them have the full definition of NZEB which includes both the numerical primary energy use indicator and the renewable energy share.

This progress report was updated in October 2014 (Ecofys, 2014). The updated report mentions that 13 Member States submitted their NZEB definitions including numerical indicator while 8 of them also include share of the renewable energy. According to this report, primary energy levels of NZEB definitions extend up to 270 kWh/m^2y. Specific to residential buildings in Member States, NZEB level is between 33 kWh/m^2y and 95 kWh/m^2y (Ecofys, 2014).

Afterwards in 2016, the European Commission (2016) published Recommendation 2016/1318 on guidelines for achieving NZEB targets. The Recommendations also summarizes the progress in MSs. According to this document, NZEB level for the new residential buildings in MSs is commonly not higher than 50 kWh/m²y. According to BPIE (2016), for the existing buildings, three MSs, which are Austria, France and Brussels Capital Region, have more tolerant NZEB requirements according to the new buildings. Three more MSs (Germany, Ireland and Slovenia) intend to do the same. Other five MSs has the same definition with the new NZEBs. More than the half of the MSs have not yet defined the maximum primary energy target for the NZEB level for the existing buildings. The tightest NZEB target for existing residential buildings was defined by Denmark which is set as 20 kWh/m²y while the most tolerant one is in Austria and at 200 kWh/m²y (BPIE, 2016).

With regard to the progress, the Commission introduces the recommendations on NZEB applications and policy implementation in order to speed up the transformation since the retrofit rates are still low as shown in Figure 2.3 below.

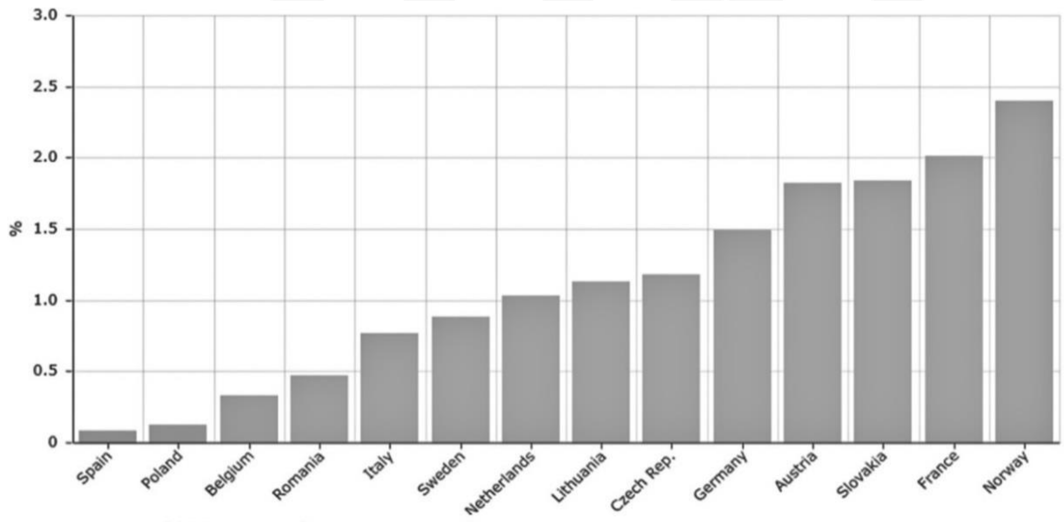


Figure 2.3 : Retrofit rates of residential buildings in MS (Artola et al, 2016).

Another report prepared by D'Agostino et al. (2016) also presents the progress in MS. Figure 2.4 shows the summary table given with this report related to the progress on NZEB definition for new buildings, determination of renewable energy share expected in NZEB, intermediate targets and set measures for promoting deep retrofits towards NZEB. In the table, green coloured cells represent the satisfactory development in the MSs while the orange colour represents the partial development and the red colour is for uncertainty or undefined target. As shown in this figure, NZEB concept still draws attention. Intermediate targets are mainly incomplete yet. NZEB targets for new buildings are ahead of the targets for building retrofits.

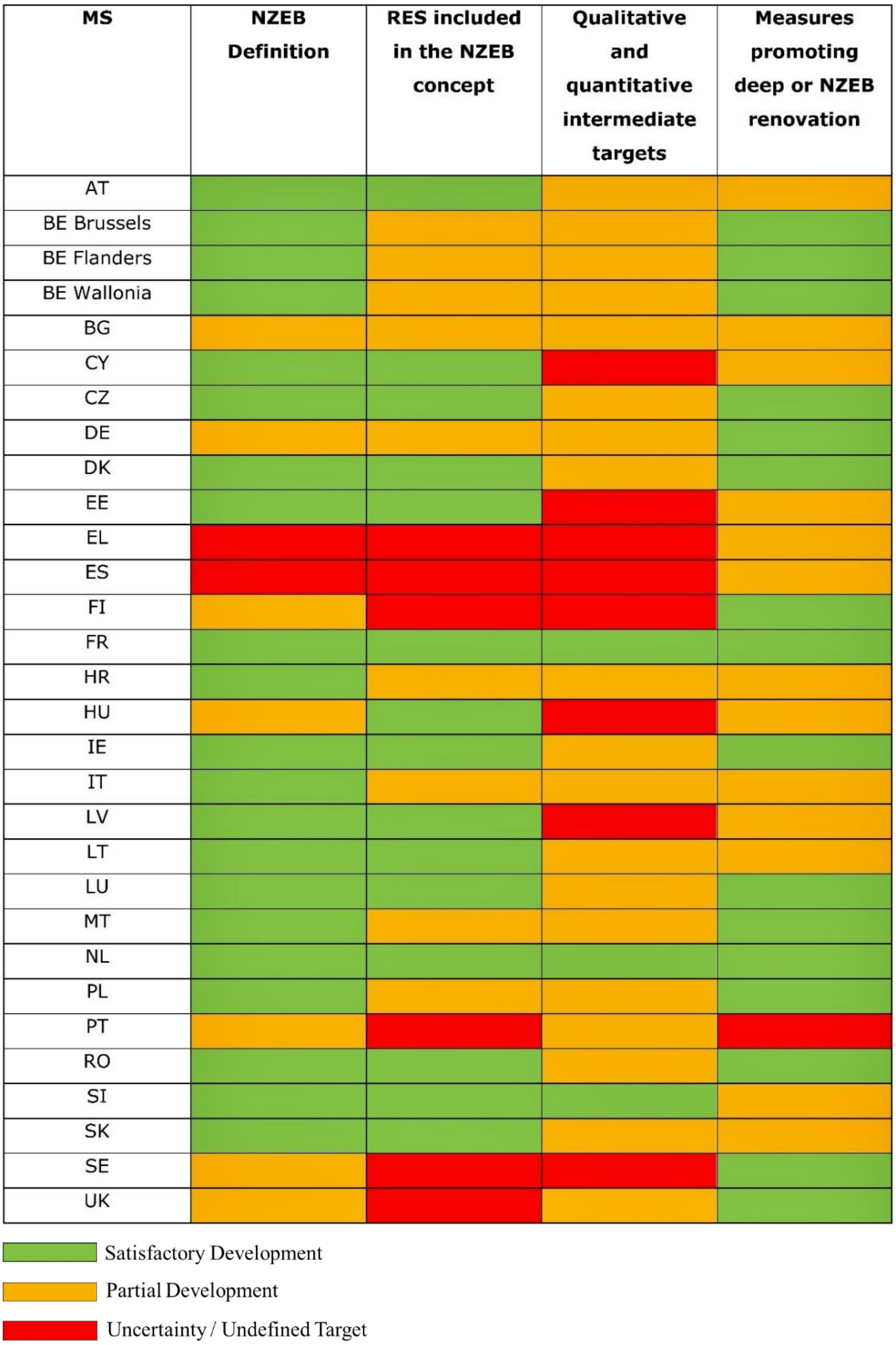


Figure 2.4 : Retrofit progress of residential buildings in MS towards NZEB (D'Agostino et al., 2016).

3. BUILDING ENERGY PERFORMANCE ISSUE IN TURKEY

Turkey has been keeping up with EU legislation through EU harmonization process. Throughout this process, related legal instruments were established in Turkey such as Building Energy Performance Regulation (Republic of Turkey Ministry of Public Works and Settlement, 2008) which complies with the earlier version of EPBD before the recast (The European Parliament and The Council of The European Union, 2003).

Presently, the following stages for Turkey to be progressed in the immediate future are adaptation of cost optimal methodology framework, identification of cost optimal and NZEB levels and preparation of national plans for increasing number of NZEBs. This chapter presents the building energy performance issue and related legislation in Turkey since the sample application of the proposed approach (Chapter 4) is applied to a reference building in Turkey as presented in Chapter 5.

3.1 Significance of Building Energy Performance

In Turkey, buildings sector is the second biggest energy consumer that is responsible for 30% of total final energy consumption (The World Bank, 2010) and moreover, the consumption in buildings has tendency to increase (International Energy Agency, 2015).

On the other side, in G20 countries that Turkey is also involved in, 74% energy saving potential exists in final energy consumption of buildings (International Energy Agency, 2015) and this potential represents a strong opportunity considering the fact that 73% of energy is imported in Turkey (The World Bank, 2010). Therefore, in accordance with the Energy Efficiency Strategy Paper 2012-2023, ensuring energy efficiency in buildings is among the future strategic targets of the country (Republic of Turkey High Planning Council, 2012). This strategic target is indeed related to recent EU legislation on building energy performance that Turkey follows within the EU harmonization process.

The actions needed to be taken in Turkey are not only necessary for EU harmonization process but are also required to utilize energy saving potential lying on the buildings. The energy saving potential is needed to be revealed through a cost effective approach in order to direct investments to the accurate activities. A particular national plan based on this approach is able to provide long term environmental and economic benefits.

3.2 Legislative Framework in Turkey

Until 2007, the only binding tool related to building energy performance was the national heat insulation standard TS 825 (Republic of Turkey Official Gazette, 2000). After EPBD was enacted in 2003 (The European Parliament and the Council of the European Union, 2003), considering the EU harmonisation process, the requirements were followed by Turkey as well. In parallel with the EU Harmonization process and the national strategic targets, necessary legal arrangements linked with energy performance of buildings including laws and regulations have been bringing in since 2007 in Turkey. In this frame, Energy Efficiency Law (Republic of Turkey Official Gazette, 2007) and based on this law Building Energy Performance Regulation were introduced by Republic of Turkey Ministry of Public Works and Settlements (2008). Detailed information about this legislation is provided in the subchapters below.

3.2.1 Energy Efficiency Law

Energy Efficiency Law was enacted in April 2007 as the law with number 5627 in Turkey (Republic of Turkey Official Gazette, 2007). Ensuring energy efficiency, decreasing energy costs and protecting the environment are among the aims of this law. The law points at providing energy efficiency in industry, buildings sector and transportation. In addition, use of renewable energy sources and increase of consciousness level in public are addressed in the law.

Specific to buildings, the law authorises the Ministry of Public Works and Settlement for publishing the norms related to building energy performance including architectural design, heating, cooling, electric wiring, lighting and heat insulation. It requires a regulation for these norms and energy performance certificates for buildings.

3.2.2 Building Energy Performance Regulation

Republic of Turkey Ministry of Public Works and Settlements brought Building Energy Performance Regulation (2008) into force at the end of 2008 based on the requirements of Energy Efficiency Law (Republic of Turkey Official Gazette, 2007). This regulation follows the requirements of EPBD (The European Parliament and the Council of the European Union, 2003) and aims to classify buildings in terms of their energy performance levels, to set minimum energy performance requirements for new and existing buildings, to utilize renewable energy sources, to control HVAC systems and correspondingly to limit greenhouse gas emissions and to protect environment. The regulation also requires to establish a calculation method that considers climatic conditions, requirements of the space and function and also cost efficiency.

Article 5 of the Building Energy Performance Regulation requires to follow EU course related to minimum building energy performance applications and introduce related revisions. In accordance with this article, revisions referring to EPBD Recast (The European Parliament and The Council of The European Union, 2010) are mandatory for Turkey.

3.2.3 National Heat Insulation Standard TS 825

Heat insulation rules for buildings was published in the Planning Regulation for the first time in 1981 (Republic of Turkey Official Gazette, 1981). This regulation refers to four categories in terms of heat insulation applications and requires heat insulation project for the new buildings in accordance with the given thermal resistance and heat transfer coefficients. The regulation refers to TS825 standard for the calculations.

In 1985, the Regulation addressed three different regions for heat insulation requirements instead of the previously defined four regions. (Republic of Turkey Official Gazette, 1985). Later revisions in 1989, 1999 and 2000 points at tighter and more detailed requirements in terms of limiting the heat loss of the buildings (Republic of Turkey Official Gazette, 1999, 2000).

In 2008, required heat insulation levels in Turkey are increased once more (Turkish Standards Institution, 2008). This standard is still binding for getting the construction licences of buildings. The standard considers four degree day regions according to their heating degree days. Figure 3.1 shows the degree day regions on the map.

Since TS825 considers only heating degree days, the south-east part of Turkey which is characterized by dry and hot summers and the north and west part which has mild climate are assumed in the same region in this standard as shown in Figure 3.1. Therefore, the building envelope requirements are the same for these regions.

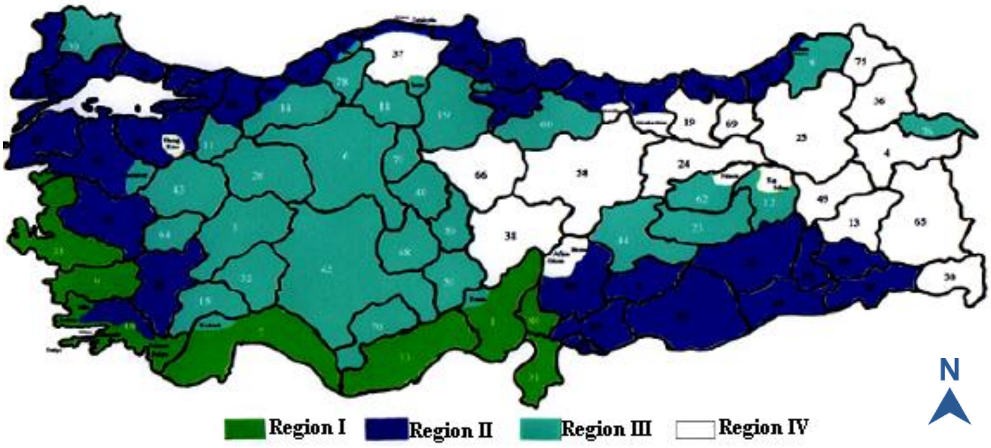


Figure 3.1 : Degree day regions given in TS825:2008.

The last revision on TS825 was introduced recently in 2013 (Turkish Standards Institution, 2013). Although this new version cancels the previously published TS 825 standards, it is not still binding for building constructions because it has not been published in the national official gazette yet.

3.3 Progress in Turkey

Since Building Energy Performance Regulation was introduced in 2008, actions related to EPBD has been taken. As this regulation requires, in 2010 a national method for calculating building energy performance (BEP-TR) was developed for certifying the buildings (Republic of Turkey Ministry of Public Works and Settlements, 2010). Although the regulation brought into force in 2009 requires energy performance certificates for sale and rent of buildings starting from 2017, the Ministry of Environment and Urbanization (2017) postponed this date to 2020.

Presently, any legislation or officially identified energy performance level referring to cost-optimal or NZEB concepts does not exist in Turkey. On the other hand, there are research activities directed at these concepts.

One of the research activities in this area is the project entitled "Determination of Turkish Reference Buildings and National Method for Defining Cost Optimum Energy

Efficiency Level of Buildings". The project, numbered as 113M596, was supported by Scientific and Technological Research Council of Turkey (TUBITAK) and conducted between 2013 and 2015 (Yılmaz et al., 2015).

By the project 113M596, a legislation compatible framework for national cost optimal energy efficiency level calculations was developed. The first stage of the cost-optimal methodology framework, reference building establishment, was given great importance since the further stages are constructed on this first one and it is important to have reliable assumptions on the building stock.

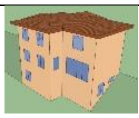
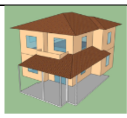
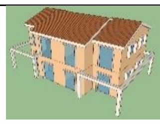
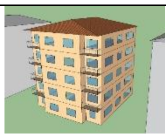
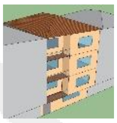
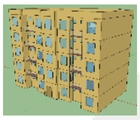
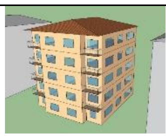
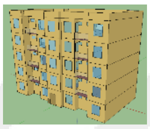
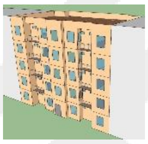
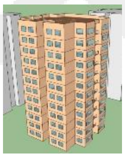
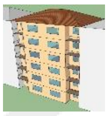
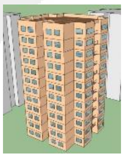
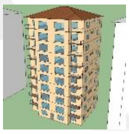
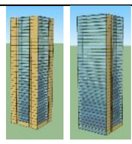
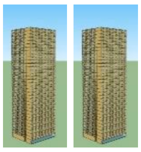
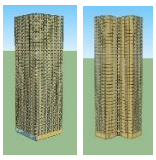
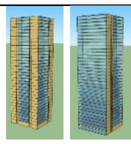
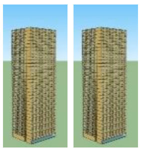
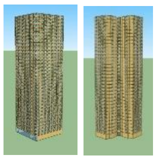
In the project, reference buildings were identified for a selected pilot region and the cost-optimal calculation methodology was nationally adapted for the residential building typologies since these buildings have the priority.

In order to draw a picture of the stock, general information about residential buildings was collected and the initial categorization was made according to the typology. The categories are single family houses (SFH), apartment blocks (APT) and luxury high-rise residential buildings (R). Afterwards, available information related to physical properties, transparency ratios, number of floors, thermo-physical properties (heat transfer coefficients, solar heat gain coefficients, air change rates, material properties…) and HVAC system properties were gathered. The missing information was obtained from the existing building investigations, national and international standards and building projects. At the end of this investigation, 26 reference buildings for three different time period between 1985 and 2012 were identified (Table 3.1).

In addition to the reference buildings, reference building occupants are also identified in the project. For the most frequent family type in Turkey, a couple with two children, people, equipment and lighting schedules were defined. In addition, for 1+1 flats in luxury high rise residential buildings, a family consisting of a couple without any children was established. These families constitute 15.8% of Turkish households.

After the reference buildings and reference occupants were identified, the cost-optimal methodology framework was adapted nationally. The comparative analyses were performed by detailed dynamic simulation tools and global cost calculations. After the conclusion of the project, framework of the national method for calculating cost optimum energy performance level was defined in coherence with national circumstances. Through sample applications of the method on defined reference buildings, solutions for future obstacles were also developed.

Table 3.1 : Reference residential buildings defined in project 113M596.

	1985-1999	2000-2008	2009-2012
Single Family Houses	 SFH111  SFH112	 SFH121  SFH122	 SFH131
Apartments	 APT211  APT212  APT213  APT214-A  APT214-B  APT215  APT216	 APT221  APT222-A  APT222-B  APT223	 APT231  APT232  APT233  APT234
Luxury High Rise Residential Buildings	---	 R321  R322  R323	 R331  R332  R333

As explained, this research project numbered 113M596 provides a comprehensive national application of cost-optimality concept. However, number of these research activities are limited and required to be increased to cover all aspects of the cost optimality concept and for all types of buildings.

On the other hand, NZEB concept has not been given much attention in Turkey yet. It is necessary to conduct research on this concept since it refers to the future actions and also to the national plans for providing a continuous increase of building energy performance level through a cost effective approach. Definitely, the accurate definition of national NZEB level requires to be concluded by policy makers however, it is needed to be based on a reliable scientific approach considering national interests.

As a further step, considering both EU harmonization process and necessary improvement in environment and economy, it is compulsory to develop a national calculation methodology for cost effective transformation of existing buildings into NZEBs as defined in EPBD recast. In order to have a realistic perspective, the targeted energy performance levels should be reasonable and achievable within the targeted time period. future plans, outcomes open new research areas for the near future.

4. A NEW APPROACH TO IDENTIFY ACHIEVABLE NEARLY-ZERO ENERGY BUILDING TARGETS FOR EXISTING BUILDING RETROFITS

The recast of European Directive on the Energy Performance of Buildings (Directive 2010/31/EU) obliges the Member States to ensure transformation of existing buildings into nearly-zero energy buildings (NZEBs) through a cost-effective renovation strategy as comprehensively explained in Chapter 2 (The European Parliament and the Council of the European Union, 2010). Considering that it is also obliged to prepare national plans for increasing the number of these transformed buildings, NZEB level definitions appear as essential prior to these national plans. In order to be consistent with the national plans in the future, NZEB targets have to be achievable in terms of both energy and economic points of view. Achievability of these targets is also necessary for providing a rapid increase in the retrofit rates which are still lower than supposed (Artola et al, 2016). Therefore an approach is required to be developed in order to identify achievable NZEB targets for building retrofits.

This chapter introduces an approach in order to be followed for identification of achievable NZEB targets for existing building retrofits. The approach is presented below explaining objectives and concept, main phases included and detailed description of the stages.

4.1 Objective and Concept of the Approach

The approach introduced in this study was developed regarding NZEB level as the future cost-optimal level since these two concepts are required to be converged in the future with respect to periodically revised requirements for energy performance of buildings. Considering the context of NZEB concept, the focus was on the investigation of cost-effective energy performance levels which corresponds to a higher energy performance levels than the present cost-optimal level.

Although this approach was developed for NZEB definitions for existing building retrofits, innovation of the approach may be applied to NZEB definitions both for existing and new building types. The innovation lies mainly behind the two bases. The first one is the extension of the scope of cost-optimal calculation methodology in a way that effect of the occupant behaviour is also integrated within the concept since the existing cost-optimal approach is needed to be extended by considering effect of occupant behaviour (Barthelmes et al, 2016). The second main innovation is the utilization of sensitivity analyses within cost-optimal calculations as a tool to investigate relevance of different energy performance levels as the future NZEB target.

This approach aims to identify potential NZEB levels for building energy retrofits and to obtain achievable NZEB targets at national level. Directed at this aim, the approach consists of three main phases; national adaptation of cost-optimal methodology framework, development of proposals for achievable NZEB targets and decision-making procedure assessing these potential NZEB targets. These phases are shown in Figure 4.1 below.

Figure 4.1 : Main phases of the introduced approach.

The first phase adopts the EU cost-optimal calculation methodology, which is explained in Section 2.2.2 in detail, considering the national context. This phase involves the steps of cost-optimal methodology based on national application of the methodology for existing building retrofits. The aim of this phase is to identify present cost-optimal levels for building energy retrofits and to determine the scenarios which achieve further energy performance levels in order to investigate in the second phase. The effect of occupant behaviour is also taken into account as an integral part of the cost-optimal approach. It is considered both for cost-optimal analyses and for determination of the scenarios to be analysed in the second phase.

The second phase is the main part that directly serves to the aim of the approach and uses the sensitivity analyses with an extended context. The approach offers sensitivity analyses as a tool to investigate potential NZEB levels and correspondingly to demonstrate the financial gap between cost-optimal and NZEB levels. Besides financial variables, these analyses also consider the investment cost, payback periods and expected remaining lifetime of the existing building. The main outputs of this phase are solutions developed for bridging the gap between cost-optimal and NZEB levels and proposals for policy-makers on potential NZEB targets.

The third phase is a complementary phase of the whole approach. Since policy-makers are in charge of the legal NZEB level definitions based on the national policy, the approach introduces only the frame of a procedure for them to assess both the potential NZEB levels and the developed solutions for bridging the gap between cost-optimal and NZEB levels based on their policy.

Detailed descriptions and stages of the above-mentioned three phases of the introduced approach are explained below.

4.2 National Adaptation of Cost-Optimal Methodology Framework

National adaptation of the cost-optimal methodology framework, which was provided by EU Regulation No 244/2012, is the first main phase of the approach. In compatible with the cost-optimal methodology framework, the steps involved in this phase are; establishment of reference buildings (RB), identification of energy efficient retrofit scenarios, calculation of primary energy consumptions of the RB for different retrofit scenarios, calculation of the global costs of the RB for different retrofit scenarios and comparative analyses of the energy performance and global cost results. In addition to these stages based on EU legislation, content of the cost-optimal approach is extended and analysing the effect of occupant behaviour on cost-optimal levels is also included as a step within this phase since occupant behaviour is one of the main factors influencing energy performance of the buildings.

In order to display relations between the steps of this phase, a flowchart is provided with Figure 4.2. Detailed explanations regarding each step are provided under the related subtitles below.

At the end of this phase, building retrofit scenarios are expected to be determined for the analyses in the second phase to investigate potential NZEB levels.

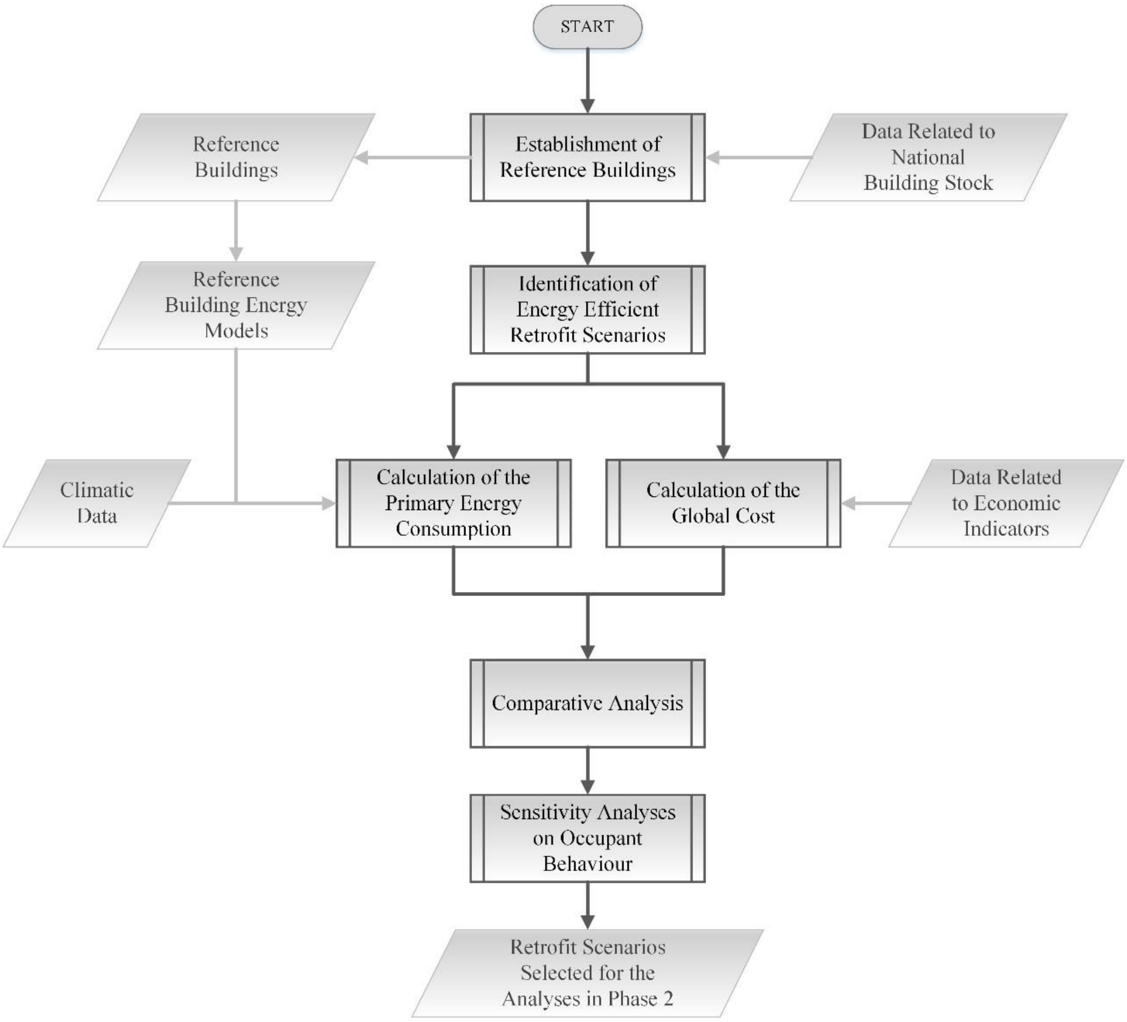


Figure 4.2 : Flowchart of the first phase of the introduced approach.

4.2.1 Establishment of the reference buildings

Establishment of the reference buildings is the first stage of the cost-optimal methodology framework as explained in Section 2.2.2. Accordingly, it is the first step of this first phase of the introduced approach. Since the introduced approach points at building retrofits, reference buildings, which are established in this step, refer to the existing buildings.

Reference buildings should be defined in accordance with one of the three methods which are selection of RB, establishment of hypothetical RB or establishment of example RB as described in Section 2.2.2.

Data related to national existing building stock is the main input of this step. Based on the availability of this data, one of the reference building establishment methods should be selected and national reference buildings representing the existing building stock should be identified in this first step of the approach. RB definitions should include general information about the building, architectural properties, thermo-physical properties of the building envelope, building energy systems and their properties and also occupancy patterns. Accordingly, output of this step is reference building definitions to be used in the following stages.

4.2.2 Identification of energy retrofit scenarios

Subsequent to reference building establishment stage, cost-optimal methodology framework requires to identify energy efficiency measures and packages of measures for the analyses of these reference buildings (The European Commission, 2012a). Since this approach is proposed for existing buildings, energy efficiency measures identified in this step should refer to the energy retrofit actions.

This approach requires to follow a comprehensive approach, covering the actions related to all three main constituents of an overall building retrofit process. These main constituents are; building envelope, energy systems and renewable energy use. Therefore identified retrofit measures should at least refer to improvements in opaque and transparent building envelope components, space heating and cooling system retrofits, upgrade of hot water preparation and lighting systems and integration of renewable energy sources on-site.

In addition, this approach requires inclusion of the analyses related to packages of energy efficient retrofit measures since constituting packages of retrofit measures ensures to achieve higher energy performance level in comparison to the individual application of measures (The European Commission, 2012b). Moreover, combining high-priced energy efficient retrofit measures, which are not cost-effective individually, with low-cost energy efficient retrofit measures may also bring reasonable global cost results in comparison to individual applications of them. Accordingly, in this approach, the term “retrofit scenarios” is associated with both individual energy efficient retrofit measures and packages of these measures which should be identified as described below.

Since it is not practical and realistic to analyse all possible combinations of retrofit measures as packages, a procedure is needed for constitution of packages to be considered in cost-optimal analyses. Therefore, this approach includes the following procedure for the constitution of packages. In order to constitute packages, the initial focus of this procedure is identifying envelope retrofit scenarios that include envelope retrofit measures and packages consist of their combinations. These scenarios should be identified considering the climatic conditions in which the analysed reference building is located. Afterwards, the cost-optimal calculation procedure should be applied only for identified envelope retrofit scenarios. In order to have a rapid progress in this stage, inputs that are the same for all scenarios may be excluded. According to the results obtained from these analyses, cost optimal building envelope retrofit scenarios and the scenarios which lead to the highest energy performance level should be selected for including within further packages. The further packages should be constituted by combining the selected envelope retrofit scenarios with the building energy system retrofits and installation of renewable energy systems. This procedure is summarized in the flowchart given with Figure 4.3 below.

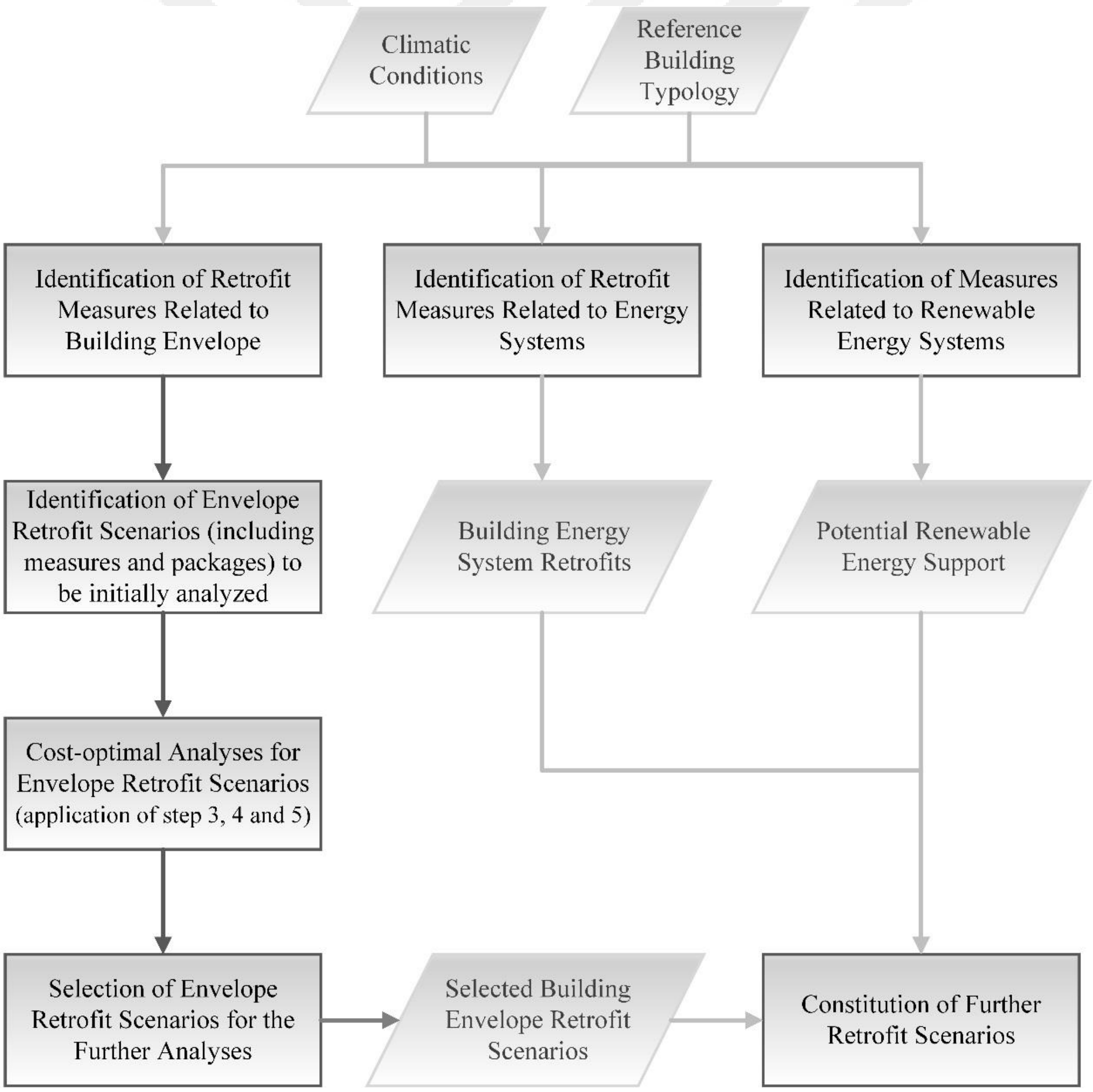


Figure 4.3 : Flowchart representing identification of retrofit scenarios.

Although this procedure introduces a systematic way in identifying packages, it still requires expertise in the field since energy efficient retrofit measures are required to be selected considering the climatic conditions and building typology. In addition, at the end of this step, the experts are required to make sure that the scenarios, as the output of this step, include measures needed for achieving existing minimum energy performance requirements and measures needed for meeting NZEB levels as expected by EU cost-optimal methodology.

4.2.3 Calculating primary energy use of the RB for retrofit scenarios

As the third step of EU cost-optimal methodology framework is calculating primary energy use of the RB for retrofit scenarios, this step of the approach is also associated with calculations for each RB in order to determine energy performance levels as a consequence of different retrofit scenarios.

In compliance with the Guidelines, energy consumption calculations in this approach are based on detailed dynamic simulation method in order to consider the synergic influence of many different variables affecting the absolute thermal behaviour of a building and also interaction between them (The European Commission, 2012b).

In order to use detailed dynamic simulation tools, an energy model should be prepared for each RB. These models should reflect the properties affecting their energy performance which are identified in the first step. After performing energy simulations for actual status of the reference buildings, simulations should be repeated for each energy retrofit scenario in order to analyse the effect of these scenarios on the energy performance of the reference buildings. Analyses for the actual status of reference building and for different energy retrofit scenarios should be performed using the same building energy performance modelling and simulation tool.

Energy generated by on-site renewable energy systems should be subtracted from energy use in order to obtain net primary energy results. Figure 4.4 presents the flowchart of the calculation scheme that is required to be followed for the reference buildings and for each energy retrofit scenarios.

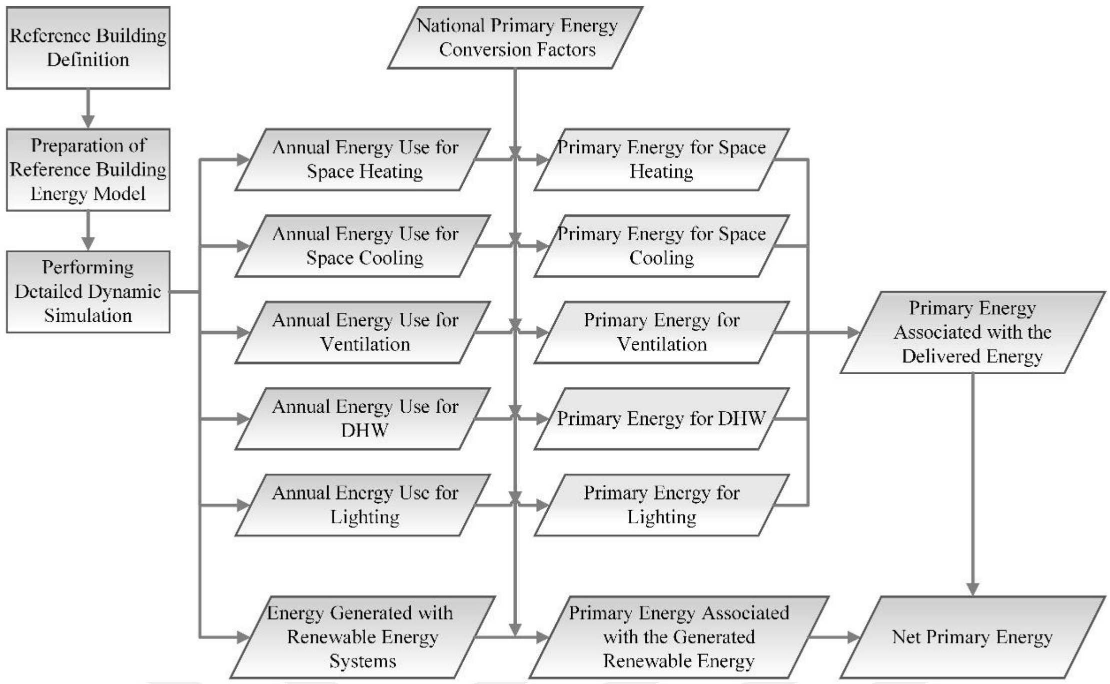


Figure 4.4 : Flowchart representing primary energy calculation procedure.

4.2.4 Calculating global cost of the RB for retrofit scenarios

Calculation of global cost which occurs as a result of applying different energy retrofit scenarios on the reference buildings is the fourth stage to be adapted at national level.

The global cost should be calculated for each energy retrofit scenario in compliance with EU cost-optimal methodology framework. According to this method, net present value of initial investment costs, annual costs, energy costs and residual value should be calculated and their sum represents the global cost as presented in Section 2.2.2. Besides, this proposed approach brings some specific additional requirements and suggestions as described below.

Prior to the global cost calculations, a comprehensive data gathering process is required. The data should include market-based prices of the retrofit investments for calculating the initial investment costs and correspondingly replacement costs, running costs except energy costs and residual value. In order to be able to represent flexible market conditions, this approach requires to collect at least three different market-based investment costs for each of the retrofit measures and use average of them in the global cost calculations.

Other data, which are required to be gathered for global cost calculations, are financial data such as market interest rate, inflation rate and discount rate as mentioned in Section 2.2.2 and price development rates.

Using the average market prices, initial investment costs should be calculated for energy retrofit scenarios. It is not necessary to calculate the present value of the investment costs since the calculation period starts with investment and it already represents the present value of the expenditure. In order to calculate the present value of replacement costs, investment costs and discount factors for the replacement year are required. The discount factor is calculated using inflation rate, interest rate and number of years pass until replacement as presented with Equation 2.2 and Equation 2.3 in Section 2.2.2. Lifespan of the HVAC components are provided within EN 15459 Standard (CEN, 2007). Running costs except energy costs should be calculated by using the percentages of annual costs per investment costs given in EN 15459. Since running costs are periodic costs that occur every year within calculation period, it should be multiplied by the present value factor, which should be calculated using Equation 2.4 (see Chapter 2), to calculate total present value of running costs.

For calculating energy costs, required input data are; annual energy consumption results from third step, energy tariffs and energy price development rates. Annex II of the EU Regulation, provides energy price development rates for calculating the net present value of the energy costs (The European Commission, 2012a). However, considering the countries in which the energy price developments occurred in recent years are significantly different than the rates provided in Regulation (as observed in the sample application of this method presented in Chapter 5), the approach proposed in this dissertation offers an additional alternative method. For these countries, energy price development rates may be assumed based on the statistics of previous years. However, in this case, addressing energy price developments in sensitivity analyses is mandatory and requires particular attention in order to take into account the effect of different rates.

Present worth of residual value of the retrofit investment that will exist at the end of considered calculation period should also be considered for the global cost calculations. Discount factor at the end of the calculation period, RB lifespan and calculation period are required for this calculation.

Taxes, charges and subsidies should be included in case of an individual end user perspective (financial perspective) is followed and should be excluded for applying macroeconomic calculation perspective. Macroeconomic perspective requires to include also carbon costs.

Figure 4.4 presents the flowchart of the global cost calculation approach. As explained in Section 2.2.2, inclusion of carbon costs is optional based on the selected cost calculation perspective. It should be included in macroeconomic calculation perspective.

4.2.5 Comparative analyses

This step includes the comparative assessment of the results of primary energy use and global cost calculations obtained for the retrofit scenarios defined for each reference building. Therefore this step incorporates all of the previous stages in order to define the cost-optimal levels. In this step, results should be analysed on a cost-optimal graph for each of the reference buildings.

Using the cost-optimal graphs, initially, cost-optimal levels achieved with the existing assumptions should be identified. One of the main targets of this step is to select the retrofit scenarios to be analysed in the second phase. Therefore, in the selection process, it should be considered that the second phase focuses on the investigation of potential NZEB levels and the NZEB concept refers to a raised energy performance level in comparison to the existing cost-optimal solution. Therefore, this approach requires to include the retrofit scenarios corresponding the cost-optimal range and the scenarios pointing at lower primary energy consumptions than the cost-optimal level among the selected scenarios.

4.2.6 Analysing the effect of occupant behaviour on cost-optimal levels

Besides climatic conditions, building properties and installation; energy performance of a building is also directly affected by the occupant behaviour. Therefore, recent studies indicate the importance of occupant behaviour effect on NZEBs as explained in Chapter 2. Considering this aspect, the proposed approach extends the scope of cost-optimal calculations by suggesting to integrate effect of occupant behaviour into the energy and economic assessment of building retrofits. In this way the approach regards

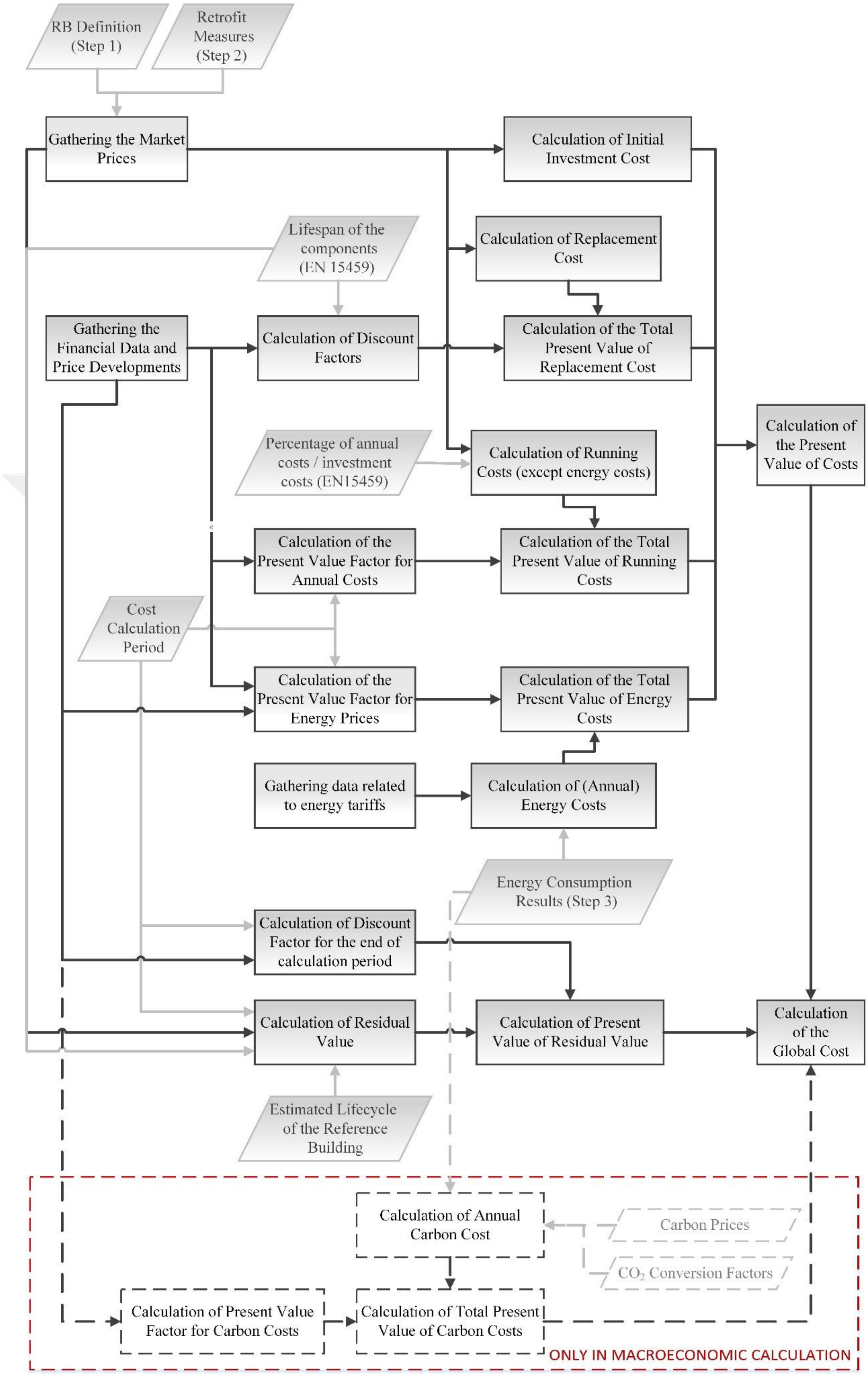


Figure 4.5 : Flowchart of global cost calculation.

occupant behaviour as an integral part of cost-effective retrofit of existing buildings to guide actualization of future targets.

This step includes a sort of sensitivity analyses on the occupant behaviour variations which are different than the reference occupancy pattern identified for the reference buildings.

Analyses on the effect of occupant behaviour should at least include the existing status of the reference building and the retrofit scenarios which are determinative for the cost-optimal curve, as being resulted as on the boundary of the curve, in order to examine the possible variation of the cost-optimal level.

For the analyses on these selected retrofit scenarios, initially the boundary conditions should be identified. The boundary conditions may cover the inputs affecting the following aspects of occupancy pattern: schedules related to operating hours, internal heat gains, power densities or ventilation rates.

Cost-optimal calculations should be repeated for the selected retrofit scenarios considering the effect of identified occupant behaviour variations on energy consumptions and corresponding energy costs. The results should be compared with the reference occupant behaviour on the cost-optimal graph. In case of the analysed occupant behaviour lead to a noteworthy change in cost-optimal results, the scenario(s) in discussion should be added among selected retrofit scenarios in order to be taken into account in the second phase.

4.3 Development of Proposals for Achievable NZEB Targets

The second phase of the approach aims to introduce proposals for policy makers about achievable NZEB targets related to building retrofits. The proposals are determined by identifying potential NZEB levels for existing building retrofits and then developing solutions for bridging the gap between cost-optimal and proposed NZEB levels in order to ensure that the NZEB target is achievable as the future cost-optimal level. These processes may have feedbacks to each other.

In order to determine the potential NZEB levels, sensitivity analyses should be carried out by focusing on the building retrofit scenarios which are selected in accordance with the results of cost-optimal analyses in the first phase.

Although the aim of sensitivity analyses is explained in the Regulation as determining the substantial parameters of the cost-optimal calculations, this approach attributes an additional function to the sensitivity analyses by utilizing them as a tool to investigate achievability of potential NZEB levels. Particularly, sensitivity analyses are not used only to visualize the influence of economic scenarios on the cost-optimal results but also to investigate a future cost-optimal level which corresponds to an improved energy performance in comparison to the existing cost-optimal level.

This phase involves:

- sensitivity analyses on economic indicators as obliged by the Regulation,
- sensitivity analyses on probable investment cost decreases,
- analyses on cost calculation periods and
- investigation of beneficial loans to promote retrofits up to NZEB level.

Results of these analyses refer to specific future conditions which may ensure the NZEB levels are cost-optimal and lead to develop achievable proposals on NZEB targets. In addition, this approach allows including further sensitivity analyses in case of other necessary investigation is regarded as convenient.

Method, details of the analyses and the assessment procedure for the results are explained below.

4.3.1 Determination of boundary conditions for sensitivity analyses

Prior to the sensitivity analyses, boundary conditions should be set for every category of sensitivity analyses. The boundary conditions for sensitivity analyses on economic indicators should be in compliance with the EU Regulation and the national circumstances should also be considered in the process.

4.3.2 Sensitivity analyses on economic indicators

Cost-optimal analyses are built on assumptions about the future economic indicators. Therefore, sensitivity analyses on these indicators are necessary to visualise whether variations of them leads to significant change in the cost-optimal graph.

Sensitivity analyses on economic indicators include analyses for real discount rate (R_R) and the energy price development rate regarding the requirements of the Regulation.

As mentioned above, further sensitivity analyses may be adapted to this approach considering other economic indicators as well.

In addition to the minimum requirements of EU Regulation, this approach requires to consider at least two different rates for energy price development where one of them is lower and the other one is higher than the existing assumptions for energy price development.

Results of the sensitivity analyses on economic indicators should be assessed by investigating the new cost-optimal levels with an increased energy performance which may be obtained through variations. The retrofit scenarios which may be regarded as in cost-optimal range but still require further support should also be considered in the evaluation of the results.

4.3.3 Sensitivity analyses on investment cost decreases

The investment cost of retrofit actions may decrease in the future as a result of technological development, invention of new fields to use existing technologies or increase in industrialization of a technology due to expanded use. PV system costs can be given as an example for this as has been decreased continuously as shown in Figure 4.6 below.

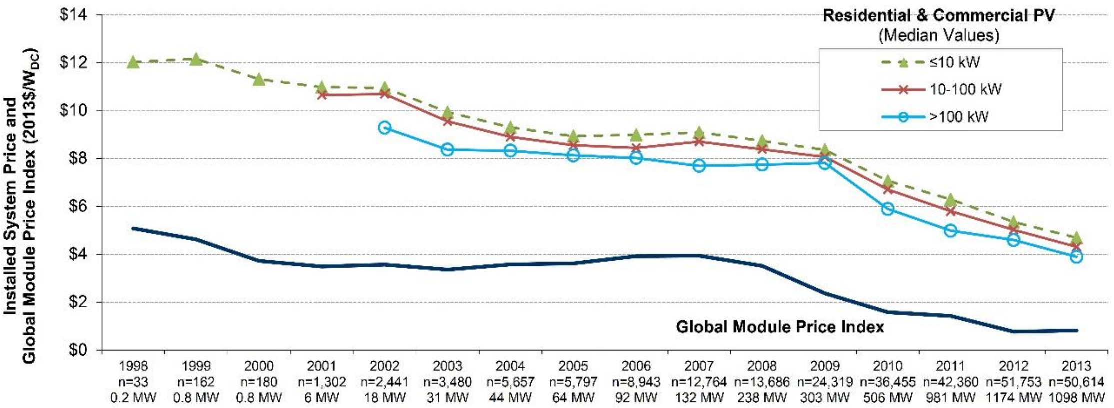


Figure 4.6 : Decrease in the PV System Price, 1976-2010 (Feldman et al., 2014).

Besides the autogenous decrease in the investment cost of retrofit actions, the decrease may also be triggered by the governments in order to upgrade the market towards NZEBs. This upgrade may be provided by subsidies or incentives for building retrofit investments.

Nevertheless, independent from the origin, effect of the investment cost decrease on the cost-optimal analyses is based on the amount of decrease. Therefore different occasions appearing with similar cost-decreases may result in the same way in terms of their effects on cost-optimal analyses.

Sensitivity analyses on investment cost decreases are required to be coupled with the analyses related to the economic indicators in order to see the synergic effect of these two variables. This conjugation is crucial especially for the applications of the approach where the financial rates used in the first phase are based on the statistical data.

Results of the sensitivity analyses on investment cost decreases should be examined considering cost-decreases in certain technologies or applications which come up with a more ambitious cost-optimal level and thus refer to an achievable NZEB level as future cost-optimal.

4.3.4 Sensitivity analyses on cost calculation periods

The cost calculation periods are fixed in the Regulation as mentioned in Section 2.2.2. However, this approach requires performing a sensitivity analyses on the cost calculation periods. Analysing longer calculation periods in comparison to the periods fixed by the Regulation is required in order to have results enabling policy development considering long term benefits. Moreover, shorter calculation periods may also be analysed optionally considering the national market expectations related to shorter term benefits.

Results of the sensitivity analyses on cost calculation periods should be analysed with the aim of investigating both cost-optimal levels and beneficial investments for the visions targeting different time periods.

4.3.5 Identification of potential NZEB levels

NZEB level is expected to be the norm for deep retrofits of existing buildings in the near future according to the legislative frame and the existing literature as presented in Chapter 2. Therefore, NZEB targets are required to be achievable and also acceptable for the building market.

The analyses should initially consider the retrofit scenarios which may be remarked as achieving a more ambitious cost-optimal level in the future. The scenarios which show positive response as a result of sensitivity analyses should be selected and reported as potential future cost-optimal levels and correspondingly potential NZEB levels under certain future conditions. Results obtained for these selected scenarios should be investigated with a specific focus on closing the financial gap between cost-optimal and NZEB levels.

4.3.6 Determination of the financial gaps between cost-optimal and potential NZEB levels

In order to ensure that NZEB targets are achievable, financial gaps between the cost-optimal levels and the potential NZEB levels should be determined and plans to close this gap should be developed. Therefore in this step, for each retrofit scenario, which were marked as representing potential NZEB level in the previous step, the financial gap between them and cost-optimal level should be calculated for each of them. For this calculation, global cost of the cost-optimal scenario should be subtracted from the global cost of the scenario that was marked as a potential NZEB level.

4.3.7 Investigation of solutions and terms for bridging the gap between cost-optimal and potential NZEB levels

The sensitivity analyses display the retrofit scenarios which are not cost-optimal at the moment however based on the economic indicators have the potential to be autonomously cost-optimal in the future. On the other hand, this step aims to identify the potential future cost-optimal levels which can be achieved by taking certain actions to force more ambitious energy efficiency levels. Therefore in this step, solutions should be investigated to bridge the financial gap. These solutions should refer to the national plans for increasing the number of retrofitted NZEBs.

This stage includes investigation of the followings:

- determination of the tax reductions which are effective on bridging the gap
- determination of fields to give priority in R&D activities
- determination of beneficial low-interest loans

Effective tax reductions should be defined by analysing the results of sensitivity analyses. The retrofit scenarios that lead to a more ambitious cost-optimal level or a cost-optimal range with the help of tax reductions should be determined by analysing these results. The scenarios which achieve more ambitious cost-optimal level under certain financial conditions should also be identified. These certain conditions may be specific values or ranges of discount rates, energy price developments or cost calculation periods. Especially when individual end user perspective is used, results of sensitivity analyses on investment cost decreases constitutes the main input.

Determination of fields to give priority in Research and Development (R&D) activities needs a similar approach as determination of effective tax reductions however it is also related with technological developments in products and attraction of market. Therefore this part requires information or knowledge about the latest activities. With this point of view, potential NZEB levels which can be achieved in practice through R&D support and corresponding cost decreases should be defined considering the results of sensitivity analyses.

The above-mentioned potential NZEB levels represent the future cost-optimal energy performance levels which can be conditionally achieved depending on investment cost decreases. However, based on the decisions at national level, NZEB definitions may also be more ambitious than conditionally expected future cost-optimal levels. In this case, building market is needed to be externally supported to achieve this ambitious NZEB target. Low-interest loan is one of the tools for this support to ensure that the target is an acceptable investment by the market.

In order to identify useful and beneficial loans, investment cost and payback periods of the selected scenarios should be calculated. Payback period should consider the investment cost of the retrofit scenario and annual energy cost savings obtained. Simple payback period is calculated as below.

$$PP = \frac{C_I}{C_{s,a}} \tag{4.1}$$

In Equation 4.1, PP is payback period in years, C_I is investment cost of the retrofit scenario and $C_{s,a}$ is annual energy cost savings obtained by the retrofit investment.

Regarding the calculated investment costs and the payback periods of the retrofit investments, amount of the beneficial loans and the repayment period of them that are required for supporting the retrofit actions towards NZEB level should be determined.

Assessment of beneficial loans should consider the relation between payback period of the investment and the remaining lifespan of the reference building. This consideration is important especially in countries where the building lifespans are not long since demolishing and reconstruction is common.

4.3.8 Development of proposals for achievable NZEB levels

Development of proposals for achievable NZEB levels is the last step of the second phase. Subsequent to the sensitivity analyses and investigation solutions and terms for bridging the gap between cost-optimal and potential NZEB levels, obtained results should be assessed together with the aim to have an overall composition of potential NZEB levels.

Both the autogenous cost-optimal levels that can be achieved by certain financial conditions and beneficial incentives which are able to close the gap between a potential NZEB level and existing cost-optimal level should also be reported as a proposal together with the tools to achieve this level such as tax exemptions or low-interest loans. This step aims to ensure policy makers to assess the opportunity of regarding these as NZEB target depending on their policy and economic expectations.

In the proposal development procedure, attention should be paid to the tendency of the prices and preferences in building market within recent years. Moreover obtained solutions for bridging the financial gap between existing cost-optimal levels and NZEB levels should consider the building characteristics and potential actions related to both economy and policy.

The proposals for potential NZEB levels and the effective tools to close the gap between these and existing cost-optimal levels should be the main output of the second phase.

The flowchart of the second phase explained above is given with Figure 4.7. in order to provide a better understanding of this main phase of the introduced approach.

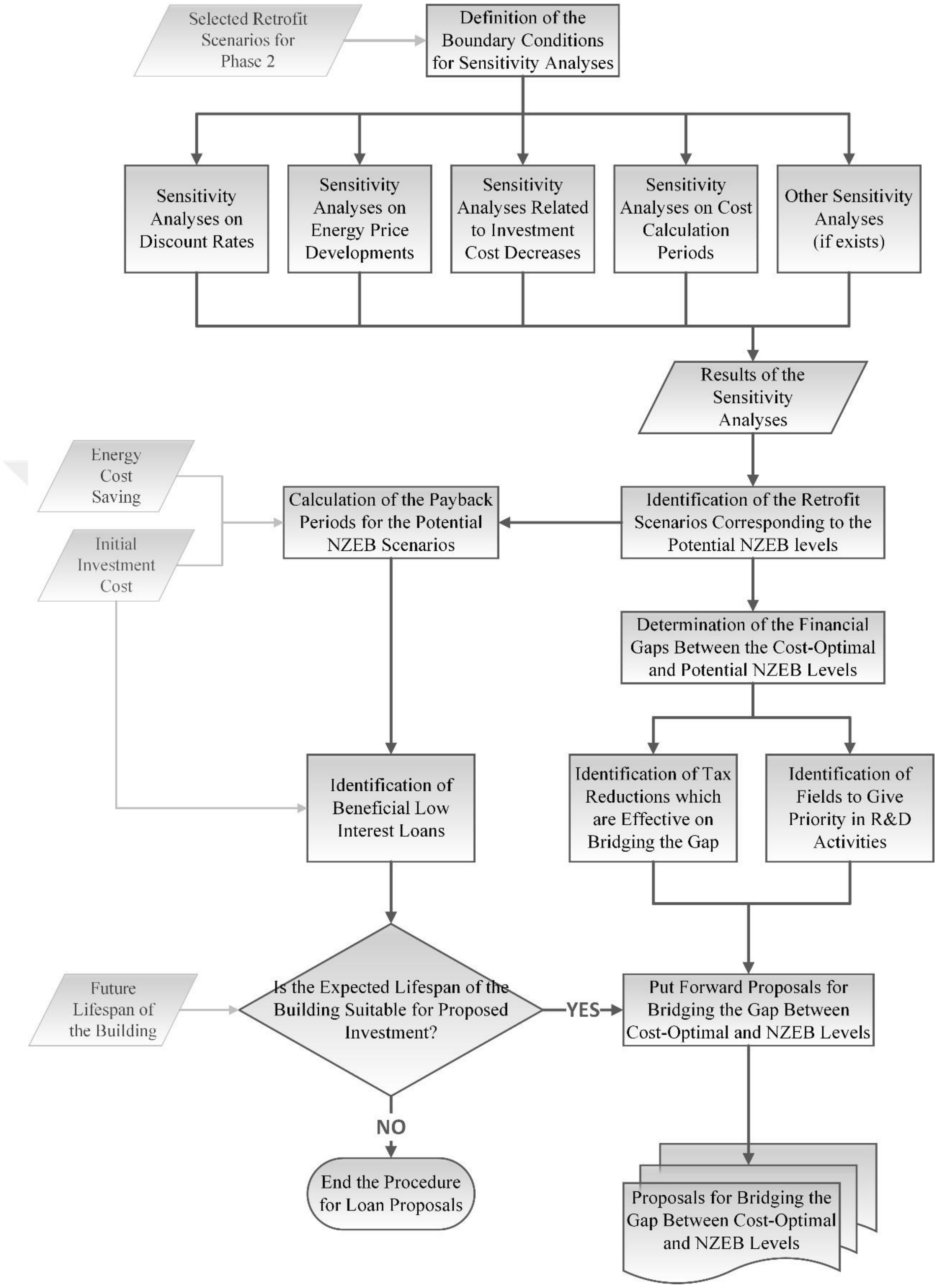


Figure 4.7 : Flowchart of the second phase of the introduced approach.

4.4 Decision-Making on NZEB Levels of Existing Building Retrofits

The last phase of the introduced approach is giving decision on national NZEB levels for building retrofits. Although policy makers are in charge of this phase, a general frame is necessary regarding the two previous phase.

The main inputs of this phase are the proposed potential NZEB levels and the tools which are labelled as effective in closing the financial gap between cost-optimal and NZEB levels. These inputs, which are the outputs of the second phase, should be assessed by policy makers in terms of applicability, acceptability and effectiveness within the policy frame. Therefore other input data should be the energy policy, economy policy and national targets based on the expectations.

All of the proposals on NZEB definitions, which were determined in the second phase, are required to be assessed individually considering the national policy until the appropriate target is achieved. Once the appropriate NZEB target is determined, the provisions of the application should also be identified legally. The provisions should refer to the practical application and inspection mechanisms while it may also refer to tax reductions, amount and repayment period of low-interest loans or other subsidies if the accepted proposal requires.

Based on the accepted proposal for NZEB target and related provisions for the application, NZEB levels should be defined as a certain energy performance level indicated as kWh/m^2y. In accordance with the NZEB definition, national legislation on energy performance of buildings should be revised in a way that NZEB targets are identified.

The flowchart of this decision-making procedure (third phase) is given in Figure 4.8.

It should be stated that NZEB definitions should not be regarded as permanent due to the minimum energy performance requirements are expected to be revised in each five years. These revisions are based on the cost-optimality and aim to gradually achieve more ambitious cost-optimal building energy performance levels in order to meet the aim of NZEB concept of EPBD referring to “a very high energy performance level” (The European Parliament and the Council of the European Union, 2010).

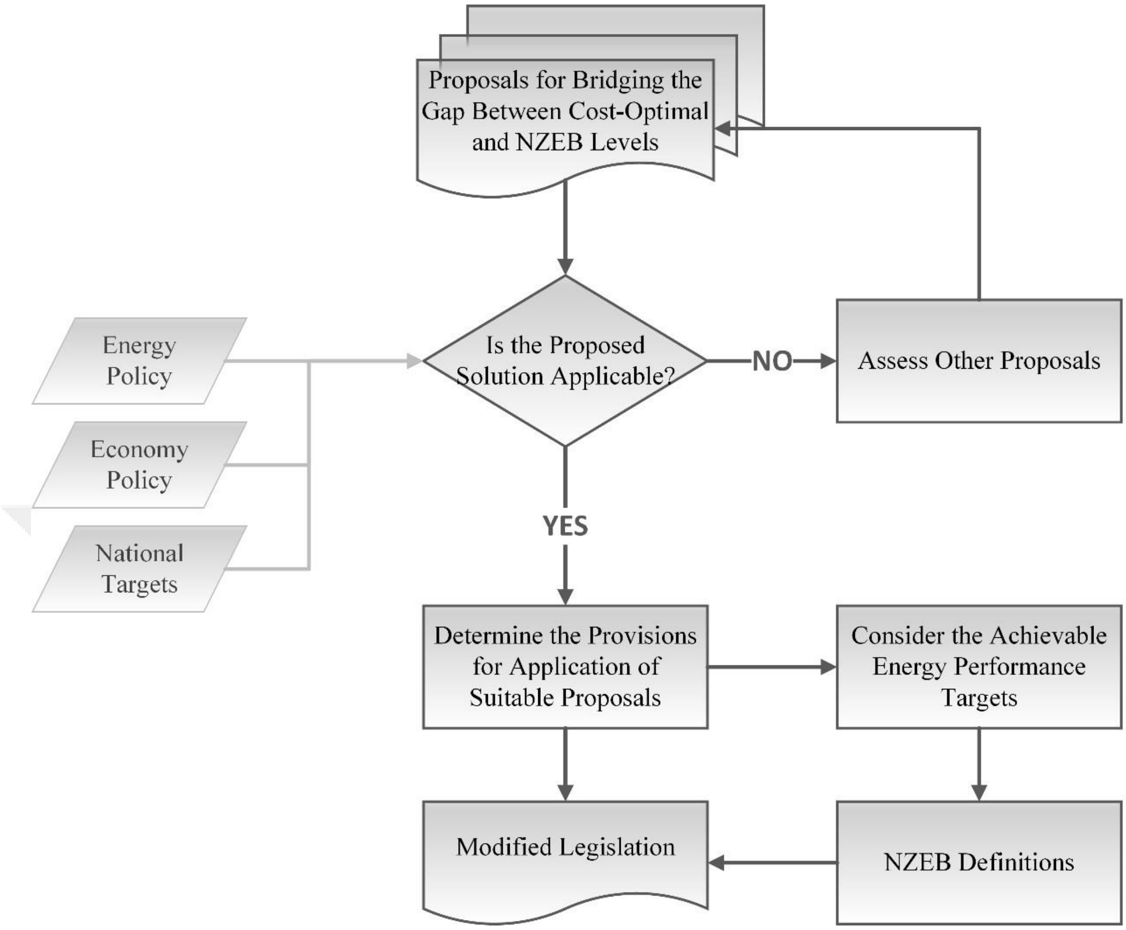


Figure 4.8 : Flowchart of the third phase of the introduced approach.

5. IMPLEMENTATION OF THE APPROACH FOR A REFERENCE RESIDENTIAL BUILDING IN TURKEY

This chapter illustrates a sample implementation of the approach to identify achievable targets for NZEB levels of existing building retrofits. The first and second phases of the approach were implemented in this chapter since the third phase is directly associated with policy makers.

The approach was implemented to a reference building in Turkey. As thoroughly explained in Chapter 3, in accordance with national legislation, Turkey is in charge of adapting requirements of EPBD recast. Since this country involves different climatic regions which show significant distinction from each other, this sample application may refer to the various building refurbishment strategies in Europe. On the other hand, both economic indicators and the practices in the building market of Turkey show significant distinctions in comparison to EU. Considering the excessive building stock in this country, it is necessary to point out achievable NZEB targets for building retrofits.

Residential buildings were selected for this sample implementation since these buildings represent the majority (75%) of the building stock in Turkey (State Institute of Statistics Prime Ministry Republic of Turkey, 2001). Furthermore, 23.1% of the households reside in dwellings which have 6 or more floors (TURKSTAT, 2011). This ratio corresponds to a large population around 4.5 million Turkish families. Therefore, the reference building selected for the implementation is a high rise apartment building.

For retrofit of the reference building, cost-optimal energy performance levels were identified considering different climates by implementing the first phase of the approach. In the second phase, sensitivity analyses were performed to determine potential NZEB levels. Within the whole implementation, more than 1300 energy retrofit scenarios for three different climates were analysed in terms of cost-optimality and their potential to refer NZEB level. In accordance with the results, proposals for bridging the gap between cost optimal and NZEB levels were constituted as the output of this implementation.

5.1 Adaptation of Cost-Optimal Methodology Framework

This part explains sample implementation of the first phase of the approach introduced with this dissertation. Since the first phase is national adaptation of cost-optimal methodology framework, this section presents reference building definition, analysed energy efficiency scenarios and their selection method, primary energy consumption calculations, global cost calculations, comparative analyses and sensitivity analyses related to occupant behaviour. These steps concluded with determination of cost-optimal energy performance levels.

5.1.1 Reference building

The reference building (RB) represents a group of existing high rise residential buildings in Turkey to achieve generalized results about cost-effectiveness of energy efficiency renovations applied on them. Therefore, RB definition includes the general description, architectural layout, physical and thermo-physical properties, occupancy pattern and equipment use and building service system properties together with schedules and boundary conditions for their operation.

5.1.1.1 General description of the reference building

The studied reference building (RB) is one of the reference apartment buildings which are determined within the national research project indicated in Section 3.3 (Yılmaz et. al, 2015). RB is a multi-storey apartment building which has a basement floor and twelve floors with four flats in each. Illustrations displaying building geometry are given in Figure 5.1 and the typical floor plan is given in Figure 5.2 below. It is assumed as constructed between years 1985 and 1999. Total floor area of the building is 5186 m², total facade area is 3823 m² with 590 m² glazing area.

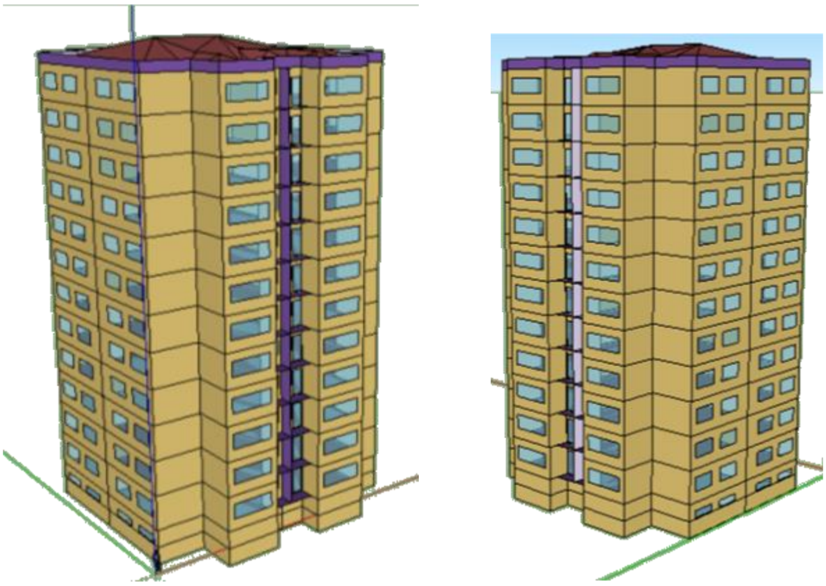


Figure 5.1 : Geometry of the reference building.

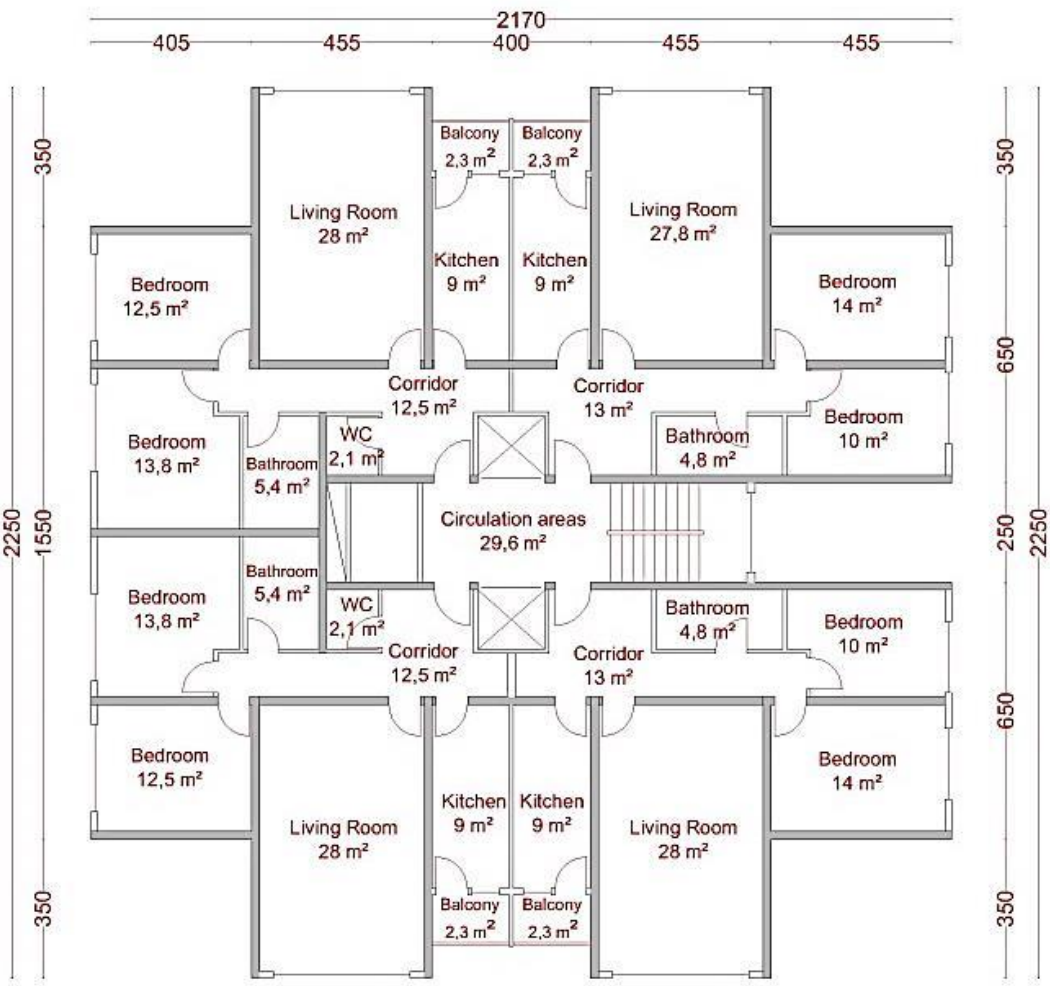


Figure 5.2 : Typical floor plan of the reference building.

5.1.1.2 Envelope properties

Construction type of the reference building is reinforced concrete tunnel form system and the facades were completed using concrete panel walls. Table 5.1 explains thicknesses and thermal conductivities (**λ**) of the layers and the calculated heat transfer coefficients (U value) of the building envelope components. Windows located on the external walls are considered as double glazing with two layers of 4 mm flat glass and 12 mm air gap between them while the frame material is considered as polyvinyl chloride (PVC). Heat transfer coefficient (U value) of the window glazing is 2.9 W/m²K, visible transmittance (T_{vis}) is 0.80 and solar heat gain coefficient (SHGC) is 0.75.

Table 5.1 : Thermal properties of the building envelope.

	Layers	**Thickness (m)**	**λ (W/mK)**	**U (W/m²K)**
External Concrete Wall	External Plaster	0.005	1.4	**1.04**
	Reinforced Concrete	0.2	2.1	
	Herapor Heat Insulation	0.035	0.051	
	Internal Plaster	0.005	0.7	
External Concrete Panel Wall	Reinforced Concrete	0.12	2.1	**1.09**
	Herapor Heat Insulation	0.035	0.051	
	Internal Plaster	0.005	0.7	
Basement Ceiling	Oak Parquet	0.016	0.2	**1.25**
	Asphalt	0.005	0.7	
	Concrete Screed	0.03	1.4	
	Reinforced Concrete	0.16	2.1	
	Herapor Insulation	0.025	0.09	
Attic slab	Rockwool	0.05	0.045	**0.71**
	Reinforced Concrete	0.16	2.1	
	Ceiling Plaster	0.01	0.87	

5.1.1.3 Occupancy

User profile, schedules related to occupancy and activities were previously defined in the national research project considering national and international standards and statistical data gathered from Turkish Statistical Institute (TURKSTAT) database (Url-2). The findings which were used as the input of this research are explained below.

According to 2011 Population and Housing Census of TURKSTAT (2011), in Turkey, average household size is 3.8. In addition, Income and Living Conditions Survey of TURKSTAT (2012) indicates that 54% of the households in Turkey consist of a couple with children. Therefore, in this sample implementation, it was assumed as in each apartment flat, a family consists of four people (parents and two children) lives. Moreover, in accordance with the Family Structure Survey conducted by Ministry of Family and Social Policies (2011, 2013), 67% of women older than 18 years old are housewives in Turkey. Family members frequently come together at weekends (80%) and dinners (81%). Also 64% of the families make breakfast together often.

Considering these statistical information, occupancy schedules for each flat were defined as given in Table 5.2. Activity levels are gathered from ASHRAE-55 - Thermal Environmental Conditions for Human Occupancy standard according to the related activity (ASHRAE, 2010).

Table 5.2 : Occupancy and Activity Level Schedules.

	Hours	**Number of Person**	**Activity**	**Activity Level** (W/m²)	**Name of the Space**
WEEKDAYS	00:00 - 07:00	4	Sleeping	40	Bedrooms
	07:00 - 07:30	4	Breakfast	60	Kitchen
	07:30 - 12:30	1	Housework	115	All spaces
	12:30 - 15:30	1	Rest	45	Living Room
	15:30 - 16:30	1	Housework	115	All spaces
	16:30 - 19:00	3	1 person: Housework 2 people: Rest	115 45	All spaces
	19:00 - 20:00	4	1 person: Housework 3 person: Reclining, Light work, Reading	115 60	Kitchen Living Room
	20:00 - 20:30	4	Dinner	60	Kitchen
	20:30 - 23:00	4	Reclining, Light work, Reading	60	Living Room, Bedrooms
	23:00 - 24:00	4	Sleeping	40	Bedrooms

Table 5.2 (continued) : Occupancy and Activity Level Schedules.

	Hours	Number of Person	Activity	Activity Level (W/m²)	Name of the Space
WEEKEND	00:00 - 00:30	4	Reclining, Light work, Reading	60	Living Room, Bedrooms
	00:30 - 08:30	4	Sleeping	40	Bedrooms
	08:30 - 12:30	4	Reclining, Light work, Reading	60	Living Room, Bedrooms
	12:30 - 15:30	0	-	-	-
	15:30 - 18:30	2	Reclining, Light work, Reading	60	Living Room, Bedrooms
	18:30 - 22:30	3	Reclining, Light work, Reading	60	Living Room, Bedrooms
	22:30 - 24:00	4	Rest	45	Living Room, Bedrooms

Based on these assumptions, heat gain from occupant were considered in the energy performance calculations.

5.1.1.4 Equipment use

In this implementation, home appliances were considered as the equipment used by the occupants. In order to take heat gain from home appliances into account in the energy performance calculations, power and operating time of the appliances were analysed and were defined as given in Table 5.3 for each flat (Url-3, Url-4, Url-5).

Table 5.3 : Power and Operating Time of the Electrical Equipment.

Home Appliance	Power (W)	Operating Time
Refrigerator	37,8	All day (24 hours)
Oven	2600	4 hours in a week
Dishwasher	1030	5 hours in a week
Washing Machine	851	4 hours in a week
Tea Kettle	1650	Weekdays: 3 hours in a day Weekend: 2 hours in a day
Iron	2300	2 hours for 2 days in a week
Vacuum Cleaner	2000	2 hours for 2 days in a week
TV	105	Weekdays: 5 hours in a day Weekends: 4 hours in a day
Notebook	120	3 hours in a day
Stove	1800	2,5 hours in a day
Cooker hood	290	1.5 hours in a day

5.1.1.5 Building service systems

Building service systems were also a part of the RB identification procedure followed in the national research project 113M596 (Yılmaz et. al, 2015). Since heating, cooling, ventilating, domestic hot water (DHW) and lighting systems were defined together with this RB, these inputs were considered in this research.

The heating energy demand of the building is met by a central hot water boiler using natural gas. The nominal thermal efficiency of this natural gas boiler is 80%. In each flat, there are radiators for emitting the heat generated by the boiler by circulating hot water.

The cooling energy demand is met by individual split air conditioners using electricity. SEER (seasonal energy efficiency ratio) of the split air conditioners are equal to 5.8 kWh/kWh.

DHW system is also individual and an electric water heater with 80% thermal efficiency exists in each flat in order to provide hot water for the occupants.

Since the RB is a residential building, the heating and cooling systems were assumed as being operated continuously in order to ensure the required setpoints in the building. The heating setpoint is assumed as 20°C and cooling setpoint is 26°C (Republic of Turkey Ministry of Public Works and Settlements, 2010).

Ventilation was assumed as provided naturally and the air change rate per hour is 0.5 h^{-1} for this apartment building according to BEP-TR (National Calculation Methodology for Building Energy Performance in Turkey) considering that the building has a high air tightness (Republic of Turkey Ministry of Public Works and Settlements, 2010).

In order to calculate the lighting energy consumption and also consider the heat gains from the lighting equipment, lighting power density (LPD) values were calculated using DIALux evo software (Url-6). In the lighting simulations, boundaries for minimum average illumination levels are 200 lux for kitchen, 300 lux for children bedroom and 100 lux for living room, bedroom, corridor and bathroom (Sümengen and Yener, 2013) (IESNA, 2011). The required luminous flux is met by compact fluorescent lamps and their properties are explained in Table 5.4.

The calculated LPD values considering these compact fluorescent lamps achieved average illumination level in the work plane and the operating time of the lighting system are provided with Table 5.5 below. The lighting power densities were used in the RB energy model as an input.

Table 5.4 : Properties of compact fluorescent lamps considered in the calculations.

Power	Luminous flux	Color Temperature
20W	1160 lm	2500K
14W	800 lm	2500K
7W	430 lm	2500K

Table 5.5 : Calculated lighting power densities and illuminaton levels for rooms.

Room	Area (m^2)	LPD (W/m^2)	Average illumination level (lux)	Operating Time
Bedroom 1	12.5	9.6	115	2 hours/day
Bedroom 2	10.0	8.0	112	
Children Bedroom 1	13.8	17.4	300	Manually controlled depending on the illuminance provided by daylight in occupied hours
Children Bedroom 2	14.0	20.0	313	
Living Room	28.0	5.7	104	
Kitchen	9.0	10.7	215	4 hours/day
Bathroom 1	5.4	7.4	103	2 hours/day
Bathroom 2	4.8	8.3	104	
WC	2.1	10	111	
Corridor	4.5	8.9	105	
Entrance	8.0	10	124	

5.1.1.6 Climatic regions

In order to have a complete view, three different climatic regions of Turkey, which are considerably different from each other, were considered for this sample implementation of the approach. These are tempered humid climatic region that is observed in the north-west, hot humid climatic region, which appears in the Mediterranean coast of Turkey with hot humid summers and warm wet winters, and cold climatic region, which is able to refer Northern Europe since it is characterized by cold, strong and long winter period where the air temperatures are mostly below zero. Representative cities for these climates are respectively Istanbul, Antalya and Erzurum. Locations of these cities are provided on the map given with Figure 5.3.

Figure 5.3 : Locations of the representative cities analysed in the .

Istanbul is located at 40°58´ North latitude and 29°05´ East longitude. The tempered humid climatic region of Turkey that is represented by this city has warm summers and cold wet winters longer than summers.

Antalya is located at 36°53´ North latitude and 30°42´ East longitude. The hot humid climatic region, where Antalya is located, has Mediterranean climate with hot summers and mild and rainy winters. Relative humidity is high in this region.

In the cold climatic region, winters are long and cold while summers are short and cool. The representative city Erzurum is located at 39°57´ North latitude and 41°10´ East longitude.

Monthly average of outdoor air temperatures occurred in these three cities between years 1950 and 2015 are reported by Turkish State Meteorological Service as shown in Figure 5.4 (Url-7).

Global solar radiation map is given with Figure 5.5 (Republic of Turkey Ministry of Energy and Natural Sources, 2016). As seen from this map, among the analysed cities, Antalya receives the highest global solar radiation and Istanbul receives the lowest global solar radiation. Although Erzurum is in the cold climatic region, this city is more advantageous than Istanbul in terms of total global solar radiation.

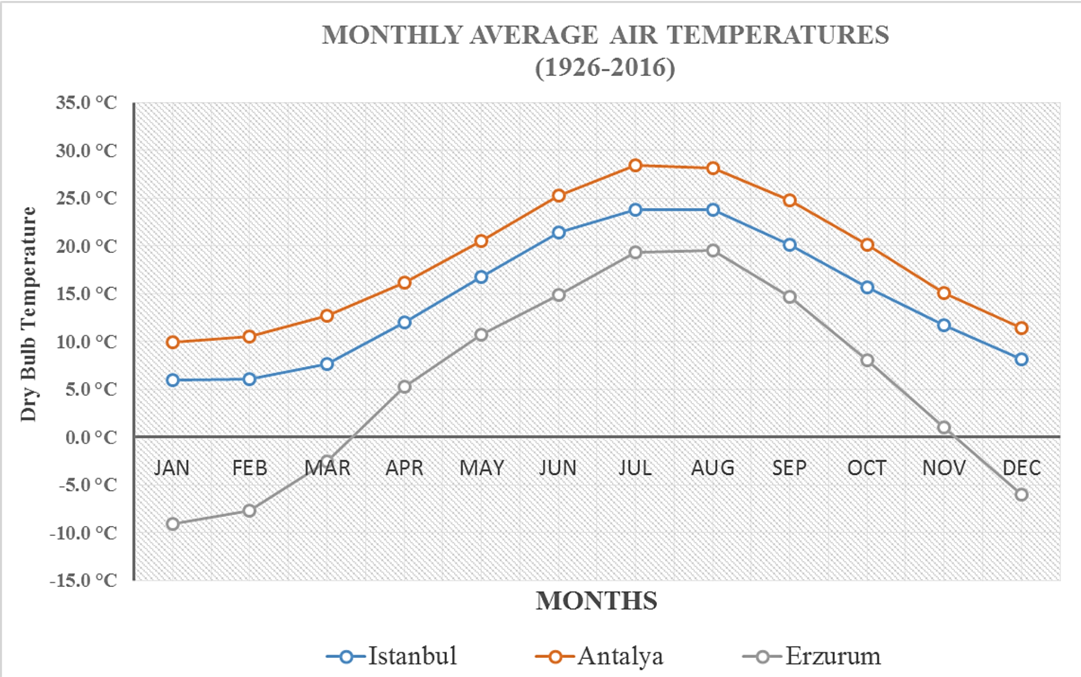


Figure 5.4 : Monthly average air temperatures of analysed cities (Url-7).

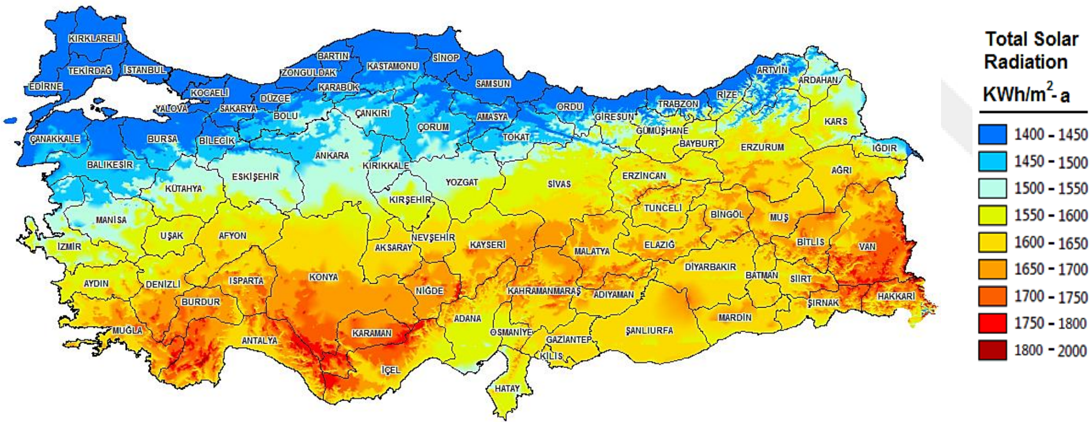


Figure 5.5 : Total solar radiation map of Turkey (Republic of Turkey Ministry of Energy and Natural Sources, 2016).

5.1.2 Energy efficiency measures and packages

In order to calculate expected energy performance levels of the RB as a consequence of different retrofit practices, energy efficiency measures and packages were identified in accordance with the method explained in Section 4.2.2. A global approach was followed and architectural measures, measures related to building service systems and measures for renewable energy use were all considered for the calculations. Besides these energy efficient renovation measures, packages of measures were also constituted. In this section, the selected measures and packages of measures are explained.

5.1.2.1 Architectural measures

Architectural measures analysed in this research refer to the application of heat insulation on the opaque building envelope, replacement of window glazings and use of solar control devices. Table 5.6 explains the selected energy efficiency measures related to heat insulation.

Table 5.6 : Energy efficiency measures related to heat insulation.

Abbrev.	Definition of the measure
IN1-W	Application of xps heat insulation on external walls to meet the maximum allowed limits of U values in national heat insulation standard (TS 825) (TSE, 2013).
IN2-W	Application of xps heat insulation on external walls to meet 25% lower U values than the maximum limits given in TS 825.
IN3-W	Application of xps heat insulation on external walls to meet 50% lower U values than the maximum limits given in TS 825.
IN4-W	Application of xps heat insulation on external walls to meet 75% lower U values than the maximum limits given in TS 825.
IN1-R	Application of rock wool heat insulation on attic slab to meet maximum allowed limits of U values given in TS 825.
IN2-R	Application of rock wool heat insulation on attic slab to meet 25% lower U values than the maximum limits given in TS 825.
IN3-R	Application of rock wool heat insulation on attic slab to meet 50% lower U values than the maximum limits given in TS 825.
IN4-R	Application of rock wool heat insulation on attic slab to meet 75% lower U values than the maximum limits given in TS 825.
IN1-F	Application of xps heat insulation at ceiling of basement floor to meet maximum allowed limits of U values given in TS 825.
IN2-F	Application of xps heat insulation at ceiling of basement floor to meet 25% lower U values than the maximum limits given in TS 825.
IN3-F	Application of xps heat insulation at ceiling of basement floor to meet 50% lower U values than the maximum limits given in TS 825.
IN4-F	Application of xps heat insulation at ceiling of basement floor to meet 75% lower U values than the maximum limits given in TS 825.
IN1-E	Application of heat insulation on the whole envelope (external walls, roof, ground floor) to meet maximum allowed limits of U values given in TS 825.
IN2-E	Application of heat insulation on the whole envelope to meet 25% lower U values than the maximum limits given in TS 825.
IN3-E	Application of heat insulation on the whole envelope to meet 50% lower U values than the maximum limits given in TS 825.
IN4-E	Application of heat insulation on the whole envelope to meet 75% lower U values than the maximum limits given in TS 825.

As explained in Section 3.2, although TS 825 Standard was amended by the new version in 2013, it has not been mandatory for new buildings in Turkey yet (TSE, 2013). However, in this research, TS 825:2013 was considered in order to analyse the latest version of this national standard.

Since the maximum limits of heat transfer coefficients (U values) allowed by the national heat insulation standard TS 825:2013 differ based on climatic regions, the analysed heat insulation thicknesses applied on the building envelope differ according to the analysed city as well (TSE, 2013). The maximum allowed limits of U values for the building components in three cities are provided in Table 5.7 below.

Table 5.7 : Maximum limits of heat transfer coefficients allowed by TS 825:2013 standard (TSE, 2013).

Maximum Limits for Heat Transfer Coefficients (U) - (W/m²K)			
	Istanbul	**Antalya**	**Erzurum**
$\mathbf{U_{wall}}$	0.57	0.66	0.36
$\mathbf{U_{roof}}$	0.38	0.43	0.21
$\mathbf{U_{floor}}$	0.57	0.66	0.36
$\mathbf{U_{window}}$	1.80	1.80	1.80

Considering the available options in the market, heat insulation materials in different thicknesses were considered for the building envelope in order to ensure previously identified levels given in Table 5.6. Below mentioned Table 5.8 displays calculated heat transfer coefficients considering the heat insulation application.

The second focus of energy efficiency measures was on the glazing renovation. For this renovation, it is considered that window glasses were replaced with new double or triple glazings. Heat transfer coefficient (U), visible transmittance (T_{vis}) and solar heat gain coefficient (SHGC) properties and the configuration of the analysed glazing types are selected according to the availability in the national market. These thermophysical and optical properties are explained in Table 5.9.

As an addition to the improvements in the opaque and transparent components of the existing envelope, installation of the shading devices were also examined among the energy efficiency measures. Two different types of shading devices were considered. The first related measure was abbreviated as SHD1 and represents installation of fixed aluminium shading devices on the facades. These shading devices are assumed as overhangs on south facade and as overhangs and fins on east and west facades. The width of the shading devices is 60cm. Second related measure which was abbreviated as SHD2, represents installation of external roller blinds with semi-transparent textile. These roller blinds were in south east and west facades and were assumed as manually controlled by the occupants. Solar transmittance of the textile is 0.35, solar reflectance is 0.60, visible transmittance is 0.35 and visible reflectance is 0.65. Figure 5.6 shows sample illustrations for these shading devices (Url- 8).

Table 5.8 : Calculated heat transfer coefficients for the heat insulation measures.

Heat Transfer Coefficients - W/m²K			
	Istanbul	**Antalya**	**Erzurum**
IN1-W	0.56	0.60	0.34
IN1-R	0.36	0.39	0.21
IN1-F	0.56	0.66	0.35
IN1-E	INS 1 level for the whole envelope		
IN2-W	0.42	0.48	0.26
IN2-R	0.27	0.32	0.15
IN2-F	0.42	0.48	0.25
IN2-E	INS 2 level for the whole envelope		
IN3-W	0.29	0.31	0.18
IN3-R	0.175	0.18	0.11
IN3-F	0.29	0.29	0.18
IN3-E	INS 3 level for the whole envelope		
IN4-W	0.14	0.16	0.12
IN4-R	0.095	0.11	0.085
IN4-F	0.14	0.17	0.09
IN4-E	INS 4 level for the whole envelope		

Table 5.9 : Glazing properties considered in energy efficiency measures.

Abbrev.	**U**	$\mathbf{T_{vis}}$	**SHGC**	**Glazing Configuration**
GL1	1.8	0.79	0.56	4mm glass + 9mm air + 4mm glass
GL2	1.6	0.79	0.56	4mm glass + 12mm air + 4mm glass
GL3	1.6	0.71	0.44	4mm glass + 12mm air + 4mm glass
GL4	1.3	0.71	0.44	4mm glass + 16mm air + 4mm glass
GL5	1.1	0.71	0.44	4mm glass + 16mm argon + 4mm glass
GL6	0.9	0.69	0.48	4mm glass + 12mm air + 4mm glass + 12mm air + 4mm glass
GL7	0.9	0.63	0.39	4mm glass + 12mm air + 4mm glass + 12mm air + 4mm glass

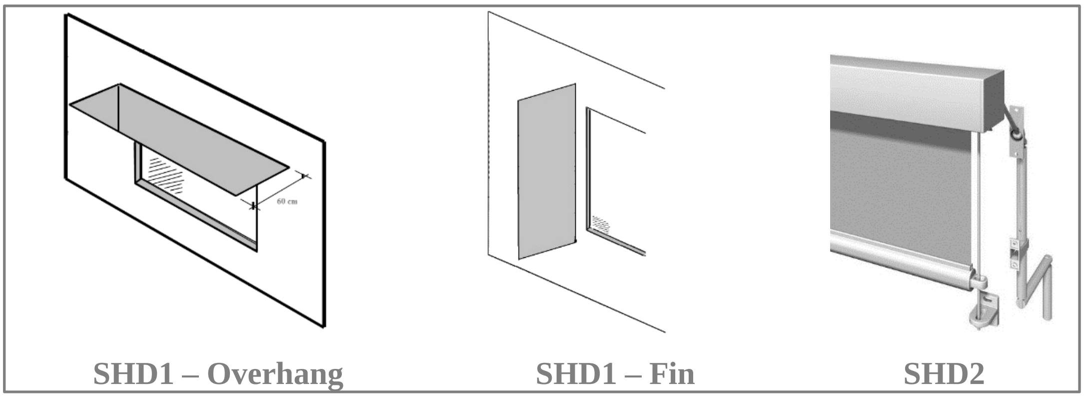


Figure 5.6 : Sample illustrations of analysed shading devices for SHD1 and SHD2 retrofits (Url-8).

5.1.2.2 Measures related to building service systems

Examined energy efficiency measures related to building service systems refer to the selected improvements in heating system, cooling system, domestic hot water preparation system and lighting system. Abbreviations and the explanations of the measures are provided in Table 5.10 below.

Table 5.10 : Energy efficiency measures related to building service systems.

Abbrev.	Definition of the measure
BOI	Replacement of the existing central boiler with a new condensing boiler. Nominal thermal efficiency of the new boiler is 95%.
RF	Replacement of the existing heating system to radiant floor heating system.
CHW	Change of the existing individual domestic hot water systems to a central hot water system supplied by a central boiler.
AC	Replacement of the existing split type air conditioners with more energy efficient air conditioners. The SEER of the new air conditioners is 8.5 kWh/kWh.
VRV	Replacement of the existing split air conditioners with a central variable refrigerant volume (VRV) system. Gross rated cooling coefficient of performance (COP) of the system is 3.1.
LED	Replacement of the existing compact fluorescent lamps to the LED (lighting emitting diode) to provide same illumination levels.

For LED measure, as in the RB model, DiaLUX evo software was used to calculate the lighting power densities which correspond to the minimum required illumination levels in spaces (Url-6). The lighting power densities and average illumination levels in the work plane that were achieved with this retrofit are expressed with Table 5.11 below.

Table 5.11 : Lighting power densities and average illumination for rooms achieved by LED measure.

Room	LPD	Average illuminance
Bedroom-1	5.3 W/m²	110 lux
Bedroom-2	4.4 W/m²	102 lux
Children Bedroom-1	10.4 W/m²	302 lux
Children Bedroom-2	11.0 W/m²	303 lux
Living Room	3.1 W/m²	102 lux
Kitchen	6.9 W/m²	225 lux
Bathroom-1	4.1 W/m²	101 lux
Bathroom-2	4.6 W/m²	102 lux
WC	7.6 W/m²	123 lux
Corridor	4.9 W/m²	103 lux
Entrance	5.5 W/m²	113 lux

5.1.2.3 Measures for renewable energy use

Energy efficiency measures which were analysed for renewable energy use are related to electricity production by photovoltaic panels and hot water obtainment from solar thermal panels. The measures and their explanations are provided with Table 5.12 below. Available roof area is considered for selection of the measures.

Table 5.12 : Energy efficiency measures for renewable energy use.

Abbrev.	Definition of the measure
SP	Installation of solar thermal system at roof. The system involves 48 solar thermal panels and each solar panel has 2.5m² gross area.
PV	Installation of photovoltaic system at roof. Rated power of the system is 11 kW. Cell efficiency is 16%.

Solar thermal panels were assumed as supporting the central hot water boiler in heating and also domestic hot water preparation in case of the hot water system is also centralized.

5.1.2.4 Composition of packages

Energy efficiency measures were analysed both individually and as packages of measures. In order to constitute the packages, initially energy efficiency measures referring to heat insulation retrofits, glazing retrofits and their combinations were analysed for all three cities. Energy performance and global cost calculations were performed for these architectural measures and packages. In the global cost calculations, cost related to building service systems were not considered since these are same for all compared scenarios. According to the results of calculations, cost optimal scenarios and the most energy efficient solutions were selected to be combined with other energy efficiency measures. Therefore the analysed packages are different for different cities. Selected energy efficiency packages for different cities are explained in Section 5.6.

5.1.3 Energy performance calculations

As explained in Section 4.2, both energy performance level of actual status of the RB and energy performance levels achieved a consequence of implementing energy efficiency measures to the RB were calculated using a building energy simulation software. Therefore this stage of the approach involves to set up an energy model for the RB and development of studies related to energy performance simulations.

5.1.3.1 Energy model of the reference building

In order to constitute energy model of the reference building, primarily the building was divided into thermal zones. Every single flat was assumed as a thermal zone and the main circulation areas are assumed as different thermal zones at each floor. The schematic drawing about the zones is given with Figure 5.7 below.

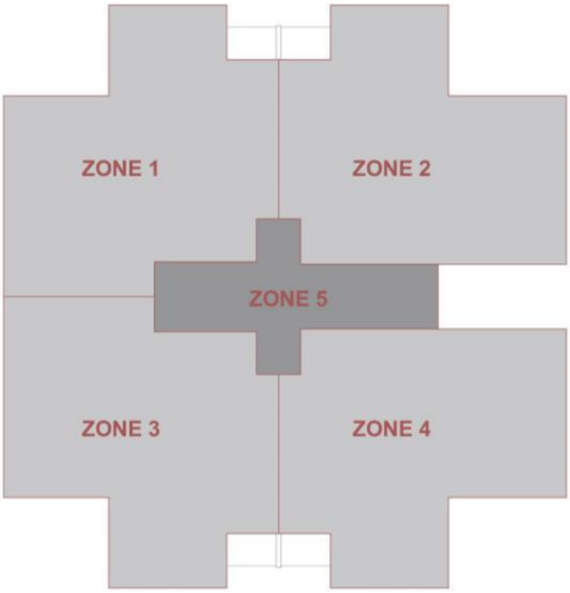


Figure 5.7 : Thermal zones of a standard floor of the reference building.

Based on these thermal zones, geometry of the building was modelled using Legacy Open Studio Plug-in for SketchUp 8 which is a 3D modelling software (Url-9, Url-10)

Afterwards, the model was exported to a detailed dynamic simulation software EnergyPlus version 8.2 and building model was completed by taking the following variables into consideration: physical and thermophysical properties of the materials and building components, internal heat gains from lighting, equipment and people, types and properties of HVAC and DHW equipment, system efficiencies (Url-11).

5.1.3.2 Calculation of primary energy consumptions

Energy consumption of the RB before and after implementation of the energy efficiency measures and packages are calculated using EnergyPlus building energy simulation software.

EnergyPlus is a modular building energy analysis and thermal load simulation program, developed by U.S. Department of Energy. It is an open-source free software and widely used all over the world for building and HVAC system design and dynamic simulation (Crawley et al, 2008).Therefore it has been chosen for the analyses of this implementation. The calculations were performed using conduction transfer function method.

For each scenario, a detailed sub-hourly simulation of the building was conducted. In the calculations, IWEC (International Weather for Energy Calculations) weather file was used for Istanbul while the weather files for Antalya and Erzurum were derived by integrating national weather data representing typical meteorological year with meteonorm files since there is no available international weather data for these cities (Url-12).

Energy consumptions for heating, cooling, DHW preparation, lighting, fans and pumps were examined in this study. The energy consumption results were converted to primary energy using national primary energy factors and are expressed in kWh/m² per year. Primary energy conversion factors are 1 for natural gas and 2.36 for electricity in Turkey. In case of renewable energy production exists, the produced energy was subtracted from the total energy consumption.

The calculated end use energy consumption of the RB subdivided into end uses and energy sources are presented in Figure 5.8 for Istanbul, Antalya and Erzurum. Final energy use for space heating is extremely high in Erzurum while energy use for space cooling is the highest in Antalya due to their climatic character.

Primary energy equivalences of the energy consumptions are given with Figure 5.9. Primary energy consumption of the RB is the highest in Erzurum and the lowest in Istanbul. These results were affected also by the primary energy conversion factors. Especially in Antalya, where the cooling energy consumption met by electricity is dominant, primary energy conversion factor of electricity has a big share in the high primary energy consumption.

Primary energy consumption results of the RB as a consequence of retrofit scenarios are presented in the following sections within comparative analyses of cost-optimality.

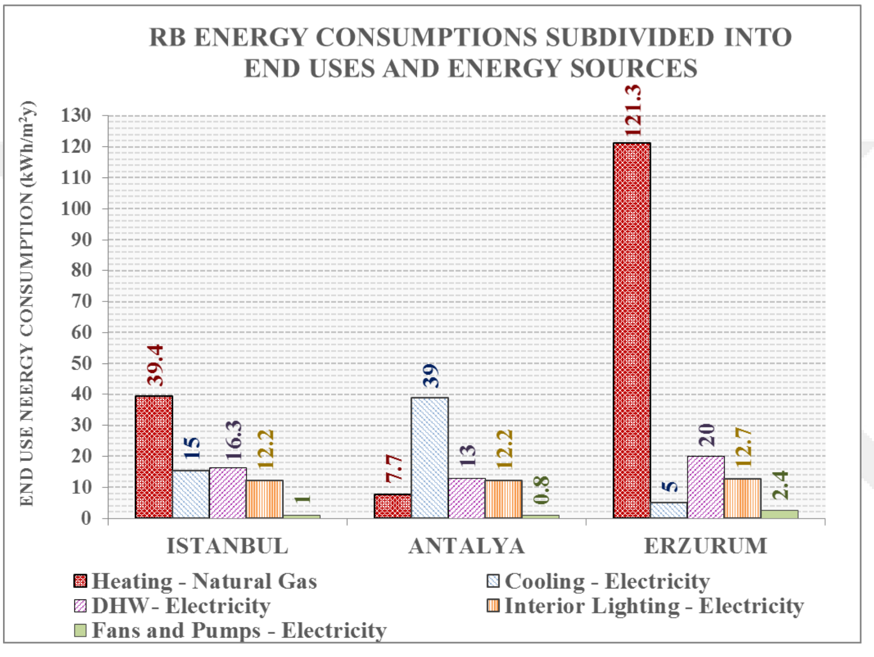


Figure 5.8 : End use energy consumption of the RB.

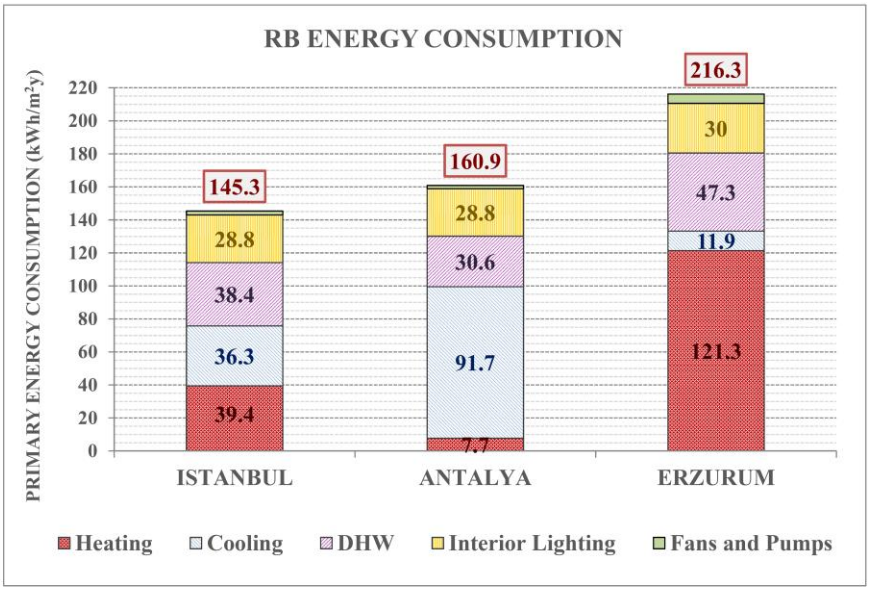


Figure 5.9 : Primary energy consumption of the RB.

5.1.4 Global cost calculations

As the cost-optimal methodology requires, global cost of analysed retrofit scenarios were calculated using Net Present Value Method which is a method explained in Chapter 2. This implementation concerns micro-economic (individual end-user) perspective for cost calculations.

Global cost calculations are dependent on the assumptions related to economic indicators, building lifespan, calculation periods and prices. This section explains the assumptions and the calculation practices while the results are presented under the following sections with cost-optimal analyses.

5.1.4.1 General assumptions for the cost calculations

General assumptions are related to ownership, building lifespan, cost calculation period and beginning year of the calculations. Since Income and Living Conditions Survey carried out by TURKSTAT indicates that 67% of the residential buildings in Turkey are occupied by the owner as shown in Figure 5.10, the reference building is considered as owner occupied in the calculations (TURKSTAT, 2012).

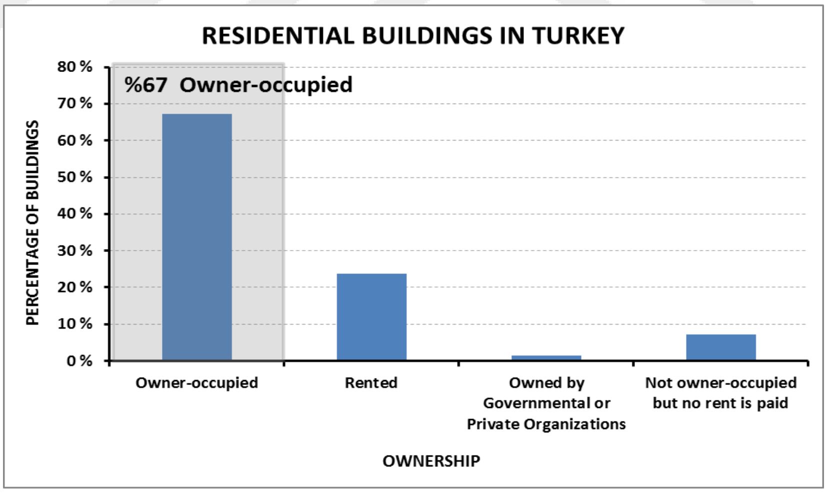


Figure 5.10 : Ownership of the residential buildings in Turkey (TURKSTAT, 2012).

For the global cost calculations, future lifespan of the RB was assumed as 50 years and the global cost calculation period is 30 years in accordance with EU Regulation no 244/ 2012 (The European Commission, 2012a). The beginning year of the cost calculations is 2015. For the calculations, initial investment cost, replacement cost, energy costs and the residual value are considered. In accordance with The European Commission (2012a), the costs that are the same for all analysed scenarios and the costs related to the building elements that does not affect the energy performance of the building may be omitted. Therefore, in this sample implementation, these costs were not included in the cost calculations.

5.1.4.2 Assumptions on economic indicators

Assumptions related to economic indicators such as inflation rate, market interest rate and energy price developments are determined based on the statistical data. In order to define the interest rate that is used in the cost calculations, Central Bank of the Republic of Turkey (CBRT) statistics were investigated for the last 10 years before the starting year of the calculations (2015) (Url-13). According to the findings presented in Table 5.13, the average of the general inflation rate occurred in Turkey during the last 5 years was selected as the rate to be used in the global cost calculations. According to this procedure followed, the inflation rate is assumed as 8,054% for the global cost calculations.

Table 5.13 : Inflation rates occurred between 2005 and 2014 (Url-13).

	General Turkey	Maintenance and Repair of Residences -Turkey	General Istanbul	General Antalya	General Erzurum
2005	8.18 %	8.94 %	8.98 %	8.80 %	8.11 %
2006	9.61 %	6.91 %	10.16 %	9.48 %	9.24 %
2007	8.75 %	6.44 %	9.16 %	8.42 %	9.76 %
2008	10.44 %	6.97 %	11.24 %	9.02 %	11.69 %
2009	6.26 %	6.40 %	5.75 %	5.81 %	5.50 %
2010	8.55 %	2.53 %	7.72 %	8.10 %	8.76 %
2011	6.49 %	4.70 %	5.56 %	6.76 %	8.39 %
2012	8.87 %	7.61 %	9.14 %	8.29 %	9.17 %
2013	7.50 %	6.17 %	7.90 %	7.25 %	7.68 %
2014	8.86 %	9.16 %	9.14 %	8.85 %	8.90 %
Average 2010-2014	**8.054 %**	**6.034 %**	**7.892 %**	**7.85 %**	**8.58 %**
Average 2005-2014	**8.351 %**	**6.583 %**	**8.475 %**	**8.078 %**	**8.72 %**

The market interest rate used in the calculations was identified with a similar approach with the inflation rate. TURKSTAT statistics were investigated for the last 10 years before the beginning year of the cost calculations. The accessed data are as shown in Table 5.14 below (Url-2) and the average of the last 5 years was selected as the market interest rate to be used in the main calculations. Therefore, 14.30% is used as the market interest rate within the calculations.

Table 5.14 : Market interest rates occurred between 2005 and 2014 (Url-2).

	Interest of Long Term Loans Given by Banks
2005	20.87
2006	21.01
2007	20.98
2008	20.59
2009	17.77
2010	12.52
2011	13.93
2012	15.58
2013	11.80
2014	14.22
Average (2010-2014)	**14.30**
Average (2005-2014)	**16.93**

The inflation rate and the market interest rate were used to calculate real discount rate by applying the formula 2.3 given in Chapter 2. The real discount rate (R_R) calculated using this formula is equal to 5.78%. This discount rate was used to calculate the discount factors based on the year of the investment using the formula given with 2.2. Amount of future investments are multiplied by the discount factors (based on the year they occur), in order to find their equivalent present value.

Another required input for the global cost calculations is the energy price developments. TURKSTAT statistics were examined for the last 5 years as given in Table 5.15 (Url-2).

Table 5.15 : Energy price development rates between 2010 and 2014 (Url-2).

Energy Price Development Rates		
	Electricity	**Natural Gas**
2010	7.9 %	-9.7 %
2011	2.2 %	4.4 %
2012	19.5 %	27.2 %
2013	9.8 %	11.9 %
2014	2.4 %	3.4 %
Average	**8.34 %**	**7.43 %**

Since these values are close to the inflation rate and they are not exactly coherent with the data provided by producers, energy price developments were assumed as the same with the inflation rate for the initial analyses. Afterwards, different energy price development rates were considered for sensitivity analyses.

The costs in foreign currency were converted to Turkish Lira (TL) to include in cost calculations. Since beginning year of the calculations is 2015, exchange rates for the United States Dollar/Turkish Lira and Euro/Turkish Lira are assumed as the average of 2015 and are respectively equal to 2.72 and 3.02 (Url-13).

5.1.4.3 Investment cost calculations

Investment cost calculations performed in this study are based on 2015 market prices. The required data is obtained by calculating the average of three cost data gathered from the standard offers of different companies. Total investment costs for implementation of energy efficiency measures related to heat insulation are listed in Table 5.16 below.

Table 5.16 : Total investment cost for implementation of heat insulation on the RB.

		Total Investment Cost (TL)	Cost per unit floor area (TL/m²)			Total Investment Cost (TL)	Cost per unit floor area (TL/m²)
IN1–W	Istanbul:	281934.9	54.4	**IN1–F**	Istanbul:	23379.8	4.5
	Antalya:	275852.9	53.2		Antalya:	23090.0	4.5
	Erzurum:	335659.9	64.7		Erzurum:	24251.4	4.7
IN2–W	Istanbul:	306924.3	59.2	**IN2–F**	Istanbul:	24263.1	4.7
	Antalya:	294099.1	56.7		Antalya:	23871.4	4.6
	Erzurum:	390574.9	75.3		Erzurum:	25426.6	4.9
IN3–W	Istanbul:	371976.1	71.7	**IN3–F**	Istanbul:	24831.9	4.8
	Antalya:	351878.8	67.9		Antalya:	24831.9	4.8
	Erzurum:	646988.0	124.8		Erzurum:	27130.6	5.2
IN4–W	Istanbul:	729666.9	140.7	**IN4–F**	Istanbul:	29268.7	5.6
	Antalya:	671405.3	129.5		Antalya:	27730.0	5.3
	Erzurum:	855883.8	165.0		Erzurum:	31831.7	6.1
IN1–R	Istanbul:	7259.4	1.4	**IN1–E**	Istanbul:	312574.1	60.3
	Antalya:	6678.8	1.3		Antalya:	305621.7	58.9
	Erzurum:	8982.2	1.7		Erzurum:	368893.5	71.1
IN2–R	Istanbul:	7854.1	1.5	**IN2–E**	Istanbul:	339041.5	65.4
	Antalya:	7259.4	1.4		Antalya:	325229.9	62.7
	Erzurum:	15113.5	2.9		Erzurum:	431115.0	83.1
IN3–R	Istanbul:	10152.7	2.0	**IN3–E**	Istanbul:	406960.7	78.5
	Antalya:	9553.3	1.8		Antalya:	386264.0	74.5
	Erzurum:	17364.9	3.3		Erzurum:	691483.5	133.3
IN4–R	Istanbul:	19134.9	3.7	**IN4–E**	Istanbul:	778070.5	150.0
	Antalya:	17364.9	3.3		Antalya:	716500.2	138.2
	Erzurum:	20305.4	3.9		Erzurum:	908020.9	175.1

Investment costs for implementation of energy efficiency measures related to glazing renovations and shading devices are presented in Table 5.17 and average investment costs for implementation of energy efficiency measures related to building systems are given in Table 5.18 below.

Table 5.17 : Total investment cost for glazing renovations and shading devices.

	Total Investment Cost (TL)	**Cost per unit floor area (TL/m²)**
GL1	51985.3	10.0
GL2	53377.7	10.3
GL3	59177.0	11.4
GL4	60569.4	11.7
GL5	65213.1	12.6
GL6	69153.5	13.3
GL7	74723.1	14.4
SHD1	114903.7	22.2
SHD2	517108.6	99.7

Table 5.18 : Total investment cost for implementation of measures related to building service systems.

		Total Investment Cost (TL)	**Cost per unit floor area (TL/m²)**
BOI*	Istanbul:	43348.8	8.4
	Antalya:	43348.8	8.4
	Erzurum:	46013.8	8.9
RF*		367067.4	70.8
CHW		22157.7	4.3
AC*	Istanbul:	311788.2	60.1
	Antalya:	323294.3	62.3
	Erzurum:	302035.2	58.2
VRV*	Istanbul:	386300.5	74.5
	Antalya:	451824.3	87.1
LED		84052.4	16.2
SP		107941.8	20.8
PV		53744.7	10.4

5.1.4.4 Replacement cost calculations

Periodic replacement cost is regarded as another cost category in the calculations and was calculated considering the lifespan of the building materials and components. It is considered that, at the end of each cycle of lifespan the components are replaced. Lifespan of the building materials and components are gathered using EN 15459:2007 standard and assumptions of producing companies (CEN, 2007).

Table 5.19 : Assumptions on lifespan of the building materials and components.

Building component/material	Lifespan
Heat insulation on the façade (XPS)	50 years
Heat insulation on the attic slab (Rockwool)	40 years
Heat insulation at basement ceiling (XPS)	40 years
Glazing	30 years
Overhang and Fin	30 years
External Roller Blind	30 years
Boiler	20 years
Radiators	40 years
Radiant Floor System	50 years
Individual water heaters	20 years
Central Water tank	20 years
Pipes	30 years
Air conditioners	15 years
Compact Fluorescent Lamps	7.5 years
LED	15 years
Solar Panels	25 years
Photovoltaic Panels	25 years

5.1.4.5 Calculation of running costs

Running cost category covers energy costs, operational costs and maintenance costs. Operational and maintenance costs for building components and products were gathered from EN15459:2007 standard that expresses these costs in percentage of initial investment cost.

The biggest share of running costs belongs to the energy costs. Energy consumption outputs from the energy simulations are utilised in energy cost calculation as an input. In order to take energy costs into consideration, annual average energy prices of the calculation beginning year 2015 were investigated (Url-14, Url-15, Url-16, Url-17). The monthly unit prices and the annual average values that were used in the calculations are given with Table 5.20 below.

Since these are periodic annual costs that occur every year of the whole calculation period, present value factor was used for calculating the sum of the discounted costs for each year as explained in Chapter 2. Annual energy consumptions were multiplied with average cost of related energy carrier and multiplied with present value factor to obtain present value of long term energy costs.

Table 5.20 : 2015 Energy prices (Url-14, Url-15, Url-16, Url-17).

2015 Energy Prices (TL/kWh)				
	Electricity (Turkey)	**Natural Gas (Istanbul)**	**Natural Gas (Antalya)**	**Natural Gas (Erzurum)**
January	0.310484	0.09418233	0.08190423	0.08813158
February	0.310484	0.09408900	0.08190423	0.08808421
March	0.310484	0.09412923	0.08190423	0.08810461
April	0.310485	0.09427594	0.08190423	0.08817904
May	0.310485	0.09440583	0.0997703	0.08824493
June	0.310485	0.09458459	0.10002575	0.08833562
July	0.310485	0.09472538	0.10022688	0.08840705
August	0.310485	0.09475742	0.10027265	0.08842331
September	0.310485	0.09471626	0.10021391	0.08840244
October	0.310485	0.09484182	0.10039333	0.08846617
November	0.310485	0.09503976	0.10067622	0.08905855
December	0.310485	0.09501344	0.10063872	0.08953525
AVERAGE	**0.3104848**	**0.094563417**	**0.09415289**	**0.08844773**
Average including VAT	**0.366372**	**0.1115848**	**0.1111004**	**0.1043683**

5.1.5 Comparative cost-optimal analyses

After energy performance and cost calculations had been performed in accordance with the assumptions explained in the previous sections, results were comparatively analysed in order to investigate cost-optimal levels.

As previously mentioned, in order to identify all retrofit scenarios, envelope retrofits were initially analysed for selecting convenient scenarios to combine with further measures. Therefore, comparative analyses were initially applied to building envelope retrofit scenarios for each of the three climates. Since these initial calculations were made only to compare envelope retrofit measures, cost of the other measures which are same for all scenarios are not included. Therefore the final results are different than the preliminary analysis since final results also involve HVAC and lighting system maintenance costs.

As presented in Section 5.1.2, initial analyses include cost optimality assessment of heat insulation and glazing retrofits. It covers wall insulation, floor insulation, roof insulation and whole envelope insulation retrofits as well as glazing retrofits and retrofit packages combining wall insulation and glazing retrofits. Since it is possible to provide the same heat transfer coefficient using different heat insulation materials, the cost calculations were performed for XPS (extruded polystyrene), EPS (expanded polystyrene) and rock wool (RWL) materials.

5.1.5.1 Results of envelope retrofit scenarios analysed for Istanbul

Results of the envelope retrofit scenarios analysed for Istanbul are presented in Figure 5.10. As seen from the figure, among the analysed scenarios, only glazing retrofits (GL) achieve cost-efficient results. The most efficient glazing retrofit is GL7 which provides 10% primary energy saving with %5 global cost saving comparing to the existing situation of the reference building which is named as RB. Heat insulation retrofits (IN) provide better energy efficiency levels in Istanbul, in comparison to glazing retrofits, however, these are not cost effective. Combining heat insulation retrofits with the glazing retrofits works well to decrease the global costs but the calculated costs are still higher than the RB. According to the results of this initial analyses, GL7 is the cost-optimal solution among the envelope retrofit scenarios. In comparison with the RB, the scenario combining insulation level 4 (IN4-E) and glazing (GL) retrofits provides 38.2 kWh/m² annual primary energy saving which corresponds to 26% decrease without cost efficiency in terms of global cost.

As seen from Figure 5.11, heat insulation retrofits using rock wool as the insulation material, resulted with the comparatively highest cost since the investment cost of rock wool is the highest. EPS has the lowest investment cost and correspondingly scenarios with EPS result with the lowest global cost among the insulation retrofits. However, cost cannot be the only consideration for the retrofit decision. In example, Fire Code of Turkey brings some legal limitations on the heat insulation materials depending on the building properties. On the other hand, this approach does not focus on single building retrofits but aims to obtain general results that can be expanded to similar buildings through the analyses on RB which represents a crowded group of apartment buildings higher than 6 floors. Therefore, requirements for a single building were not considered in this sample application of the method. Aim of the comparison between heat insulation materials aims to display that the results of cost optimality calculations can be affected by the material choice.

As the result of these analyses, cost optimal scenarios and the scenarios which lead to the highest energy performance level among the building envelope retrofits were selected for further energy efficiency packages for Istanbul: GL5, GL6, GL7, IN2-W+GL7, IN3-W+GL4, IN3-W+GL5, IN3-W+GL7, IN4-W+GL4, IN4-W+GL5, IN4-W+GL7, IN2-E+GL7, IN3-E+GL4, IN3-E+GL5, IN3-E+GL7, IN4-E+GL4 IN4-E+GL5 and IN4-E+GL7. Primary energy consumption and the global cost results of these selected scenarios are given with Table 5.21.

Further analyses consider XPS as the heat insulation material for the external walls since the results have to serve for a large group of residential buildings higher than 6 floors and XPS represents the average cost among the analysed heat insulation materials.

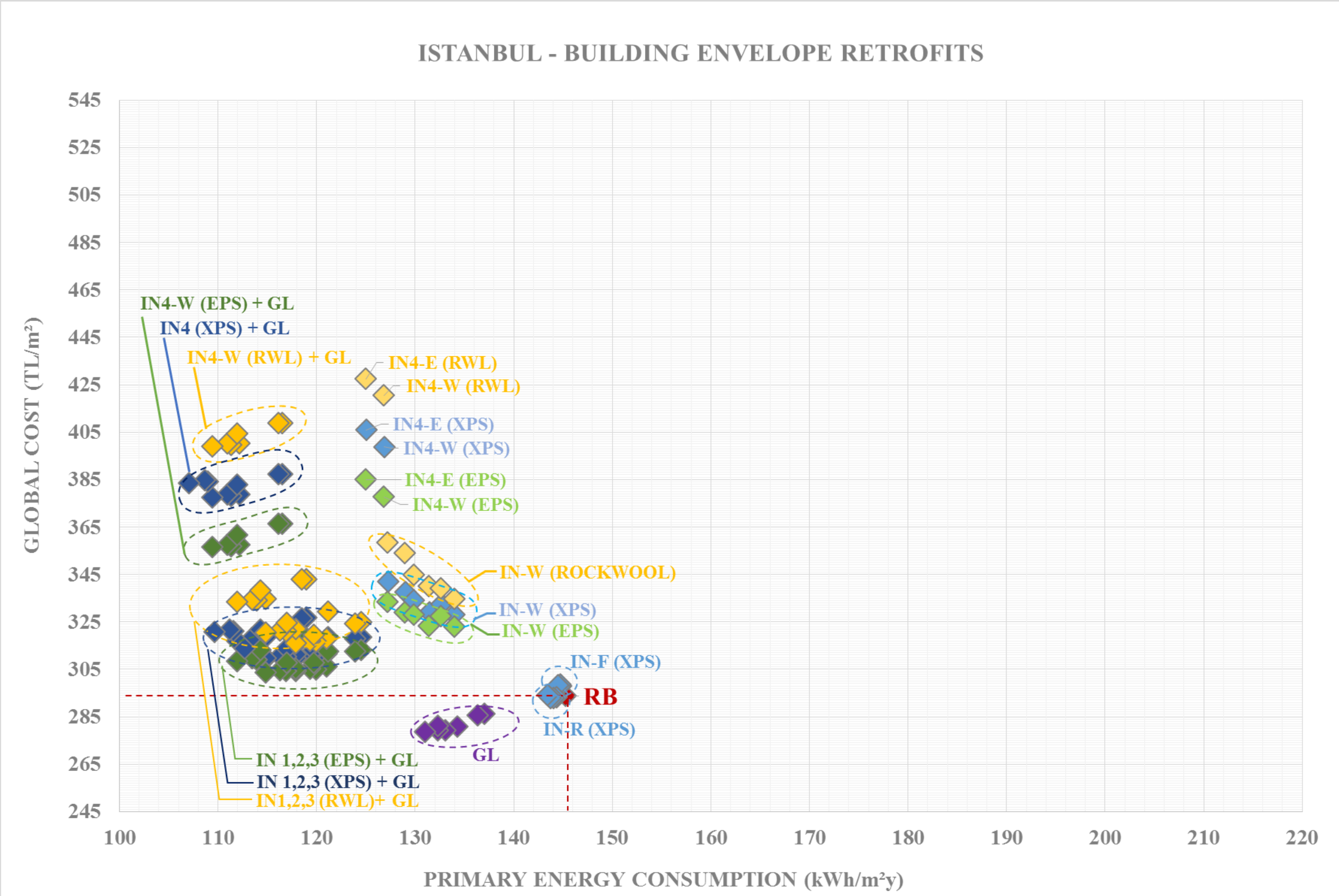


Figure 5.11 : Results of initial cost-optimal analyses on building envelope retrofits for Istanbul.

Table 5.21 : Results of the selected envelope retrofit scenarios for the RB in Istanbul.

Scenario	**Primary Energy Consumption** (kWh/m² y)	**Global Cost** (TL/m²)
RB	145.3	293.6
GL5	132.3	279.1
GL6	132.3	281.1
GL7	131.0	278.5
IN2-W + GL7	114.9	309.5
IN3-W + GL4	114.0	317.6
IN3-W + GL5	113.5	318.1
IN3-W + GL7	112.0	317.0
IN4-W + GL4	111.4	377.9
IN4-W + GL5	111.0	378.6
IN4-W + GL7	109.4	377.4
IN2-E + GL7	112.7	313.7
IN3-E + GL4	111.6	321.0
IN3-E + GL5	111.2	321.7
IN3-E + GL7	109.7	320.5
IN4-E + GL4	109.0	383.9
IN4-E + GL5	108.7	384.7
IN4-E + GL7	107.1	383.4

5.1.5.2 Comparative analyses of all retrofit scenarios for Istanbul

After the first set of calculations on envelope retrofits, the selected building envelope scenarios were combined with the measures referring to heating, cooling, DHW and lighting systems, shading devices and renewable energy systems which were previously explained under Section 5.1.2.

Obtained results were displayed in cost-optimal graph in order to enable a comparison between different retrofit scenarios. In the graph, each retrofit scenario is represented by a different point. Annual primary energy consumptions in kWh/m²y as the result of retrofit actions are expressed on horizontal axis of the cost-optimal graph and the calculated global costs in TL/m² are displayed on vertical axis. The calculations consider total net floor area of the RB. Figure 5.12 presents the cost-optimal graph for the retrofit scenarios analysed for Istanbul. For substantial scenarios, numerical result of primary energy consumption and global cost are specified and highlighted with horizontal and vertical dashed lines. Results of scenarios which are not specified with their names in the graph are given with tables in Appendix A for Istanbul.

The cost-optimal level for the RB in Istanbul was achieved by the scenario combining GL7, BOI, CHW, LED and PV retrofits. This scenario results with 79.8 kWh/m²y primary energy consumption and 253.2 TL/m² global cost, correspondingly achieves 65.5 kWh/m² annual primary energy saving and 93.1 TL/m² economic saving in comparion with the RB. These savings correspond to 45% of the primary energy consumption and 27% of the global cost of the RB.

As shown in the graph, minimum primary energy consumption level that was cost-effectively achieved is equal to 39.8 kWh/m²y for the RB retrofits in Istanbul. This level is obtained by applying the scenario involving GL5, BOI, VRV, CHW, LED, RF, SP and PV retrofits. The scenario provides 73% primary energy saving while the global cost is not considerably different than existing global cost of the RB. Applying heat insulation retrofits together with these retrofits provides higher energy performance level while it results with higher global cost. The scenario including IN3-E, GL7, BOI, CHW, LED, RF, SP, VRV and PV retrofits corresponds to 29.8 kWh/m²y primary energy consumption level and 406.3 TL/m² global cost level. In comparison to the scenario referring to cost-effective minimum energy consumption level, 10 kWh/m²y additional primary energy saving is obtained by affording 60.2 TL/m² higher global cost for thermal insulation retrofit. Primary energy saving amount that corresponds to the unit global cost increase is much lower beyond this level. When the heat insulation level is increased until IN4, only 1.2 kWh/m²y additional primary energy saving is provided by 64.7 TL/m² increase in the global cost. Effect of this high-cost heat insulation investment is limited in terms of primary energy consumption.

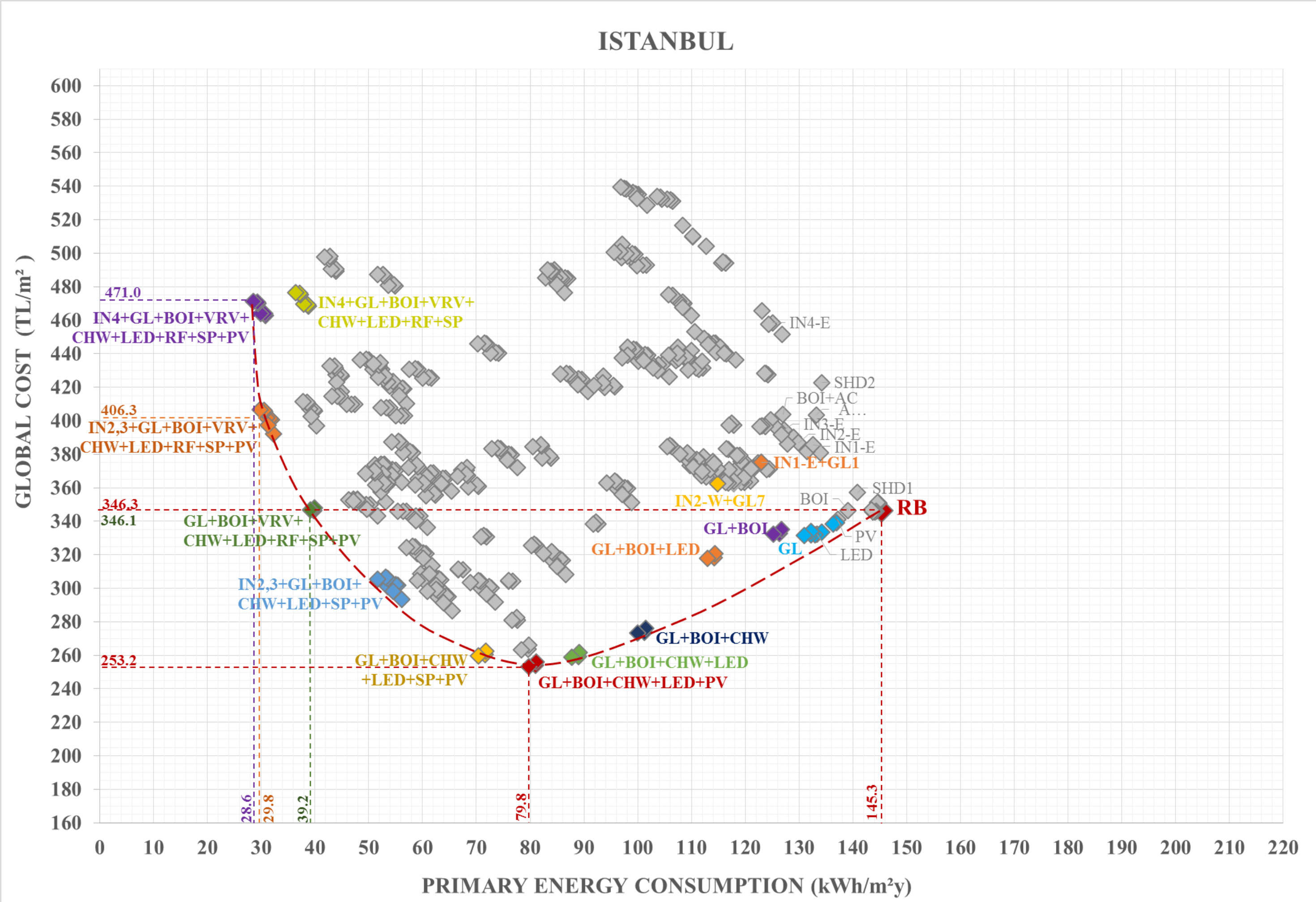


Figure 5.12 : Cost-optimal graph of retrofit scenarios for the RB in Istanbul.

When the retrofit measures are analysed in detail, it has been seen that glazing retrofits (GL) have positive effect in terms of both primary energy consumption and global cost. In addition, when the GL retrofits are combined with high-cost measures, decrement in the global cost is ensured.

Since Istanbul represents tempered humid climatic region of Turkey, retrofits referring to both heating and cooling systems are effective in increasing energy performance of the RB. However, from cost point of view, BOI retrofit is more acceptable within packages while AC retrofit does not refer to cost-effective results. VRV is more reasonable cooling system retrofit since the efficiency is high.

Thermal insulation level 4 (IN4), shading devices (SHD2) and installation of air conditioners (AC) have respectively high initial investment costs, therefore retrofit scenarios covering at least two of these measures resulted with a global cost higher than 480 TL/m². Correspondingly, these scenarios are far from the cost-optimal level.

Overall heat transfer coefficients stated in the latest Turkish National Heat Insulation Standard (TS 825:2013) were represented by the scenario combining IN1-E and GL1 retrofits. This retrofit scenario provides 27.4 kWh/m²y decrease in primary energy consumption of the RB in Istanbul, however, it is not cost-effective when applied individually. In order to achieve cost-effective results, these retrofits are required to be combined with other measures.

As mentioned in Section 4.2.5, this step aims also to select retrofit scenarios to be analysed in the second phase. According to the results of cost-optimal analyses, 10 retrofit scenarios, which are on the boundary of the cost-optimal curve, were selected. The selection was made considering potential future cost-optimal levels that will give opportunity to investigate NZEB levels in the further phases. Existing status of the RB was also selected in order to examine the effect of occupant behaviour on the building energy performance. The selected scenarios for the retrofits of RB in Istanbul are listed in Table 5.22 below. In the table, each line describes a different scenario and expresses the energy retrofit measures that were included in the scenario. As seen from the table, all of the selected retrofit scenarios for the RB in Istanbul include GL, BOI, CHW and LED measures.

Table 5.22 : Selected scenarios for the second phase (Istanbul).

1)	RB								
2)		GL7 +	BOI +		CHW +	LED			
3)		GL7 +	BOI +		CHW +	LED +			PV
4)	IN2-W +	GL7 +	BOI +		CHW +	LED +			PV
5)		GL7 +	BOI +		CHW +	LED +		SP +	PV
6)	IN2-W +	GL7 +	BOI +		CHW +	LED +		SP +	PV
7)	IN3-E +	GL7 +	BOI +		CHW +	LED +		SP +	PV
8)		GL7 +	BOI +	VRV +	CHW +	LED +	RF +	SP +	PV
9)	IN2-W +	GL7 +	BOI +	VRV +	CHW +	LED +	RF +	SP +	PV
10)	IN4-E +	GL4 +	BOI +	VRV +	CHW +	LED +	RF +	SP +	PV

5.1.5.3 Results of envelope retrofit scenarios analysed for Antalya

As in the analyses for Istanbul, the calculations for envelope retrofit scenarios for the RB in Antalya were analysed on the cost-optimal graphs as well. Results of these calculations are given in Figure 5.13.

As seen from the figure, glazing (GL) retrofits are the optimum retrofit measures in Antalya as well. Based on the low global cost of the glazing retrofits, these are also effective on decreasing the cost of the packages when they are used together with the heat insulation retrofits. The cost-optimum glazing retrofit is GL7 which results with 21.1 kWh/m²y primary energy saving that corresponds to 13% of RB energy consumption and 31.9 TL/m² global cost saving that is equal to 9% of total global cost.

It is seen that, some of the scenarios combining heat insulation (IN) and glazing (GL) retrofits are cost-effective in Antalya. The first reason of this is the global cost decrement effect glazing retrofits. Another reason is that the heat insulation thicknesses used in Antalya are lower in comparison to Istanbul and correspondingly initial investment cost of heat insulation is comparatively lower.

The scenario combining IN4-E and GL7 provides 37.7 kWh/m²y primary energy saving which is 23% of primary energy consumption of the RB in Antalya. However, this scenario is not cost-effective. Among the envelope retrofits, minimum primary energy consumption level that was achieved cost-effectively is obtained by retrofit scenario combining IN3-W and GL7 when the heat insulation material is EPS. This scenario achieves 34,3 kWh/m²y (21%) primary energy saving and 1.8 TL/m² global cost saving in Antalya. In case of a different heat insulation material use, calculated global cost of the scenario is higher than the global cost of RB.

As explained for Istanbul under Section 5.1.5.1, based on their initial investment costs, use of rock wool (RWL) as the heat insulation material increases the global cost while EPS leads to the lowest global cost among these three heat insulation material. In the following stages of this study, XPS was assumed as the heat insulation material also for Antalya.

According to the obtained results, the following scenarios were selected for the further retrofit scenario combinations for the RB in Antalya: GL3, GL4, GL5, GL6, GL7, IN2-W+GL7, IN3-W+GL3, IN3-W+GL4, IN3-W+GL5, IN3-W+GL7, IN4-W+GL7, IN2-E+GL7, IN3-E+GL3, IN3-E+GL4, IN3-E+GL5, IN3-E+GL7 and IN4-E+GL7.

Primary energy consumption and global cost results of these selected envelope retrofit scenarios, considering XPS as the heat insulation material, are given with Table 5.23.

Table 5.23 : Results of the selected envelope retrofit scenarios for the RB in Antalya.

Scenario	**Primary Energy Consumption** (kWh/m² y)	**Global Cost** (TL/m²)
RB	160.9	347.0
GL5	141.4	316.6
GL6	143.5	322.7
GL7	139.8	315.1
IN2-W + GL7	128.8	347.4
IN3-W + GL4	128.4	354.8
IN3-W + GL5	128.7	356.4
IN3-W + GL7	126.6	353.9
IN4-W + GL4	127.0	409.3
IN4-W + GL5	127.4	411.2
IN4-W + GL7	125.3	408.5
IN2-E + GL7	126.8	350.3
IN3-E + GL4	126.1	356.6
IN3-E + GL5	126.4	358.4
IN3-E + GL7	124.3	356.4
IN4-E + GL7	123.2	412.6

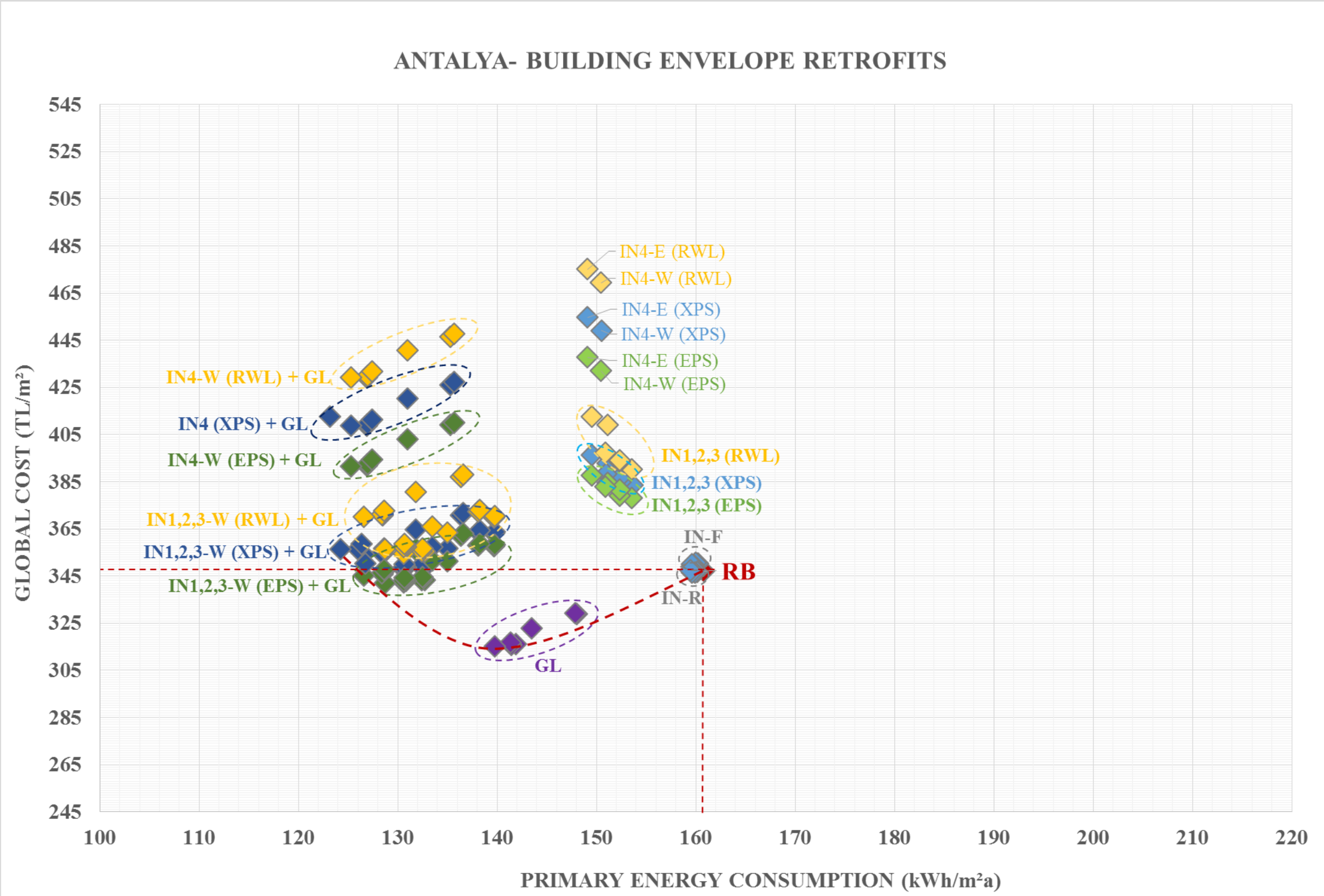


Figure 5.13 : Results of initial cost-optimal analyses on building envelope retrofit for Antalya.

5.1.5.4 Comparative analyses of all retrofit scenarios for Antalya

As described in the approach, selected building envelope scenarios for the RB in Antalya were combined with other measures related to retrofit of active systems and renewable energy use. Cost-optimal graph reflecting the calculation results for the RB in Antalya is given with Figure 5.14 below. Similar to Figure 5.12, which is given above and displays results for Istanbul, numerical results and names of substantial scenarios are highlighted in the graph while results of other scenarios are explained with tables in Appendix B.

The retrofit scenario that achieves the cost-optimal energy efficiency level for the RB retrofits in Antalya is the scenario combining GL7, CHW, LED and PV retrofits. This scenario results with 96.4 kWh/m²y annual primary energy consumption and 295.5 TL/m² global cost. Primary energy saving obtained by this retrofit package is 64.5 kWh/m²y (40%) and expected global cost saving is 105.5 TL/m² (26%) comparing to the existing status of the RB in Antalya.

Compared to the optimum retrofit scenario for the RB in Istanbul, the only difference is absence of BOI retrofit in the cost-optimal scenario. This mainly proceed from the hot-humid climate of Antalya where the BOI retrofit provides unremarkable amount of energy saving in response to the investment and correspondingly was not included in the further retrofit scenarios (see Appendix B).

In comparison to the cost-optimal retrofit solution, affording 13.9 TL/m² additional global cost for applying also VRV and SP measures provides 43.8 kWh/m²y more energy saving and carry the primary energy consumption level up to 52.6 kWh/m²y in a cost-effective way in Antalya. As an addition to the retrofits in this scenario, investing also on the thermal insulation results cost-effectively as seen from the scenario combining IN3-E, GL7, VRV, CHW, LED, SP and PV retrofits. This scenario results with 39.7 kWh/m²y primary energy consumption and 356.4 TL/m² global cost, correspondingly achieve 75% primary energy saving in a cost-effective way. Additional investments on heat insulation until IN4 decreases the primary energy consumption of the reference building while cost-effectiveness is not provided. This strategy provides 1.3 kWh/m²y primary energy saving by 56.8 TL/m² increase in global cost. A similar tendency is observed for an extra SHD2 retrofit on this package where additional 2.2 kWh/m²y primary energy saving is achieved with 94.9 TL/m² increase in global cost.

Detailed examination on the retrofit measures shows that glazing retrofits (GL) work well also in Antalya which is in hot-humid region of Turkey. Heat insulation retrofits, instead, increase the global cost of the scenario which they are involved in although they provide primary energy saving. The scenario representing the heat transfer coefficients given with the national standard (IN1-E+GL1) is not cost-effective in Antalya as well. However, use of more efficient glazing types together with the heat insulation, such as GL7, provides a decrease in the global cost. In example, the scenario combining IN2-W and GL7 retrofits is cost-effective even though the initial investment cost is higher than IN1+GL1 scenario. Moreover, it is possible to provide further global cost decrease by combining the envelope retrofits with other measures referring to energy systems and renewable energy use.

BOI retrofit is not effective both on the energy consumption and global cost in this climate. In the same manner, because of the climate, AC and VRV retrofits provide efficiency in terms of primary energy while VRV retrofit exists in cost-effective scenarios as well.

IN4, AC and SHD2 measures are expensive investments comparing to their benefits related to primary energy consumption. The scenarios resulted with a global cost higher than 500 TL/m² in Antalya include at least two of these retrofit measures.

Using the same perspective applied for the RB in Istanbul, among the analysed retrofits, 8 scenarios were selected for the investigation of occupant behaviour effect and also for the sensitivity analyses in the second phase. Selected scenarios are listed in Table 5.24. As seen from the table, all of the selected retrofit scenarios for the RB in Antalya which are on the boundary of the cost-optimal curve, include GL, CHW and LED measures.

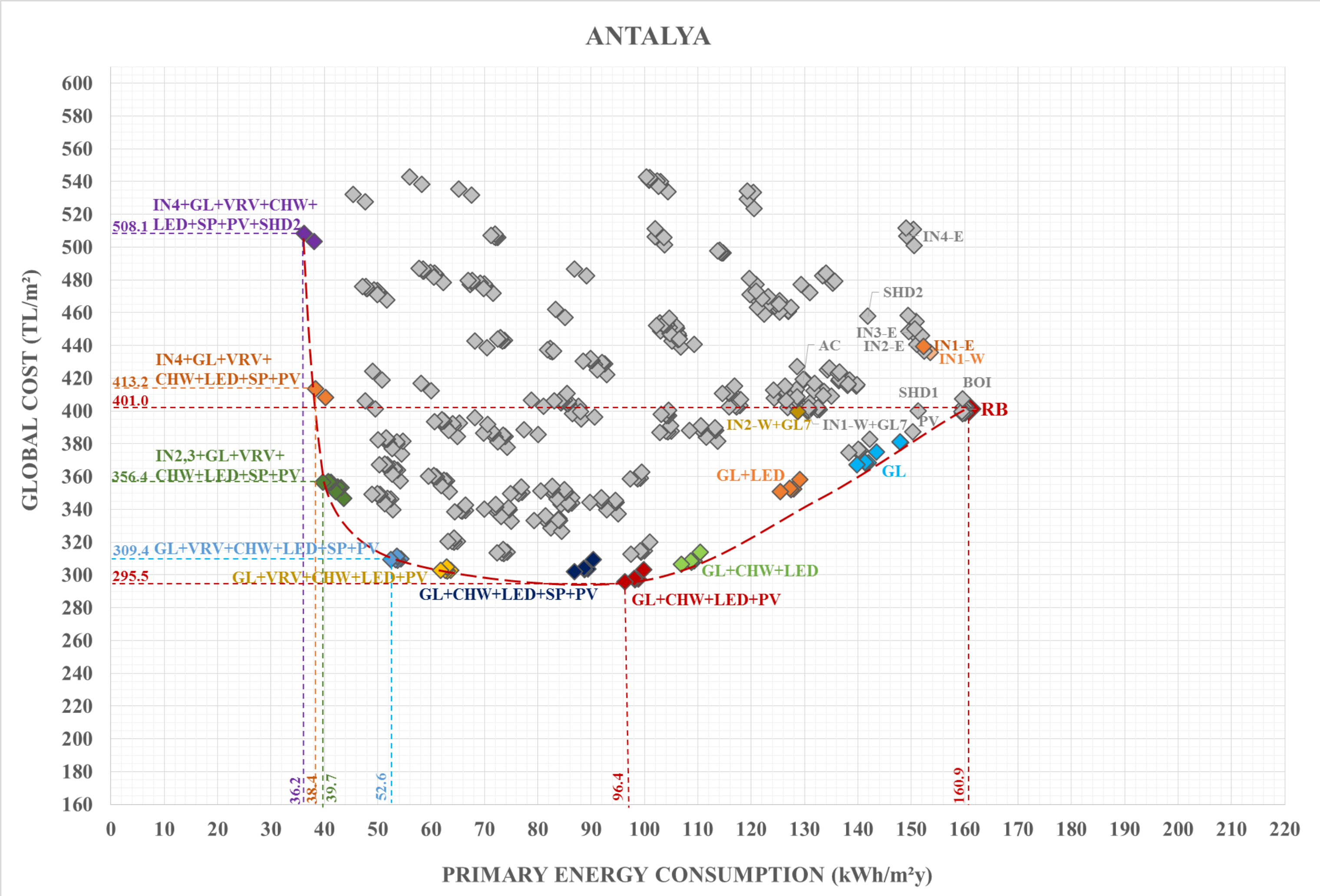


Figure 5.14 : Cost-optimal graph of retrofit scenarios for the RB in Antalya.

Table 5.24 : Selected scenarios for the second phase (Antalya).

1) RB					
2)	GL7 +	CHW +	LED		
3)	GL7 +	CHW +	LED +		PV
4)	GL7 +	CHW +	LED +	SP +	PV
5)	GL7 +VRV +	CHW +	LED +		PV
6)	GL7 +VRV +	CHW +	LED +	SP +	PV
7) IN2-W +	GL7 +VRV +	CHW +	LED +	SP +	PV
8) IN4-E +	GL7 +VRV +	CHW +	LED +	SP +	PV

5.1.5.5 Results of envelope retrofit scenarios analysed for Erzurum

Primary energy consumption and global cost results of the envelope retrofit scenarios analysed for the RB in Erzurum are presented with Figure 5.15. As seen from this figure, scenarios combining heat insulation retrofits and glazing retrofits are the optimum solutions for Erzurum while glazing retrofits are not that much effective individually since this city represents the cold climatic region of Turkey. The cost-optimum point was achieved with the combination of heat insulation level 1 (IN1) and glazing type 6 (GL6) retrofits.

Since XPS was considered as the heat insulation material in the following stages of the analyses, some of the retrofit scenarios for Erzurum were only analysed considering XPS material. According to the analyses, the scenario combining IN1-E and GL6 retrofits achieves 149.2 kWh/m²y primary consumption and 365.7 TL/m² global cost level as the cost optimum envelope retrofit scenario. The cost optimum envelope retrofit scenario provides 31% primary energy saving and 5.4% global cost saving for the RB in Erzurum. On the other hand, the combination of IN2-E and GL6 provides 5.7 kWh/m²y additional primary energy saving with 3.1 TL/m² higher global cost in comparison to the cost-optimal envelope retrofit scenario.

Cost-effective primary energy saving potential of building envelope retrofits are the highest in Erzurum comparing to other two cities. Moreover, since it has a cold climate, the heat insulation retrofits are more effective while the glazing retrofits are less effective in terms of both primary energy and global cost.

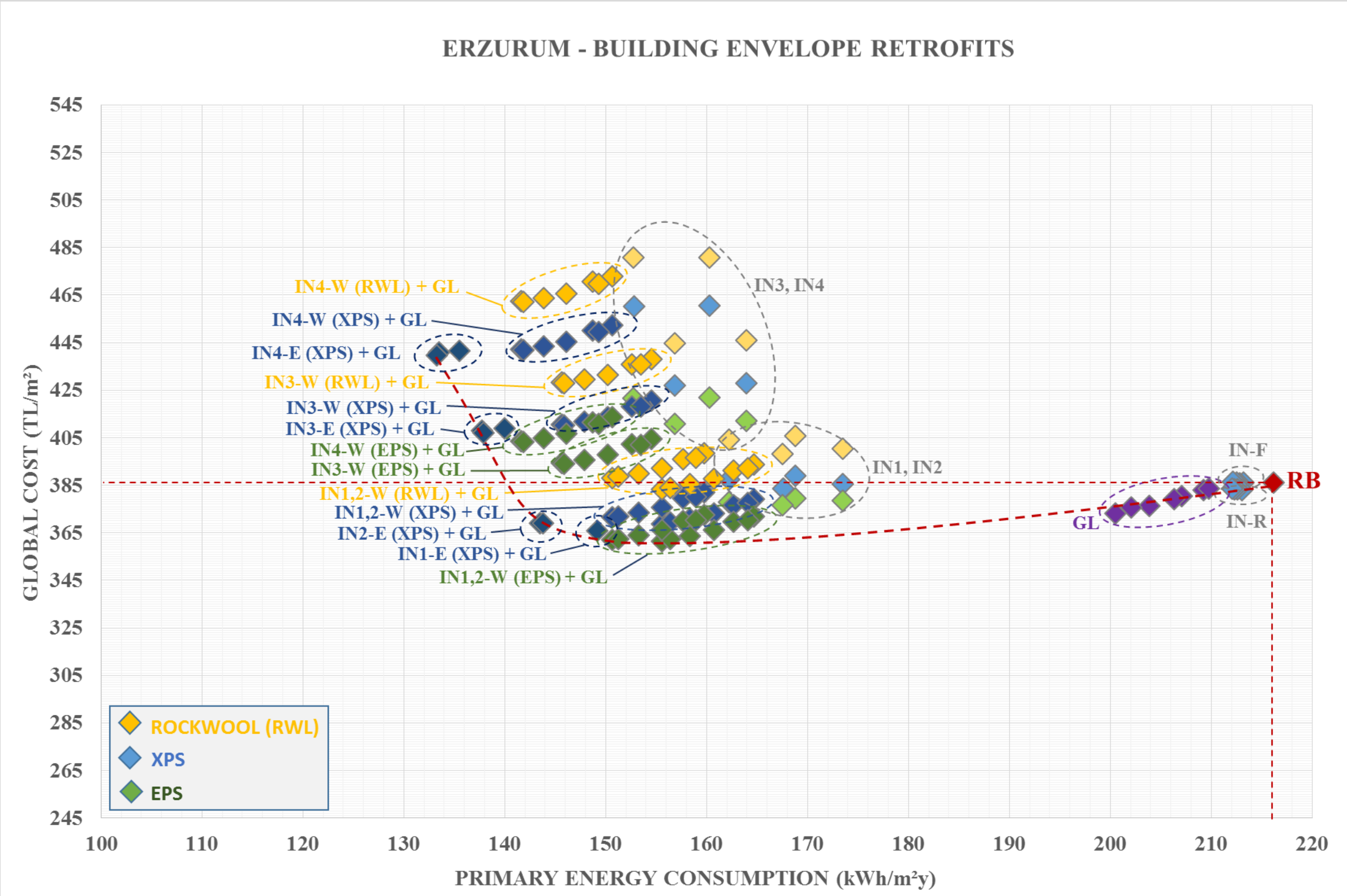


Figure 5.15 : Results of initial cost-optimal analyses on building envelope retrofit for Erzurum.

In accordance with the results obtained, the following scenarios are selected for the RB in Erzurum: GL6, GL7, IN1-W+GL6, IN2-W+GLZ6, IN2-W+GLZ7, IN3-W+GLZ5, IN3-W+GLZ6, IN3-W+GLZ7, IN4-W+GLZ5, IN4-W+GLZ6, IN4-W+GLZ7, IN1-E+GL6, IN2-E+GLZ6, IN2-E+GLZ7, IN3-E+GLZ5, IN3-E+GLZ6, IN3-E+GLZ7, IN4-E+GLZ5, IN4-E+GLZ6 and IN4-E+GLZ7. Primary energy consumption and global cost results of these selected envelope retrofit scenarios, considering XPS as the heat insulation material, are given with Table 5.25.

Table 5.25 : Results of the selected envelope retrofit scenarios for the RB in Erzurum.

Scenario	**Primary Energy Consumption** (kWh/m² y)	**Global Cost** (TL/m²)
RB	216.3	386.0
GL6	200.5	372.9
GL7	202.1	375.4
IN1-W+GL6	155.6	368.6
IN2-W + GL6	150.7	371.4
IN2-W + GL7	151.3	371.8
IN3-W + GL5	147.9	411.5
IN3-W + GL6	145.7	410.4
IN3-W + GL7	145.9	410.0
IN4-W + GL5	143.9	443.3
IN4-W + GL6	141.6	442.1
IN4-W + GL7	141.9	441.7
IN1-E + GL6	149.2	365.7
IN2-E + GL6	143.5	368.9
IN2-E + GL7	143.8	368.8
IN3-E + GL5	140.0	408.7
IN3-E + GL6	137.8	407.8
IN3-E + GL7	137.9	407.0
IN4-E + GL5	135.5	441.3
IN4-E + GL6	133.5	440.8
IN4-E + GL7	133.3	439.6

5.1.5.6 Comparative analyses of all retrofit scenarios for Erzurum

Selected envelope retrofit scenarios for the RB in Erzurum were combined with further retrofit measures as in other climates presented previously. Cost-optimal graph for the RB retrofit in Erzurum is presented with Figure 5.16. Results and names of the scenarios which are not highlighted in the graph are given in Appendix C. The cost-optimal energy efficiency level is achieved by the scenario including GL6, BOI, CHW, LED and PV retrofits. This cost-optimal scenario results with 132.1 kWh/m²y primary energy consumption and 313.4 TL/m² global cost. This level achieves 84 kWh/m²y (39%) primary energy saving and 124 TL/m² (28%) global cost saving comparing to RB without retrofit.

Besides the exact cost-optimal scenario, it is important that only 3.2 TL/m² increase in the global cost leads to 43.5 kWh/m²y higher primary energy saving. In order to achieve this level, IN1-E retrofit should also be adjoined. Likewise, 11.2 TL/m² increase in the global cost enables 17.1 kWh/m²y further primary energy saving and reaches 71.5 kWh/m²y with the scenario consisting of IN2-E, GL6, BOI, CHW, LED, SP and PV retrofits. On the other hand, investment cost of this scenario is 310 TL/m² higher than the cost-optimal retrofit scenario. Insertion of RF retrofit to this scenario and use of GL7 instead of GL6 decrease the primary energy consumption of the RB until 53.3 kWh/m²y, however, this scenario increases the global cost up to 361.5 TL/m². After this point, increasing the heat insulation level up to IN4-E results with 47.7 kWh/m²y primary energy consumption level which corresponds to a global cost level close to the global cost of the RB before retrofit. In comparison with the RB, this scenario (IN4-E+GL6+BOI+CHW+LED+RF+SP+PV) provides 78% primary energy saving with 168.6 kWh/m²y decrease in primary energy consumption in Erzurum.

When retrofit scenarios were analysed in detail, it is seen that, contrary to Istanbul and Antalya, the package representing the national heat insulation standard (IN1E + GL1) is cost-effective in Erzurum. Although this scenario leads to 58 kWh/m²y primary energy saving, achieved energy performance level is not potentially reliable for NZEB targets when it is compared with more effective retrofit scenarios.

Results reveal that, in Erzurum, retrofit measures related to space cooling systems (AC, VRV) are not effective in terms of energy and cost for the analysed RB. Therefore, these measures were not included in greater number of scenarios. BOI retrofit gives effective results as expected for this cold climate. Although RF retrofit has a high initial investment cost, it is included in the cost-effective retrofit scenarios as shown in Figure 5.16.

In order to serve to the following stage and the second phase of the approach, 11 retrofit scenarios were selected for Erzurum and listed in Table 5.26. Common retrofits included in the selected scenarios are GL, BOI, CHW, LED and PV and LED measures.

Table 5.26 : Selected scenarios for the second phase (Erzurum).

1)	RB							
2)		GL7 +	BOI +	CHW				
3)		GL6 +	BOI +	CHW +	LED			
4)		GL6 +	BOI +	CHW +	LED +			PV
5)	IN1-E+	GL6 +	BOI +	CHW +	LED +			PV
6)	IN1-E+	GL6 +	BOI +	CHW +	LED +		SP+	PV
7)	IN1-E+	GL6 +	BOI++	CHW +	LED +		SP +	PV
8)	IN1-E+	GL6 +	BOI +	CHW +	LED +	RF+	SP +	PV
9)	IN2-E+	GL7 +	BOI +	CHW +	LED +	RF+	SP +	PV
10)	IN3-E+	GL7 +	BOI +	CHW +	LED +	RF+	SP +	PV
11)	IN4-E+	GL7 +	BOI +	CHW +	LED +	RF+	SP +	PV

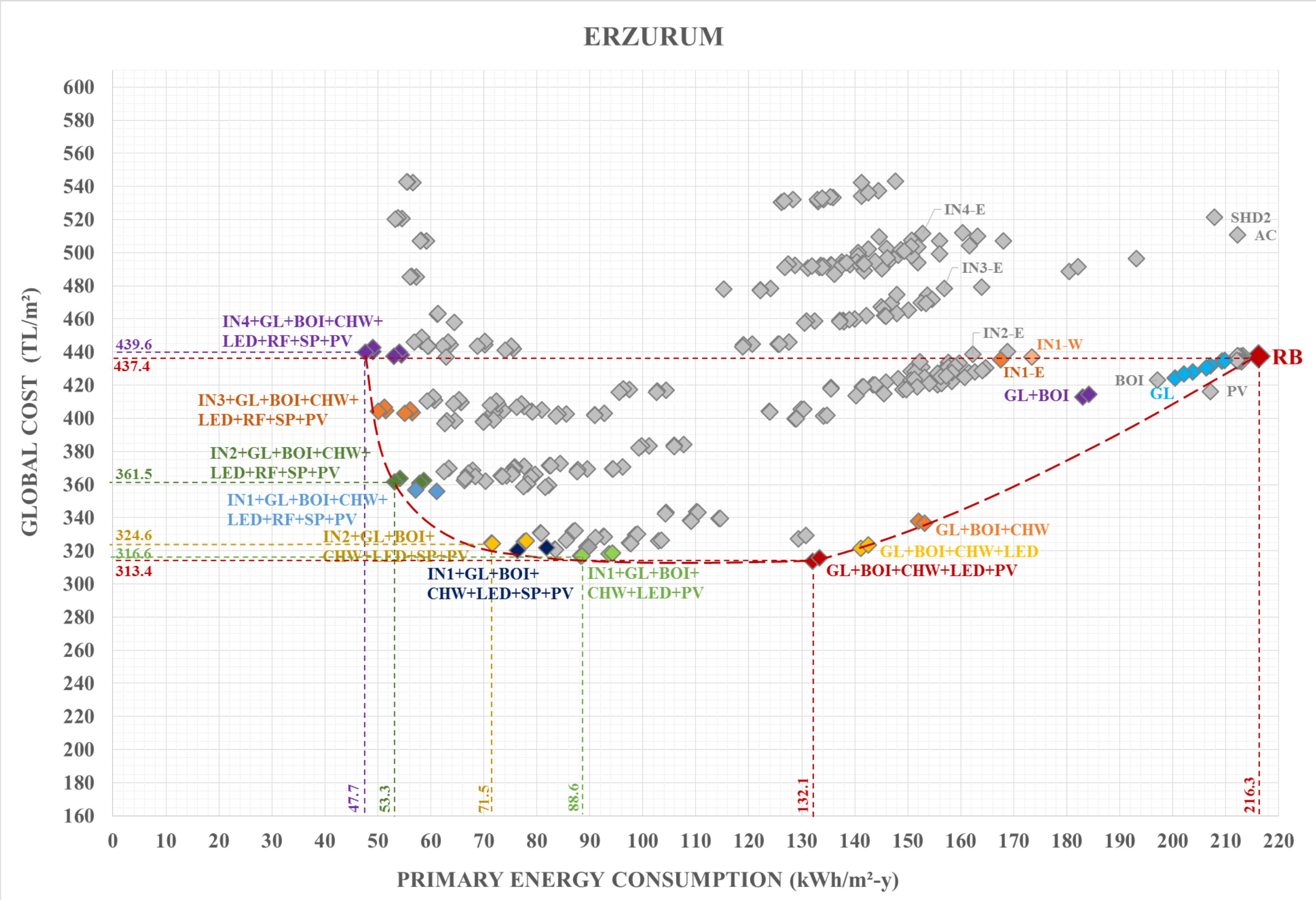


Figure 5.16 : Cost-optimal graph of retrofit scenarios for the RB in Erzurum.

5.1.6 Analysing the effect of occupant behaviour on cost-optimal levels

As described in Section 4.2.6, analysing the effect of occupant behaviour on cost-optimal levels is an innovative part of this approach. Sample implementation presented in this section examines the effect of occupant behaviour related to window openings. However, it is possible to widen this approach to all other aspects of occupancy pattern.

In this implementation, besides the reference occupant behaviour that was considered in the previous calculations, an alternate occupant behaviour (OB) representing much more use of window openings was analysed. For the alternate occupant behaviour (OB), it was assumed that RB occupants control up to 3.6 m² opening area and leave windows open while the outdoor temperature is between 21°C and 26°C. These analyses on alternate occupant behaviour (OB) were performed for the scenarios selected in the previous stage considering three different climates.

Figure 5.17 displays the results obtained from the analyses on the effect of alternate occupant behaviour (OB) for the RB in Istanbul. Primary energy consumption of the cost-optimal scenario, which includes GL7, BOI, CHW, LED and PV retrofits, was affected from OB and achieved 60.4 kWh/m²y, with a decrease around 19.4 kWh/m²y, while the global cost of this scenario decreased from 253.2 TL/m² to 210.7 TL/m² in Istanbul.

Not only the cost-optimal scenario but also other cost-effective scenarios were affected by the occupant behaviour change related to window openings. The scenario including IN3-E, GL7, BOI, CHW, LED, SP and PV retrofits responds to this change with 23 kWh/m²y primary energy saving and 50.5 TL/m² global cost saving by achieving 28.7 kWh/m²y primary energy consumption and 254.6 TL/m² global cost. With this scenario, 80% primary energy saving, in comparison with the RB without OB, can be achieved in a cost-effective way.

Results show that it is possible to decrease primary energy consumption of the RB in Istanbul until 17 kWh/m² by applying the alternate occupant behaviour (OB) and the scenario including IN4-E, GL7, BOI, VRV, CHW, LED, RF, SP and PV retrofits. This result corresponds to 88% primary energy saving (128.3 kWh/m²y), however, it is not cost-effective in Istanbul.

Effect of alternate occupant behaviour (OB) on the RB performance in Antalya is presented with Figure 5.18 below. Appropriate use of window openings changes the primary energy consumption of the cost-optimum scenario from 96.4 kWh/m²y to 74.3 kWh/m²y. Global cost of this cost-optimum scenario decreases around 48.4 TL/m² considering OB comparing to the scenario with the reference occupant behaviour. As the result of this, cost-optimum scenario with alternate occupant behaviour (OB) reaches 247.1 TL/m² global cost level.

In accordance with the calculations, among the analysed scenarios for Antalya, the lowest primary energy consumption level was achieved by the scenario including IN4-E, GL7, VRV, CHW, LED, SP and PV retrofits and also the alternate occupant behaviour (OB). Conscious use of window openings ensures changes in the primary energy consumption and global cost results of this scenario. Primary energy consumption of this scenario was decreased from 38.4 kWh/m²y to 26.9 kWh/m²y and global cost of the scenario was decreased from 413.2 TL/m² to 387.9 TL/m². In comparison to the RB before retrofit and with reference occupant behaviour, this scenario achieves 83% primary energy saving and 3% decrease in global cost.

Results obtained from the analyses related to OB for the RB in Erzurum are presented with Figure 5.19. As seen from this figure, in comparison to other two cities, effect of OB is limited in Erzurum. Among the scenarios involving OB effect, the scenario combining IN1-E, GL6, BOI, CHW, LED and PV measures appears as the cost-optimal solution for Erzurum. This scenario results with 80.7 kWh/m²y primary energy consumption and 299.9 TL/m² global cost. However, similar to the results of scenarios without OB, cost-optimal range of scenarios considering OB, which is between 299.9 TL/m² and 303.5 TL/m², refers to very different primary energy consumption levels between 68.8 kWh/m²y and 127.5 kWh/m²y.

The scenario consisting of IN4-E, GL7, BOI, CHW, LED, RF, SP, and PV retrofits and OB option for the occupant behaviour, results with 39.1 kWh/m²y primary energy consumption and 420.6 TL/m² global cost which is almost same with the RB global cost with OB option. This scenario achieves 81% primary energy saving in comparison to the RB with OB and 82% primary energy saving in comparison to the RB without OB in Erzurum.

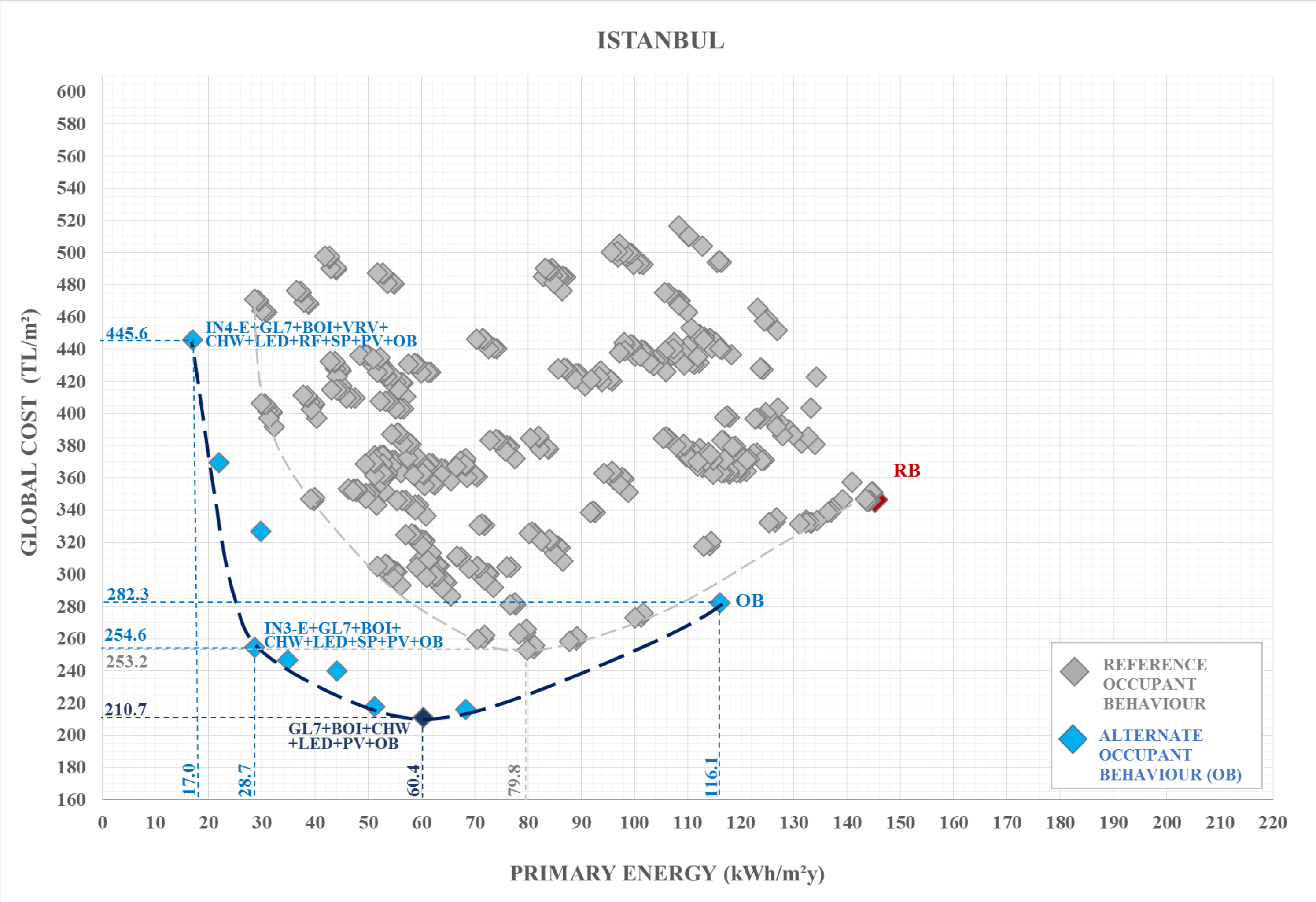


Figure 5.17 : Effect of occupant behaviour related to window openings on cost-optimality of RB retrofit scenarios in Istanbul.

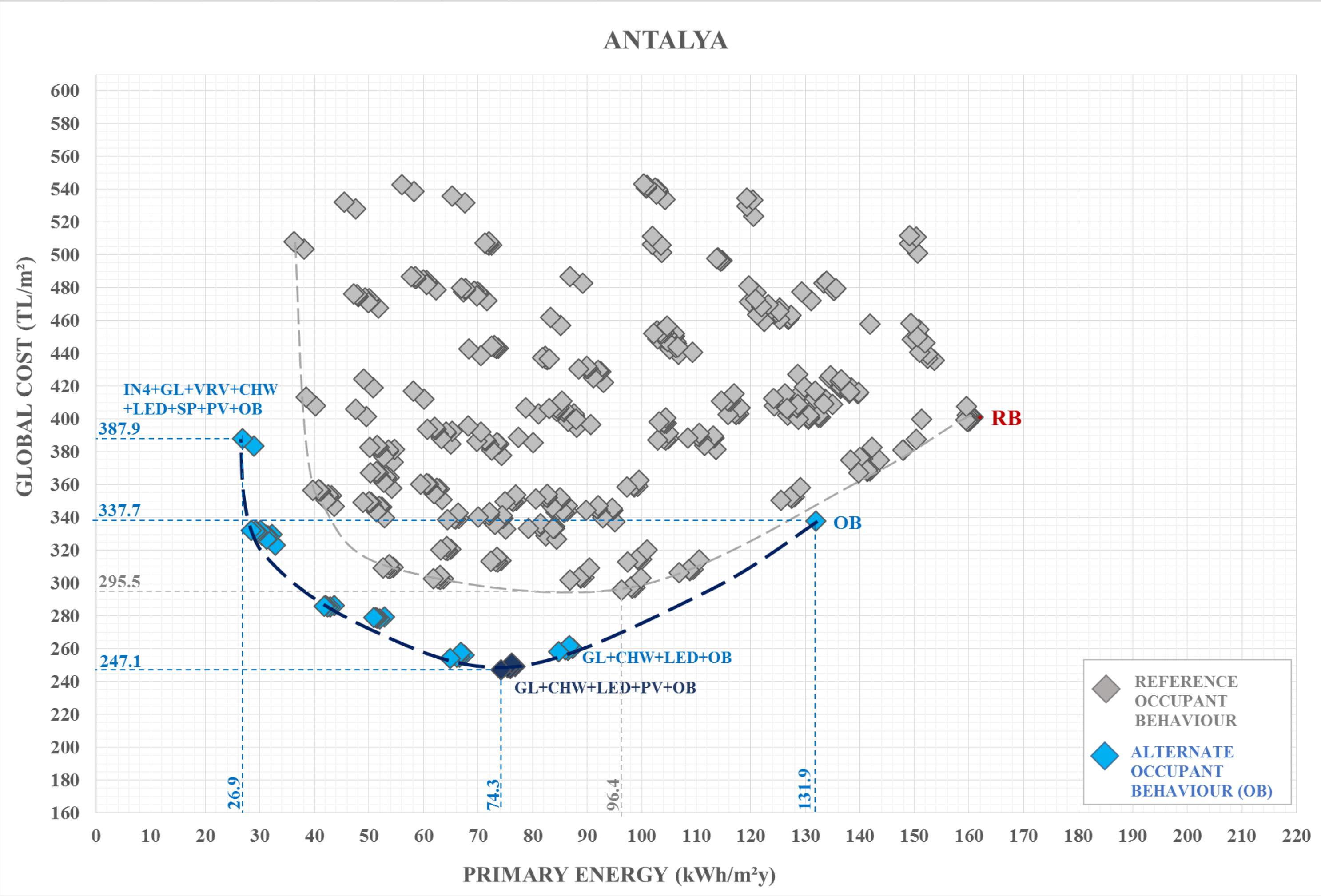


Figure 5.18 : Effect of occupant behaviour related to window openings on cost-optimality of RB retrofit scenarios in Antalya.

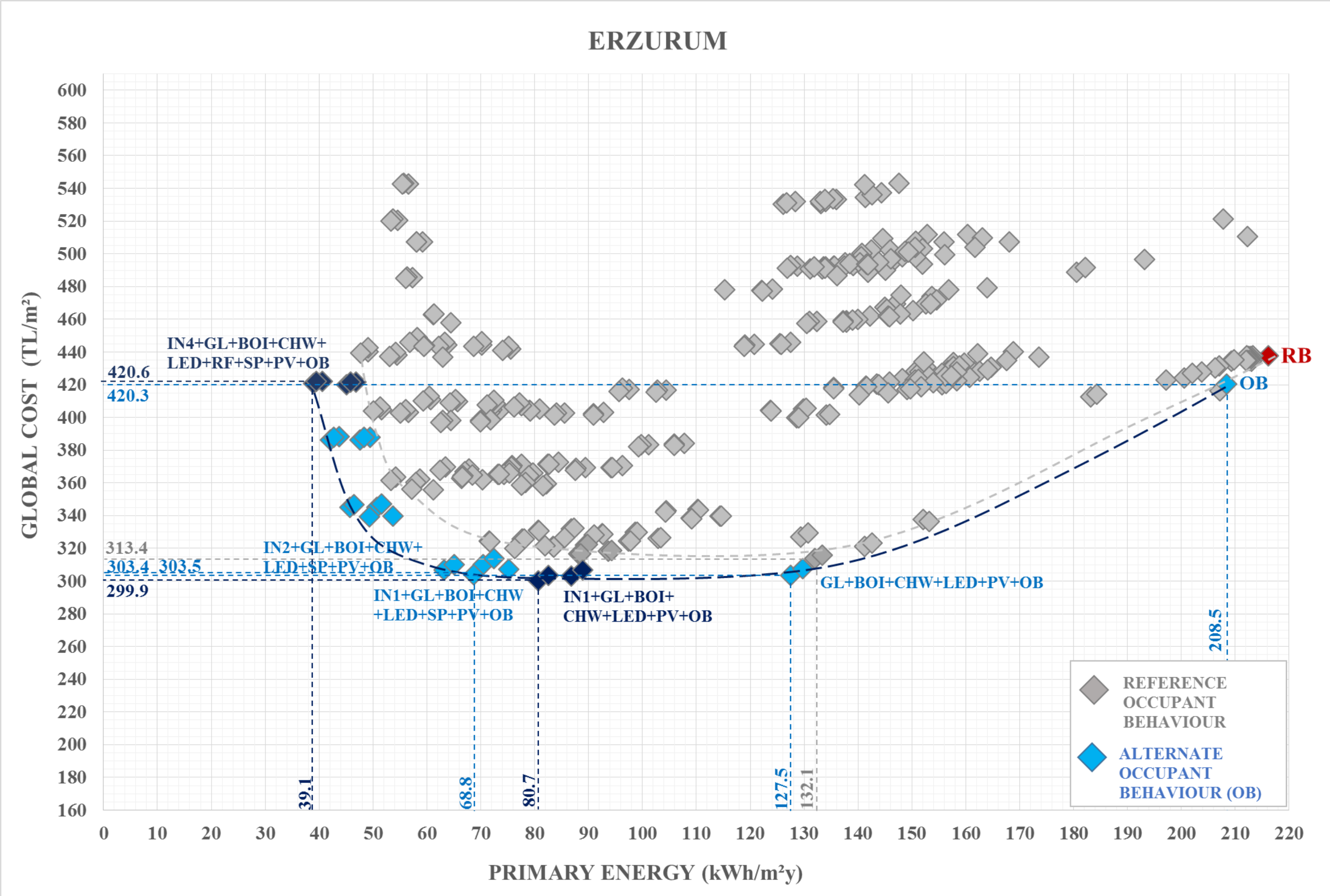


Figure 5.19 : Effect of occupant behaviour related to window openings on cost-optimality of RB retrofit scenarios in Erzurum.

5.1.7 Evaluation of the first phase

The first phase of the approach includes adopting cost-optimal methodology with an extended context by integrating analyses related to occupant behaviour effect and aims to select the retrofit scenarios for investigating potential NZEB levels in the second phase. In parallel with this aim, within the implementation of this phase, proper retrofit scenarios were selected for the second phase and OB effect was analysed on the results. Selected scenarios at the end of this first phase represent the candidates for the potential NZEB levels for the RB retrofit. Besides these, obtained results reveal some additional specific outcomes as explained under this section.

Obtained results show that, it is possible to achieve cost-effective primary energy saving higher than 70% by retrofitting existing high-rise apartment buildings in the three climatic region of Turkey. In addition, conscious occupant behaviour can change this percentage in a positive way.

Results also reveal that climate is effective on the cost-optimal analyses and the cost-optimal points for the retrofit of same reference building show significant differences according to the variations in climate. The cost-optimal primary energy consumption level of the analysed reference building is 79.8 kWh/m^{2}y in tempered-humid climatic region and 96.4 kWh/m^{2}y in hot-humid region while it changes between 88.6 kWh/m^{2}y kWh/m^{2}y and 132.1 in the cold climatic region of Turkey.

The cost-optimum and highly energy efficient retrofit scenarios include measures related to envelope retrofits, retrofits referring to HVAC system improvements and installation of renewable energy systems. This result shows that building energy retrofits should be targeted at whole building retrofit instead of focusing on individual measures.

Results obtained for the scenario including the retrofit actions which ensures the maximum limit values of heat transfer coefficients given in the national standard TS 825 show that, this national standard and the national regulations should be revised because these are far from the cost-optimal levels of energy performance.

For all analysed climates, there are common effects of some specific retrofit measures. Common retrofits included in the cost-optimal scenarios in all climates are GL, LED, CHW, DHW and PV retrofits and this shows that these measures are needed to be supported for the building retrofits. Not only the building itself but also occupant behaviour is effective both on the primary energy consumption and global cost in all analysed cities. Therefore, the occupants are required to be conscious in terms of energy consumption of their building. In example, OB has a significant effect on the primary energy consumption and global cost of the cost-optimal retrofit scenarios for the RB in Istanbul and Antalya. On the other hand, since climate of Erzurum is cold, effect of OB, to increase the natural ventilation through windows, on the results of the scenarios are not that much significant, however, OB switches the cost-optimal solution. This positive change in the occupant behaviour brings 24% further primary energy saving for the cost-optimal scenario in Istanbul, 23% primary energy saving in Antalya and depending on the selected cost-optimal level 22% or 39% primary energy saving in Erzurum in comparison with the RB without OB.

The analyses in this implementation considered different retrofit measures with a whole building retrofit approach. However, some of the retrofit measures, such as CHW and RF retrofits, may not be applicable for all residential buildings which were represented by this RB since these require certain conditions to implement. However, these measures provide higher energy efficiency, especially in cold climatic region. Therefore they should be examined in the cost-optimal analyses in order to display their effect for the available buildings.

5.2 Development of Proposals for Achievable NZEB Targets

As mentioned in Chapter 4, the second phase of the approach is development of proposals for achievable NZEB targets for building retrofits. Through the sensitivity analyses, it aims to identify potential NZEB levels by regarding NZEB as the future cost-optimal level and to develop solutions for bridging the gap between cost-optimal and NZEB levels. In accordance with the stages described for the approach in Chapter 4, this section presents implementation of the second phase and explains the boundary conditions for sensitivity analyses, application of sensitivity analyses, identification of potential NZEB levels, determination of the financial gaps, investigation of the solutions for bridging the gaps and prepared proposals for policy-makers. As in the first phase, this phase also considers three different climates.

5.2.1 Boundary conditions for sensitivity analyses

In this sample implementation of the proposed approach, economic indicators, investment cost decreases and cost calculation periods were considered within the sensitivity analyses. For the boundary conditions explained below, changes in the results of cost-optimal analyses were examined.

Sensitivity analyses on economic indicators focused on the real discount rate (R_R) as required by EU Regulation and also energy price development rates. The global cost calculations in the first phase considered the average rates of previous years and assumed the discount rate (R_R) as 5.78% and energy price development rates were assumed as equal to the inflation rate which is 8.054%. Sensitivity analyses conducted in this second phase focused on two rates for each of discount rate and energy price development. The selection procedure considered the requirements of EU regulation and selected one of the analysed discount rates as 3%. Accordingly, the rate which is higher than the existing assumption is 9% in the analyses. For the sensitivity analyses related to energy price developments, rates were selected as 5% and 10% as respectively being lower and higher according to the existing assumption.

Sensitivity analyses on investment cost decrease focused on a discount which is equal to value added tax (VAT) of the retrofit investments. Although the analyse seems as focusing on the exemption from tax, this value may be obtained by autogenous decrease in the cost or decrease as the result of technological development or may be triggered by some subsidy and incentives and these will come up with the same result from individual end user point of view. Retrofit measures which were selected for the sensitivity analyses on investment cost decrease are different for each climate. For the retrofit of RB in Istanbul and Erzurum, effect of investment cost decreases for SP (installation of solar thermal system) and IN (heat insulation) measures were analysed while for the retrofit in Antalya effect of investment cost decreases for VRV (installation of central variable refrigerant volume system) and SP measures were analysed since these measures were seen as the opportunity for decreasing the global cost of the scenarios which were slightly higher in comparison to the cost-optimal scenarios for the climate. These options were also analysed under different financial rates.

As required by the EU Regulation, global cost calculation period was assumed as 30 years for the analyses in the first phase. Within the scope of sensitivity analyses, 20 years, 40 years and 50 years of cost calculation periods were also analysed.

Summarily, boundary conditions determined for the sensitivity analyses are as below:

- Discount Rate (R_R) = 3%
- Discount Rate (R_R) = 9%
- Energy Price Development = 10%
- Energy Price Development = 5%
- Investment cost decrease (around VAT of retrofit measure investment)
- Global calculation periods of 20 years, 40 years and 50 years.

5.2.2 Results of sensitivity analyses for Istanbul

Results of the sensitivity analyses for the RB retrofit in Istanbul are presented with Figure 5.20, Figure 5.21 and Figure 5.22 below. These graphs are cost-optimal graphs including the results of sensitivity analyses for the selected scenarios. The quadrangle points refer to the scenarios considering the reference occupant behaviour while the circle shaped points refer to the scenarios considering alternate occupant behaviour (OB). As explained in the legend, in the initial two graphs, the light colours represent the results without any investment cost decrease for the retrofits and the colour gets darker when the cost decreases are considered. Variations of the cost-optimal curve under different discount rates and investment cost decreases are also shown in the graph.

Figure 5.20 reflects the results of the analyses related to the discount rates (R_R) and investment cost decreases around VAT for the retrofit measures SP and IN. Results show that lower discount rates result with higher global cost while higher discount rates lead to lower global cost results. When the exact cost-optimal scenarios are investigated, it is seen that, in case of a discount rate of 3%, tax exemption for SP measure or an investment cost decrease at same value enables to include also SP measure in the cost-optimal scenario and move the cost-optimal primary energy consumption level from 79.8 kWh/m²y to 70.4 kWh/m²y. The scenarios including also heat insulation, such as the one combining IN2-W, GL7, BOI, CHW, LED, SP and PV measures, are not exactly cost-optimal, however the investment cost decrease enables to cover these scenarios within cost-optimal range and move towards 56.2 kWh/m²y in retrofit decision since the global cost variation between this scenario and the exact cost-optimal scenario (GL7, BOI, CHW, LED, SP and PV) is only 15 TL/m² when the discount rate is 3%.

When the discount rate appears as assumed in the initial analyses (5.78%) or higher, investment cost decreases in SP and IN measures motivate to move towards higher energy efficiency level, however these are not effective on switching the exact cost-optimal results as in the analyses with 3% discount rate. When SP measure is supported with an investment cost decrease, the SP measure may be included in the decided investment scenario also under the discount rate of 5.78% with a 2.5 TL/m² higher global cost in comparison to the previous cost-optimal result.

Figure 5.21 displays the results for sensitivity analyses regarding investment cost decreases for IN and SP measures under different energy price development rates for the retrofit of RB in Istanbul. As shown in the graph, higher energy price development rates result with higher global cost as expected. Results of the scenarios with higher energy price development rate are similar to the results obtained for lower discount rates.

Investment cost decrease for IN and SP measures ensures that retrofit scenarios with higher energy efficiency are more affordable in Istanbul. This works better when the energy price development rate is higher than assumed. In case of an energy price development rate of 10%, the cost-optimal scenario includes GL7, BOI, CHW, LED, SP and PV retrofits and achieves 70.4 kWh/m²y.

Figure 5.22 shows the results regarding different calculation periods for global cost calculations. Results show that the higher calculation period comes up with the higher global cost mainly due to the energy costs. Although the exact cost-optimal scenario remains as the same, higher calculation periods provides to obtain more convenient global cost results for the retrofit scenarios which achieves lower primary energy consumption levels.

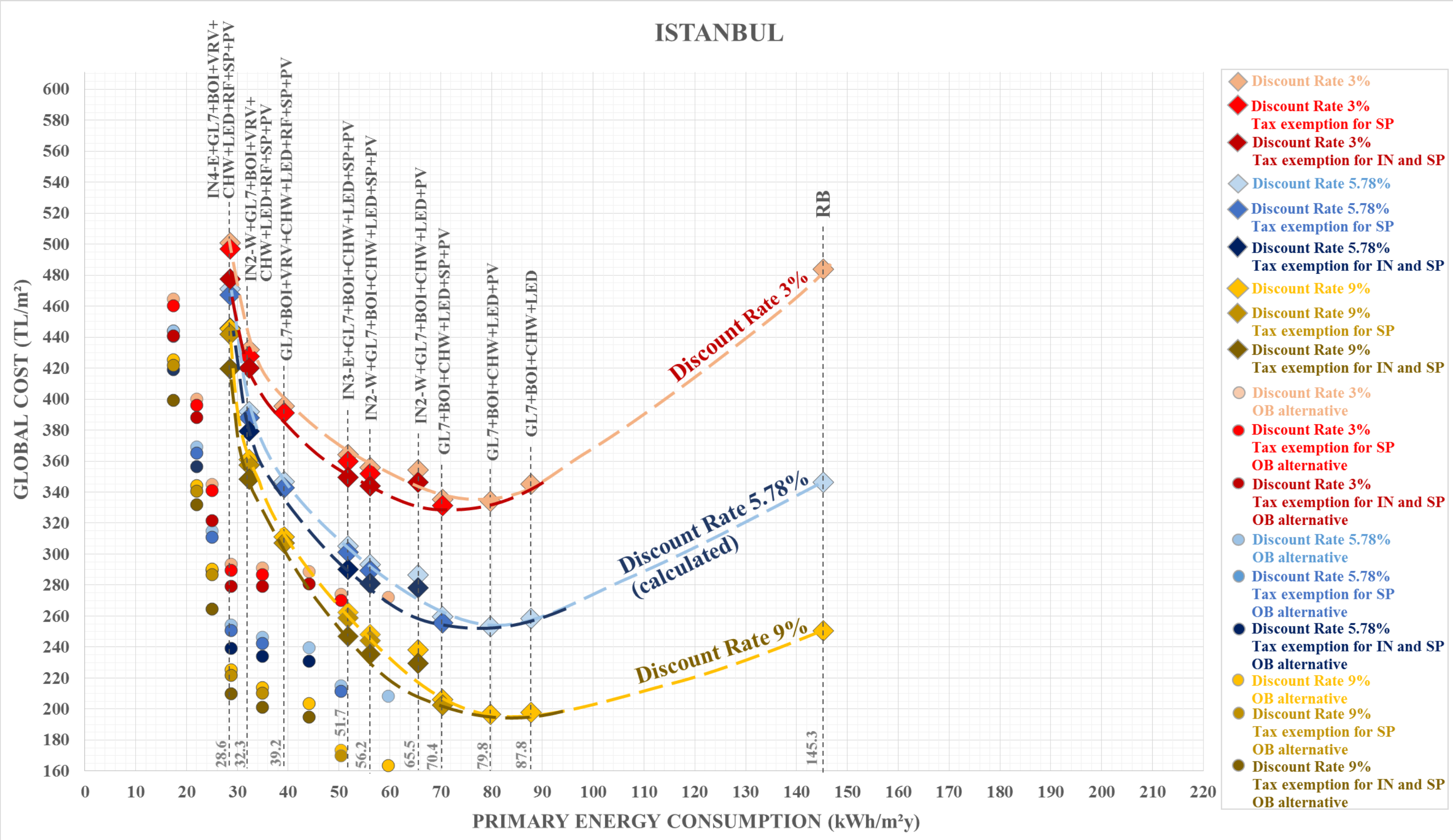


Figure 5.20 : Sensitivity analyses on discount rates and investment cost decreases for the RB retrofits in Istanbul.

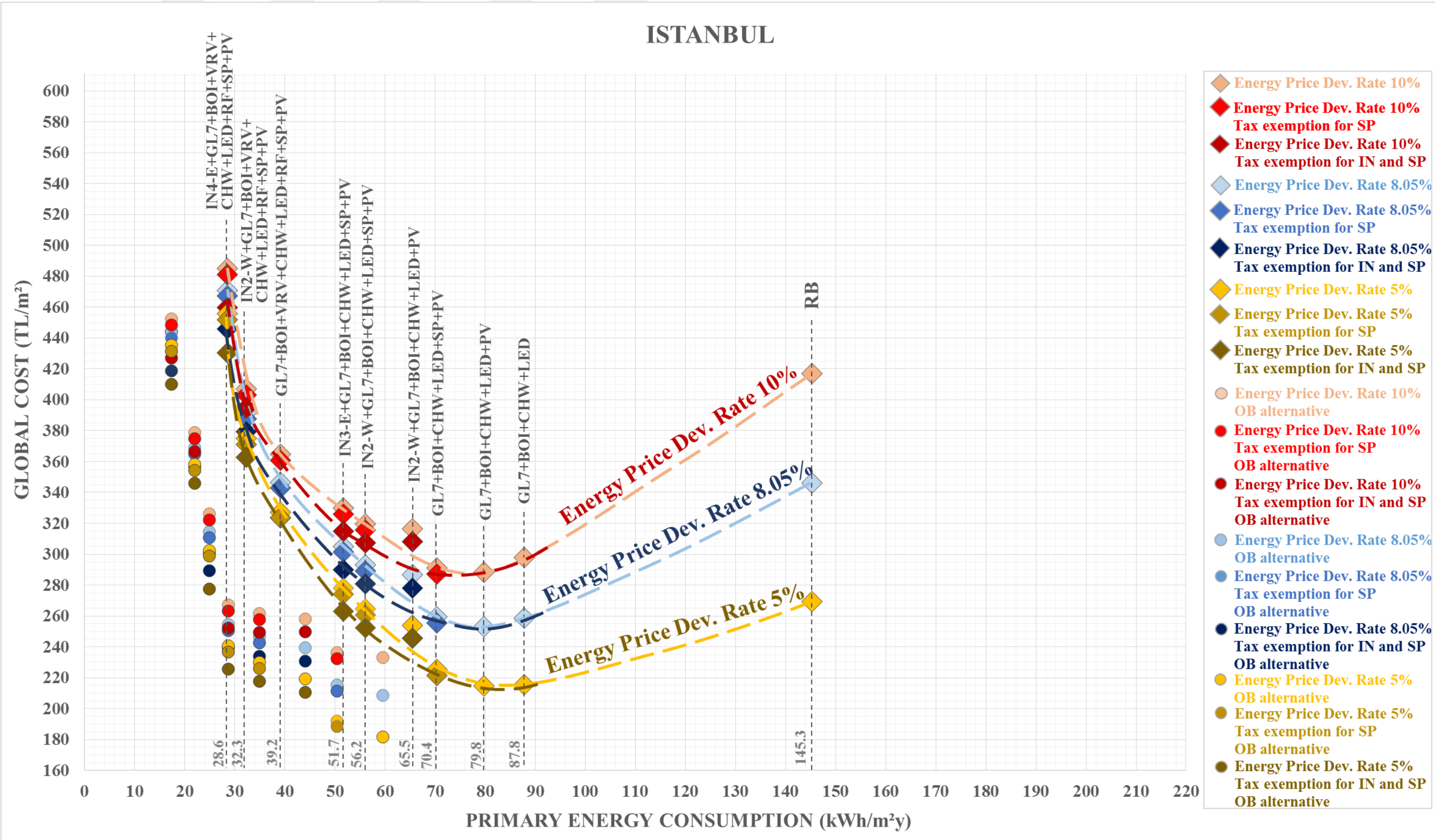


Figure 5.21 : Sensitivity analyses on energy price development rates and investment cost decreases for the RB retrofits in Istanbul.

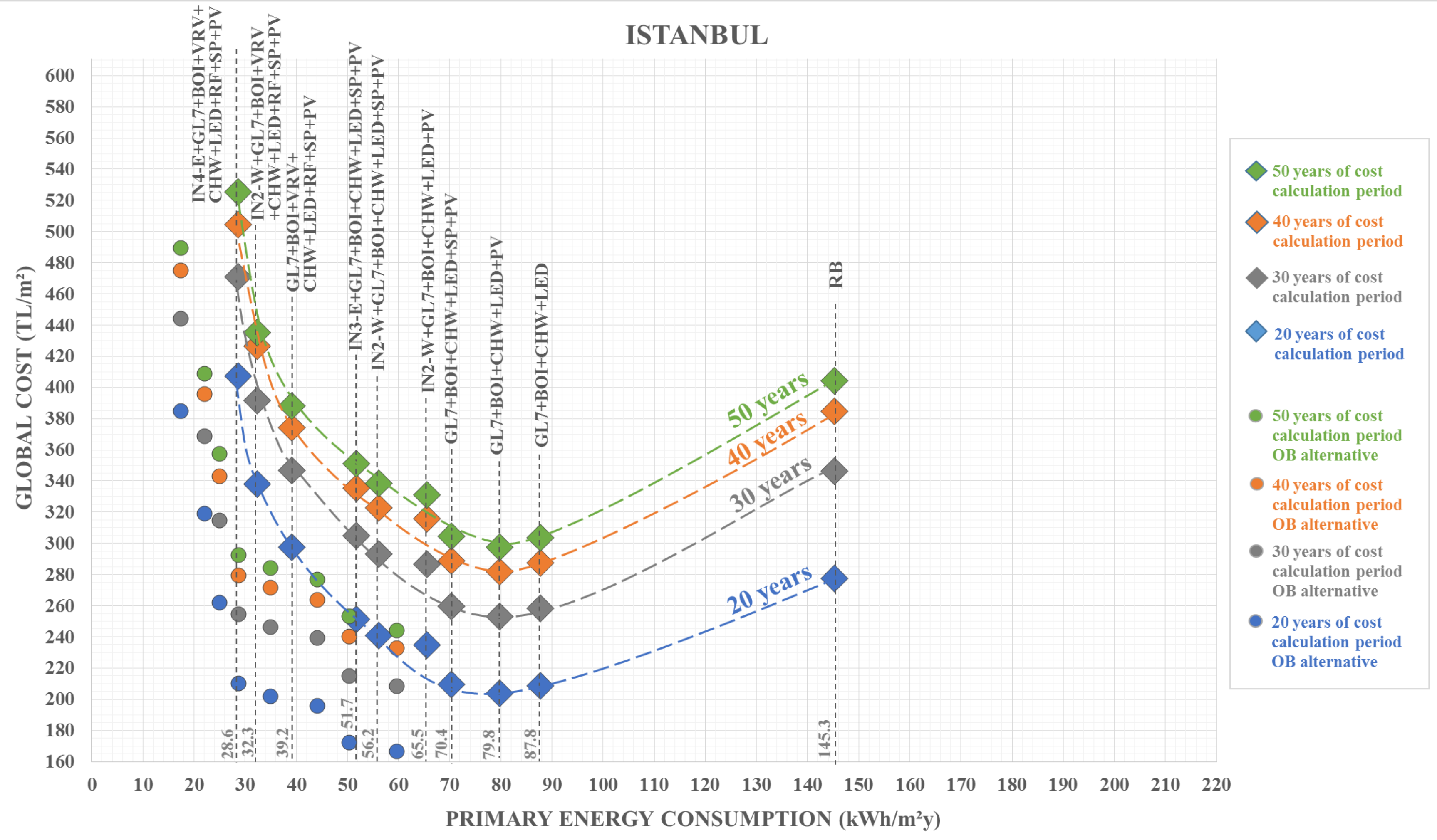


Figure 5.22 : Sensitivity analyses on global cost calculation periods for the RB retrofits in Istanbul.

In all three graphs, the scenarios including alternate occupant behaviour (OB) show similar tendency with the scenarios considering reference occupant behaviour under different financial rates and investment cost decreases. However, scenarios considering OB refer to more ambitious cost-optimal levels. Under the effect of 3% discount rate and the investment cost decreases for IN and SP measures, the scenario including GL6, BOI, CHW, LED, SP and PV retrofits is the cost-optimal level with 50.3 kWh/m²y primary energy consumption and 270.2 TL/m² global cost under OB effect. With this occupant effect, the retrofit scenario including IN2-W, GL7, BOI, CHW, LED, SP and PV measures and the scenario including IN3-E, GL7, BOI, CHW, LED, SP and PV measures resulted with the same global cost, 279.3 TL/m², while their primary energy consumptions are respectively 34.9 kWh/m²y and 28.7 kWh/m²y.

5.2.3 Results of sensitivity analyses for Antalya

Results of the sensitivity analyses for the RB retrofit in Antalya are presented with Figure 5.23, Figure 5.24 and Figure 5.25. The symbolisation used in the graphs are the same with the graphs for Istanbul.

Figure 5.23 displays the results for the analyses on discount rate and investment cost decrease for VRV and SP measures. In comparison to Istanbul, cost-optimal results for the RB retrofits in Antalya are more sensitive to the changes in economic indicators. Decrease in the discount rate definitely changes the cost-optimally resulted scenario from “GL7+CHW+LED+PV” scenario to “GL7+VRV+CHW+LED+PV” scenario and correspondingly decrease the cost-optimal primary energy consumption level from 96.4 kWh/m²y to 61.8 kWh/m²y.

Another opportunity to achieve more ambitious cost-optimal energy performance level is to ensure investment cost decrease around VAT for VRV and SP retrofits. With the support of this cost decrease, the cost-optimal energy performance level is obtained by the retrofit scenario including GL7, VRV, CHW, LED, SP and PV measures in case of a 3% discount rate. This scenario leads to 52.6 kWh/m²y primary energy consumption. When the discount rate is equal to the reference assumption (5.78%), the cost-optimal level is obtained by the scenario combining GL7, VRV, CHW, LED and PV retrofits which results in 61.8 kWh/m²y. However, additional global cost of inclusion of SP within the retrofit scenario is only 3 TL/m² in case of an investment cost decrease in SP and VRV.

Figure 5.24 shows the results obtained for the sensitivity analyses on energy price development rates and investment cost decrease for SP and VRV retrofits. As in the results for Istanbul, results obtained for higher energy price development rates are similar to the results obtained for lower discount rates and the results obtained for lower energy price development rates are similar to the results obtained for higher discount rates in Antalya as well. In case of 3% discount rate, the highest cost-optimal energy performance level can be achieved with the investment cost decrease around VAT for both VRV and SP measures and is equal to 52.6 kWh/m²y primary energy consumption. This level is also cost-effectively achievable under other two rates of energy price developments when the investment cost decreases occur.

Results obtained for the RB in Antalya are more sensitive also to the global cost calculation periods (Figure 5.25). The global cost calculation periods of 40 and 50 years ensure alteration in the cost-optimal scenario and in this case the scenario consisting of GL7, VRV, CHW, LED and PV, which achieves 61.8 kWh/m²y primary energy consumption, appears as the cost-optimal scenario for Antalya. Analyses for 20 years calculation period result with the same cost-optimal scenario with the analyses for 30 years calculation period.

The scenarios including alternate occupant behaviour (OB) act in a similar way with the scenarios considering reference occupant behaviour in response to the variations of economic indicators and investment cost. The cost-optimal solution achieves 41.8kWh/m²y primary energy consumption level under the effect of investment cost decrease and different economic indicators. This level can be obtained by the scenario combining GL7, VRV, CHW, LED, SP and PV retrofits which also includes OB effect.

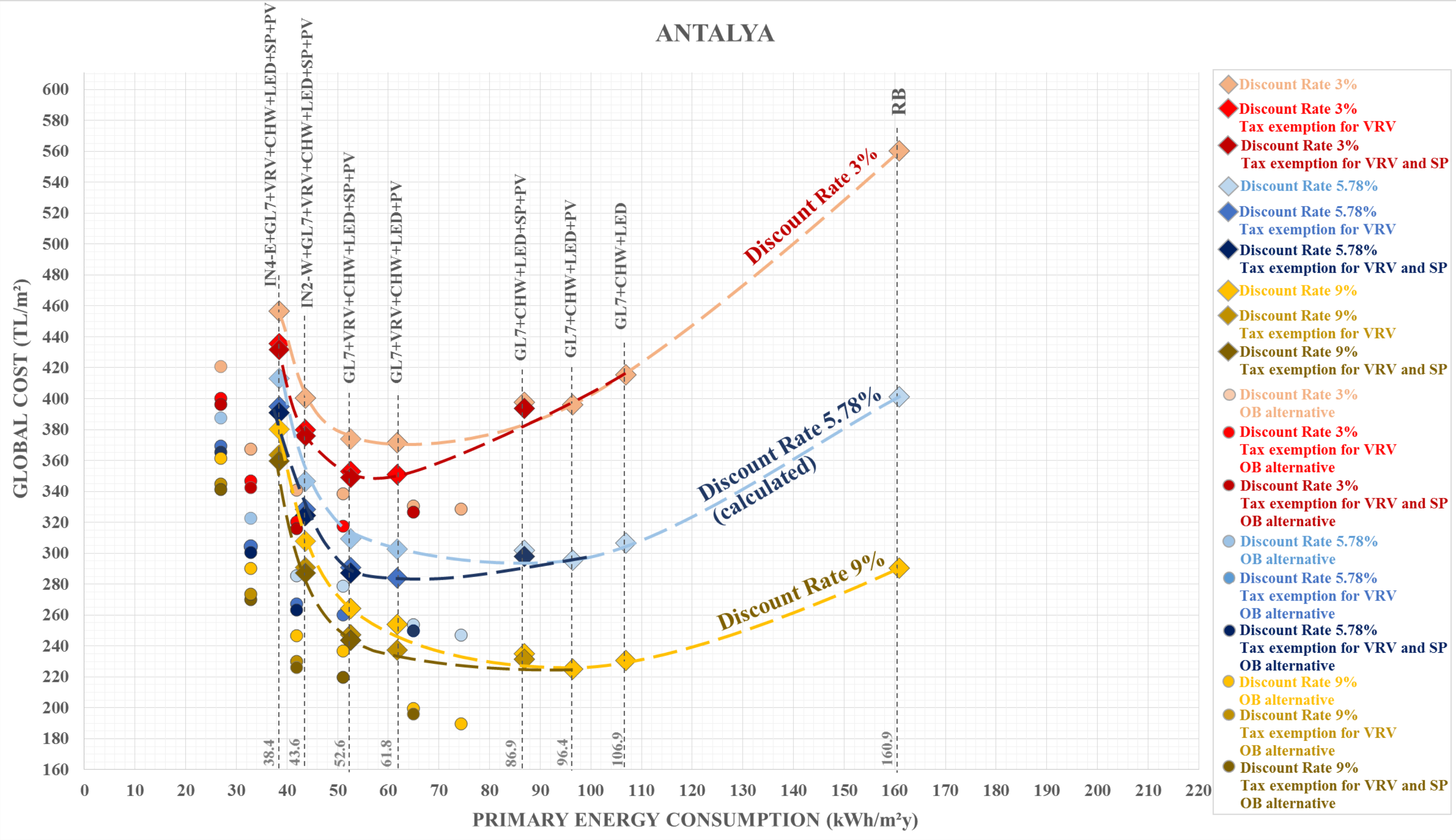


Figure 5.23 : Sensitivity analyses on discount rates and investment cost decreases for the RB retrofits in Antalya.

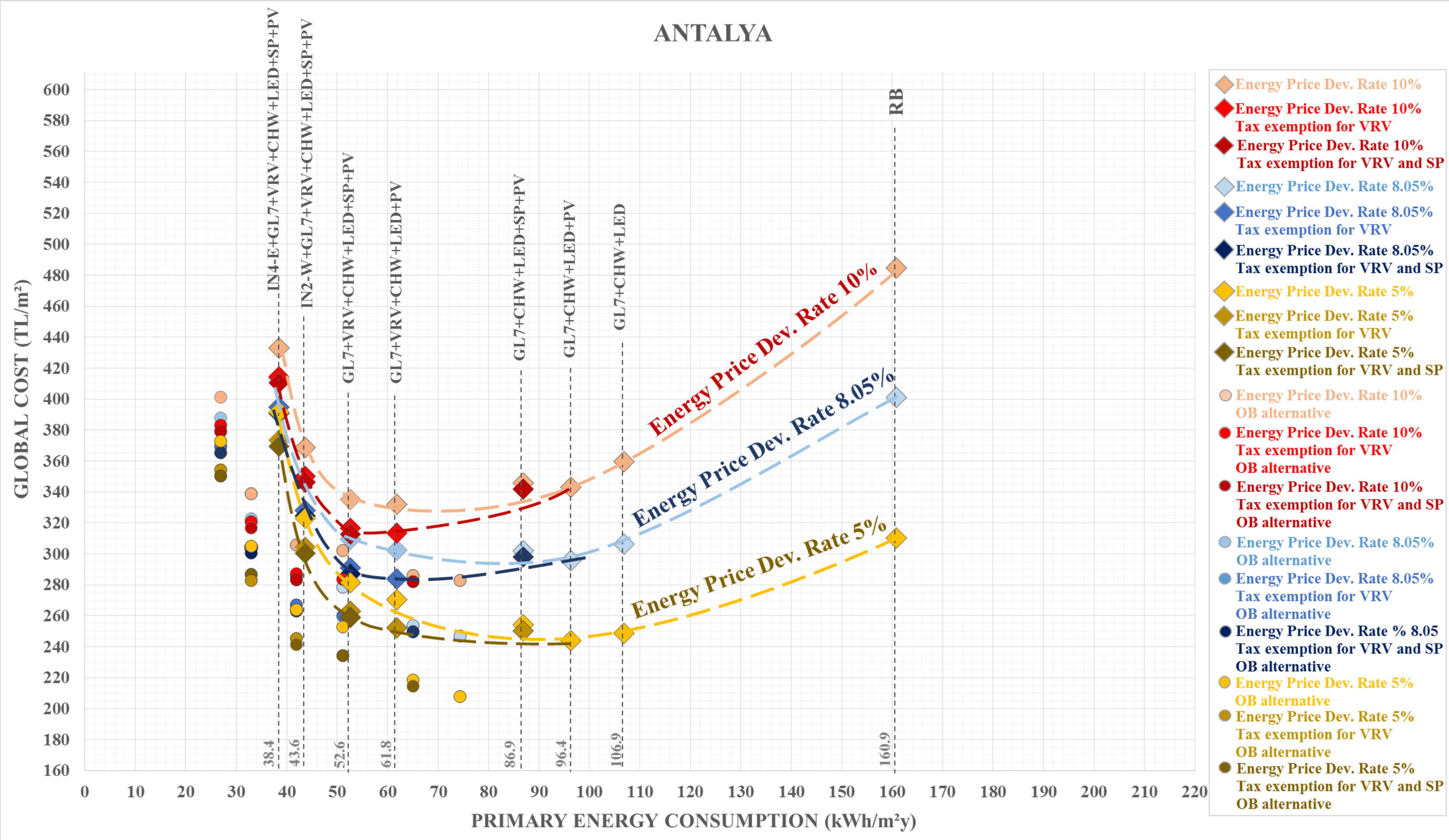


Figure 5.24 : Sensitivity analyses on energy price development rates and investment cost decreases for the RB retrofits in Antalya.

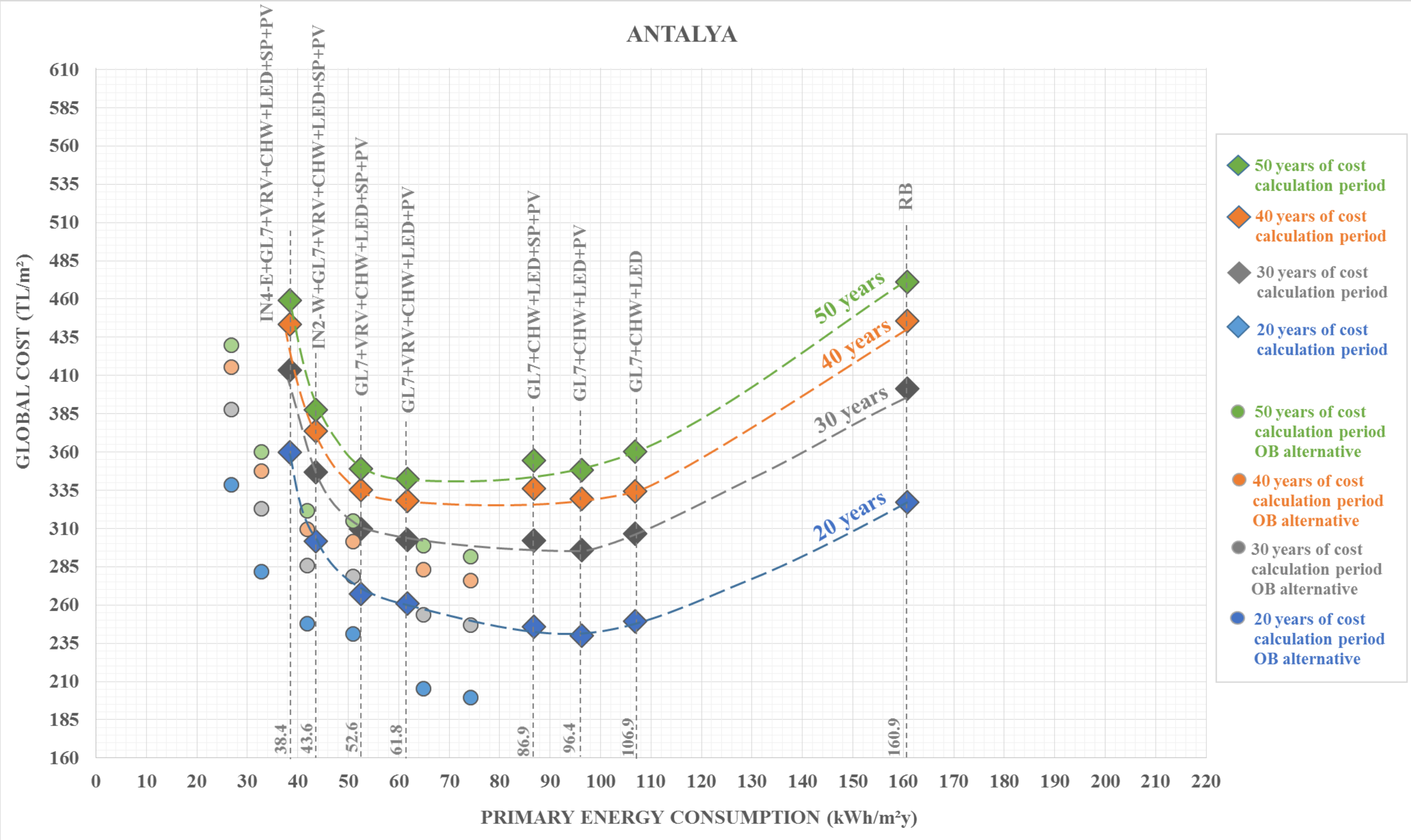


Figure 5.25 : Sensitivity analyses on global cost calculation periods for the RB retrofits in Antalya.

5.2.4 Results of sensitivity analyses for Erzurum

Results obtained from the sensitivity analyses for the RB retrofits in Erzurum are presented with Figure 5.26, Figure 5.27 and Figure 5.28.

As seen from figure 5.26, depending on the discount rate, the relation between the global cost results of the retrofit scenarios changes. If the discount rate occurs lower than assumed (as 3%) the global costs for all scenarios are higher than previously calculated reference case. Therefore, the cost optimum scenario changes and the package involving IN1-E, GL6, BOI, CHW, LED, SP and PV retrofits evolves into the cost optimum scenario for Erzurum. In accordance with this result, cost optimum scenario achieves 76.3 kWh/m²y and provides 65% primary energy saving. Moving towards 71.5 kWh/m²y primary energy consumption level increases the global only 0.7 TL/m² which enables to consider this level within the cost-optimal range. In case of an increase in discount rate, all of the cost results decreases and the cost optimum scenario is clearly the package including GL6, BOI, CHW, LED and PV.

Results show that, if the VAT equal cost is discarded from the investment cost of IN and SP measures, the cost-optimum level involves these retrofits and moves towards 76.3 kWh/m²y also when the existing assumption of discount rate (5.78%) takes place. Moreover, under the effect of 3% discount rate, 71.5 kWh/m²y primary energy consumption level appears as the cost-optimum level with this investment cost decrease in Erzurum.

In any case, while the discount rate is more than assumed and occurs as 9%, the exact cost-optimum level for the RB retrofit in Erzurum stays at 132.1 kWh/m²y primary energy consumption level.

The results of the sensitivity analyses on energy price developments and investment cost decreases for IN and SP measures are presented in Figure 5.27. As shown in this figure, if the energy price development occurs above than it is assumed (10%), cost calculations results are higher than the existing scenario. The cost optimum scenario also changes in this case and the package involving IN1-E, GL6, BOI, CHW, LED, SP and PV, achieving 76.3 kWh/m²y primary energy consumption level, gives the optimum result since energy savings become much more important in this case. On the contrary, when the energy price development is lower than assumed (as 5%), the global costs of all scenarios are lower than expected and the cost optimum scenario does not change but the position of this scenario as the cost optimum level becomes clearer. Analyses for investment cost decreases for IN and SP measures under different energy price development rates reveal that these cost decreases ensure the ambitious retrofit scenarios are more convenient.

Figure 5.28 displays the sensitivity analyses on the global cost calculation periods. This figure shows that, relation between the retrofit scenarios remains almost the same for the calculation periods of 20 years, 30 years and 40 years. However, when the calculation period is increased up to 50 years, the retrofit scenario including IN1-E, GL6, BOI, CHW, LED and PV retrofits, which results with 88.3 kWh/m²y primary energy consumption and 364.8 TL/m², is the cost optimal solution with an insignificant difference in global cost in comparison to other two scenarios. These two scenarios are GL6+BOI+CHW+LED+PV and IN1+GL6+BOI+CHW+LED+SP+PV which are respectively resulted with 132.1 kWh/m²y and 76.3 kWh/m²y primary energy consumption in response to the same global cost around 366.5 TL/m². Therefore 76.3 kWh/m²y primary energy consumption level can be assessed within the cost-optimal range for the RB retrofit when 50 years of cost calculation period is considered.

As previously presented in Section 5.1.6, OB affected the results of cost-optimal analyses in a positive way in terms of moving towards more ambitious cost-optimal levels. With the effect of investment cost decreases for IN and SP measures, the future cost-optimal level can move to 68.8 kWh/m²y primary energy consumption level achieved by the scenario involving IN1-E, GL6, BOI, CHW, LED, SP and PV measures. Under the effect of OB, the scenario including IN2-E, GL6, BOI, CHW, LED, SP and PV measures is able to achieve cost-optimal level with 63.3 kWh/m²y primary energy consumption when the discount rate is lower or the energy price development rate is higher than assumed.

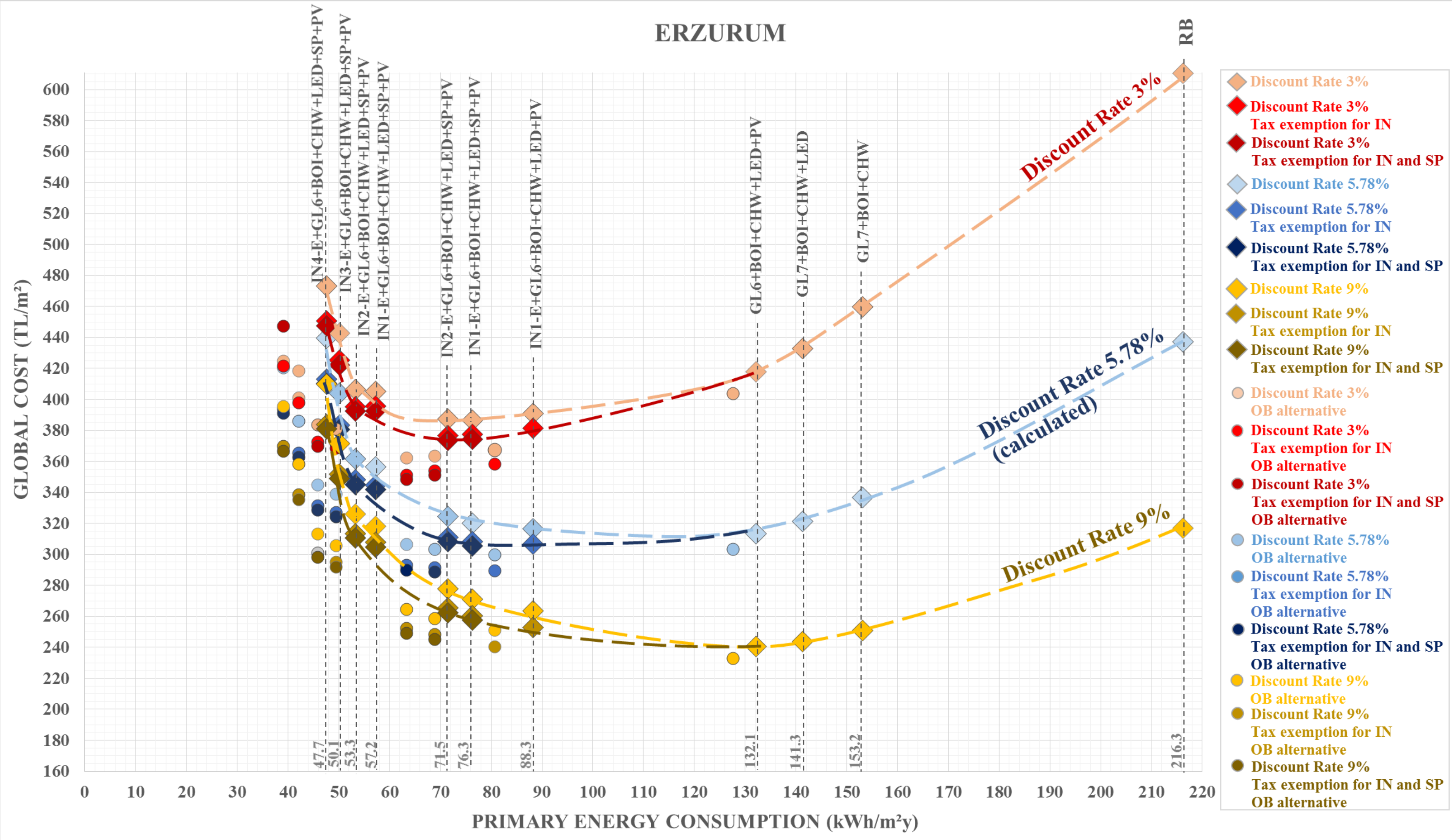


Figure 5.26 : Sensitivity analyses on discount rates and investment cost decreases for the RB retrofits in Erzurum.

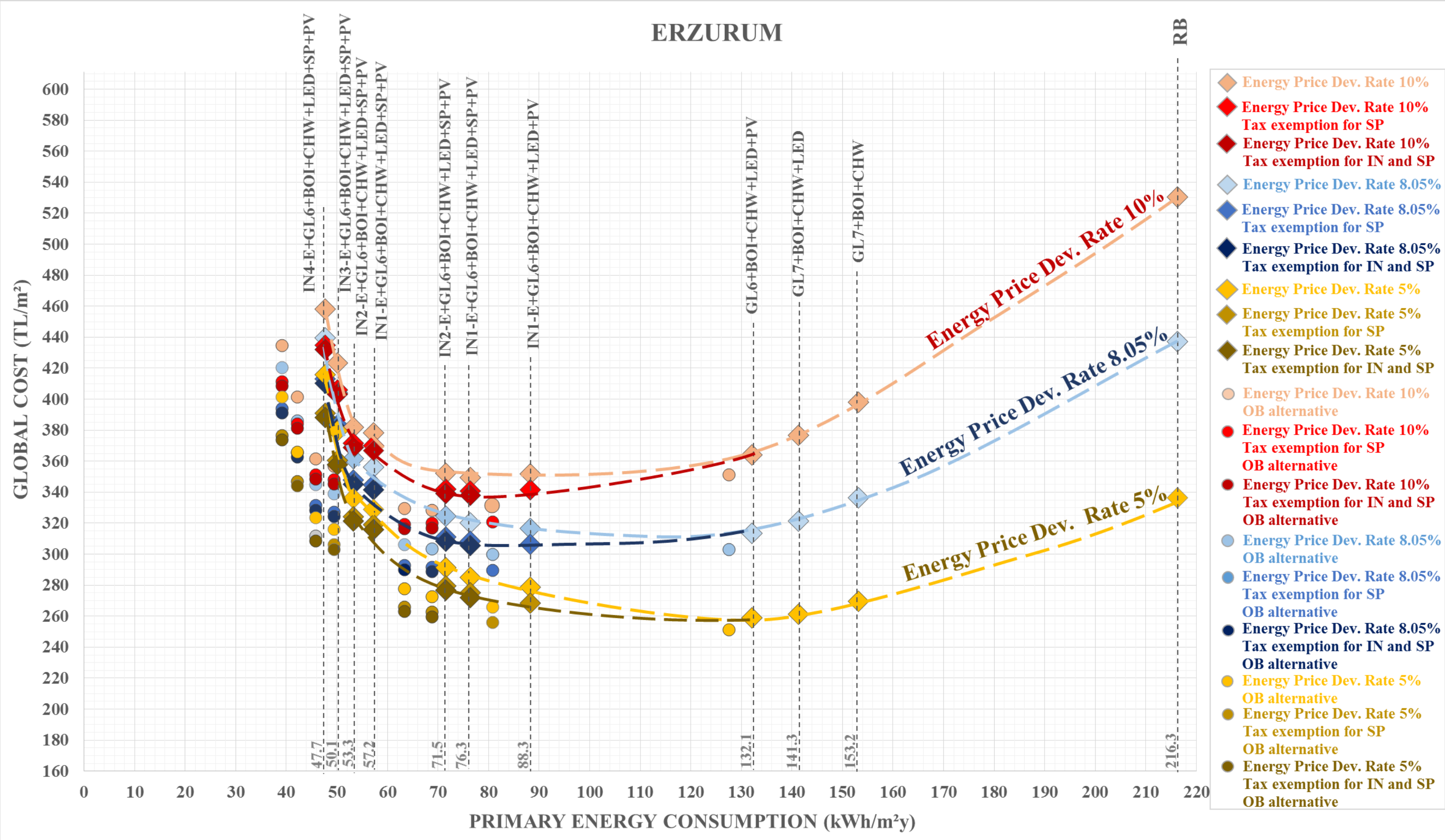


Figure 5.27 : Sensitivity analyses on energy price development rates and investment cost decreases for the RB retrofits in Erzurum.

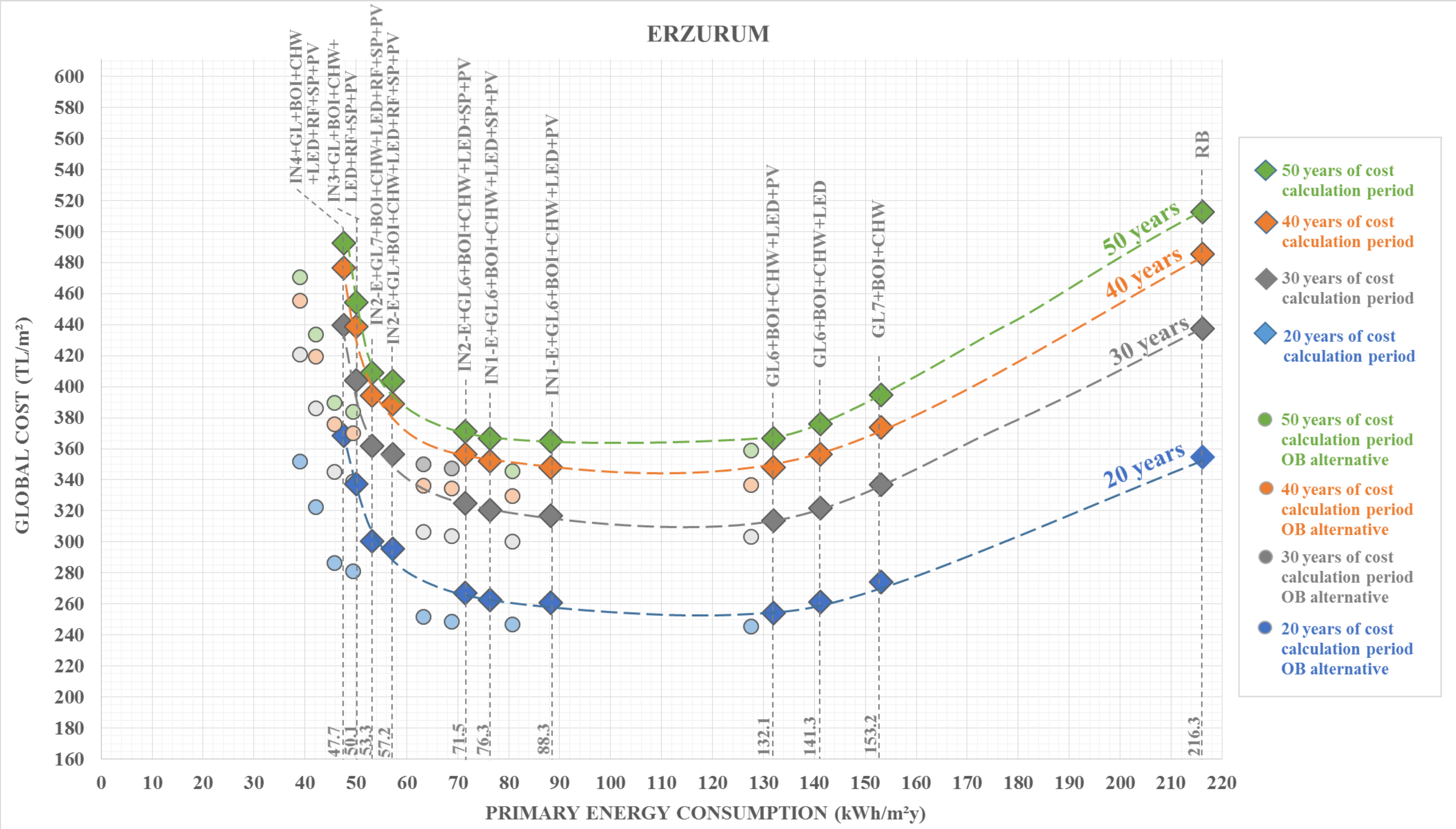


Figure 5.28 : Sensitivity analyses on global cost calculation periods for the RB retrofits in Erzurum.

5.2.5 Identification of potential NZEB levels

In accordance with the results of the comparative analyses conducted in Section 5.1.5, which are based on reference assumptions related to economic indicators, the cost-optimal level for the RB retrofit in Istanbul is retrieved as 79.8 kWh/m²y primary energy consumption level. The retrofit scenario achieving this level includes GL7, BOI, CHW, LED and PV retrofits. Involving also SP measure within the cost-optimal scenario for the RB retrofit in Istanbul requires certain economic conditions and support for cost decreases referring to SP measure (installation of solar thermal system). Therefore the primary energy consumption level of 70.4 kWh/m²y, which can be achieved by the retrofit scenario including GL7, BOI, CHW, LED, PV and SP retrofits, is identified as one of the potential NZEB levels which can be the future cost-optimal level based on the economic conditions. On the other hand, if the required economic conditions are not observed in the future, the investment cost decrease may be provided through subsidy and incentives for SP investments.

Moreover, 65.5 kWh/m²y and 56.2 kWh/m²y primary energy consumption levels are also considered as potential NZEB levels. Although these primary energy consumption levels are not referring to autonomous future cost-optimal levels in any financial conditions, due to their cost effectiveness, these levels may be considered as potential NZEB levels for the RB retrofit in Istanbul. In order to motivate the market towards these levels, subsidy and incentives are needed. The alternate occupant behaviour on window openings (OB) moves the lowest primary energy consumption among potential NZEB levels (56.2 kWh/m²y) until 28.7 kWh/m²y by allowing to include also IN3-E measure in the retrofit scenario.

Summarily, the scenarios identified as the potential NZEB levels for the RB retrofits in Istanbul are as following:

- GL7 + BOI + CHW + LED + PV (79.8 kWh/m²y)
- GL7 + BOI + CHW + LED + SP+ PV (70.4 kWh/m²y)
- IN2-W + GL7 + BOI + CHW + LED + PV (65.5kWh/m²y)
- IN2-W + GL7+ BOI + CHW + LED + SP + PV (56.2 kWh/m²y)

Based on the initial assumptions, the cost-optimal level for the RB retrofit in Antalya is retrieved as 96.4 kWh/m²y primary energy consumption level that can be achieved by the scenario involving GL7, CHW, LED and PV retrofits. However, the changes in the discount rate, energy price development rates, global cost calculation periods and the initial investment costs of VRV and SP measures are able to shift the cost-optimal level to a more ambitious primary energy consumption level. This further cost-optimal energy performance level is able to reach until 52.6 kWh/m²y which is provided by the retrofit scenario including GL7, VRV, CHW, LED, SP and PV retrofits. Result of this further cost-optimal scenario leads to 41.8 kWh/m²y in case of the alternate occupant behaviour (OB) is considered. Therefore, the scenarios representing the identified potential NZEB levels for the RB retrofits in Antalya and their primary energy consumption levels with the reference occupant behaviour are as listed below:

- GL7 + CHW + LED + PV (96.4 kWh/m²y)
- GL7 + CHW + LED + SP + PV (86.9 kWh/m²y)
- GL7 + VRV + CHW + LED + PV (61.8 kWh/m²y)
- GL7 + VRV + CHW + LED + SP + PV (52.6 kWh/m²y)

Results obtained for the RB retrofits in Erzurum showed that the range of the cost-optimal primary energy consumption level can be identified as between 88.3 kWh/m²y and 132.1 kWh/m²y. The variations of discount rate, energy price development rates and the investment expenditures affect the cost-optimal levels and enables to move towards 71.5 kWh/m²y primary energy consumption. GL6, BOI, CHW, LED and PV retrofits are the common measures which are included within this range while IN and SP measures are conditionally involved to the cost-optimal scenario with positive impact on the primary energy consumption level. OB shifts the minimum primary energy consumption level among the potential NZEB levels, which is achieved with the scenario including IN2-E, GL6, BOI, CHW, LED, SP and PV, from 71.5 kWh/m²y to 63.3 kWh/m²y. Correspondingly the retrofit scenarios representing the potential NZEB levels for the RB retrofits in Erzurum are as following:

- GL6 + BOI + CHW + LED + PV (132.1 kWh/m²y)
- IN1-E + GL6 + BOI + CHW + LED + PV (88.3 kWh/m²y)
- IN1-E + GL6 + BOI + CHW + LED + SP + PV (76.3 kWh/m²y)
- IN2-E + GL6 + BOI + CHW + LED + SP + PV (71.5 kWh/m²y)

5.2.6 Financial gaps between cost-optimal and potential NZEB levels

In accordance with the previous analyses, results for the retrofit scenarios identified as potential NZEB levels are compared with the cost-optimal scenarios in order to show the financial gap between these primary energy consumption levels. In this sample implementation, these analyses considered the results obtained using the reference assumptions on economic indicators and reference occupant behaviour. However, other scenarios may also be involved in this process for the further implementations of this approach.

The financial gap between potential NZEB levels and cost-optimal levels for the RB retrofits in Istanbul are summarized in Table 5.27. Results for Antalya and Erzurum are given with Table 5.28 and Table 5.29 respectively.

Table 5.27 : Financial gap between potential NZEB levels and cost-optimal scenario for the RB retrofit in Istanbul.

	Retrofit Scenario (Istanbul)	**Primary Energy Consumption**	**Primary Energy Saving Ratio**	**Global Cost**	**Financial gap**
Reference Assumptions	GL7 + BOI + CHW + LED + PV	79.8 kWh/m²y	45%	253.2 TL/m²	**(cost-optimal)**
	GL7 + BOI + CHW + LED + SP+ PV	70.4 kWh/m²y	52%	259.5 TL/m²	**6.3 TL/m²**
	IN2-W + GL7 + BOI + CHW + LED + PV	65.5 kWh/m²y	55%	286.6 TL/m²	**33.4 TL/m²**
	IN2-W + GL7+ BOI + CHW + LED + SP + PV	56.2 kWh/m²y	61%	293.2 TL/m²	**40 TL/m²**
Reference Assumptions with Investment Cost Decrease for IN and SP	GL7 + BOI + CHW + LED + PV	79.8 kWh/m²y	45%	253.2 TL/m²	**(cost-optimal)**
	GL7 + BOI + CHW + LED + SP+ PV	70.4 kWh/m²y	52%	255.7 TL/m²	**2.5 TL/m²**
	IN2-W + GL7 + BOI + CHW + LED + PV	65.5 kWh/m²y	55%	278.1 TL/m²	**24.9 TL/m²**
	IN2-W + GL7+ BOI + CHW + LED + SP + PV	56.2 kWh/m²y	61%	280.8 TL/m²	**27.6 TL/m²**

Table 5.28 : Financial gap between potential NZEB levels and cost-optimal scenario for the RB retrofit in Antalya.

	Retrofit Scenario (Antalya)	Primary Energy Consumption	Primary Energy Saving Ratio	Global Cost	Financial gap
Reference Assumptions	GL7 + CHW + LED + PV	96.4 kWh/m²y	40%	295.5 TL/m²	**(cost-optimal)**
	GL7 + CHW + LED + SP + PV	86.9 kWh/m²y	46%	301.9 TL/m²	**6.4 TL/m²**
	GL7 + VRV + CHW + LED + PV	61.8 kWh/m²y	62%	302.5 TL/m²	**7 TL/m²**
	GL7 + VRV + CHW + LED + SP + PV	52.6 kWh/m²y	67%	309.4 TL/m²	**13.9 TL/m²**
Reference Assumptions with Investment Cost Decrease for VRV and SP	GL7 + BOI + CHW + LED + PV	96.4 kWh/m²y	40%	295.5 TL/m²	-
	GL7 + BOI + CHW + LED + SP+ PV	86.9 kWh/m²y	46%	298.1 TL/m²	-
	IN2-W + GL7 + BOI + CHW + LED + PV	61.8 kWh/m²y	62%	284 TL/m²	**(cost-optimal)**
	IN2-W + GL7+ BOI + CHW + LED + SP + PV	52.6 kWh/m²y	67%	287 TL/m²	**3 TL/m²**

Table 5.29 : Financial gap between potential NZEB levels and cost-optimal scenario for the RB retrofit in Erzurum.

	Retrofit Scenario (Erzurum)	Primary Energy Consumption	Primary Energy Saving Ratio	Global Cost	Financial gap
Reference Assumptions	GL6 + BOI + CHW + LED + PV	132.1 kWh/m²y	39%	313.4 TL/m²	**(cost-optimal)**
	IN1-E + GL6 + BOI + CHW + LED + PV	88.3 kWh/m²y	59%	316.7 TL/m²	**3.3 TL/m²**
	IN1-E + GL6 + BOI + CHW + LED + SP + PV	76.3 kWh/m²y	65%	320.1 TL/m²	**6.7 TL/m²**
	IN2-E + GL6 + BOI + CHW + LED + SP + PV	71.5 kWh/m²y	67%	324.6 TL/m²	**11.2 TL/m²**
Reference Assumptions with Investment Cost Decrease for IN and SP	GL6 + BOI + CHW + LED + PV	132.1 kWh/m²y	39%	313.4 TL/m²	-
	IN1-E + GL6 + BOI + CHW + LED + PV	88.3 kWh/m²y	59%	306.5 TL/m²	-
	IN1-E + GL6 + BOI + CHW + LED + SP + PV	76.3 kWh/m²y	65%	305.5 TL/m²	**(cost-optimal)**
	IN2-E + GL6 + BOI + CHW + LED + SP + PV	71.5 kWh/m²y	67%	308.2 TL/m²	**2.7 TL/m²**

As shown in the tables, the highest financial gap between the cost-optimal levels and potential NZEB levels are 40 TL/m² in Istanbul, 13.9 TL/m² in Antalya and 11.2 TL/m² in Erzurum. When the investment cost decreases are considered, these gaps decrease until 27.6 TL/m² in Istanbul, 3 TL/m² in Antalya and 2.7 TL/m² in Erzurum. The highest financial gap was observed in Istanbul where the global cost of the RB retrofit is less sensitive to the economic indicators and investment cost decreases.

5.2.7 Investigation of solutions and terms for bridging the gap between cost-optimal and potential NZEB levels

Cost-optimal levels may change autonomously based on the economic indicators and investment cost variations for the retrofit actions. However, although the economic indicators does not occur to ensure more ambitious cost-optimal levels in the future, these can be achieved by subsidy and incentives or by giving priority to R&D activities. Therefore, these opportunities are investigated under this step.

Sensitivity analyses show that decrease in the discount rate and investment costs are effective for achieving more ambitious future cost-optimal levels. In the contrary case, increase in the discount rate or in the retrofit costs requires additional actions in all analysed climates. SP is an effective retrofit measure to move towards higher energy performance level in all climates. Therefore, this retrofit should be supported by tax exemptions or by encouraging R&D activities on the solar thermal systems in order to stimulate cost decreases.

Other retrofit measures which require to be supported changes with the climate in which the RB is placed. In Istanbul and Erzurum, heat insulation is needed to be supported while in Antalya VRV system should be encouraged if the market conditions and economic indicators do not seem to be positive in the future in terms of energy efficiency and global cost. Especially in hot-humid climate represented by Antalya, the effect of the support is significant.

Besides the tax exemptions and R&D activities, low-interest loans can also inspire the building owners to retrofit their residential buildings. In order to identify convincing loan amounts and repayment period, investment cost and payback periods of the retrofit scenarios are calculated for the scenarios referring to potential NZEB levels. The scenarios which represent the national heat insulation standard TS 825:2013 (IN1-

W + GL1 and IN1-E + GL1) are also involved in these analyses in order to compare them with the present and future cost-optimal levels.

Figure 5.29 presents the initial investment cost and the payback period of the potential NZEB levels for the RB retrofits in Istanbul. The graph shows that payback periods of the scenarios representing the national heat insulation standard are higher than 20 years. On the other hand, there are some other retrofit possibilities which correspond to a lower primary energy consumption with lower investment cost and shorter payback period. In case of cost decrease provision for solar thermal systems (tax exemption, R&D, etc.), the cost optimal level results with 70.4 kWh/m²y primary energy consumption and this level can be considered as a potential NZEB level for the near future. In order to boost the market, low-interest loans can be considered for the retrofit activities including these retrofits. Based on the future expectations and policy, it is possible to define more ambitious NZEB levels. In case of tax exemption for IN and SP retrofits and low cost loan provision for IN2 + GL7 + BOI + CHW + LED + SP + PV retrofit package, NZEB level may reach at 56.2 kWh/m²y in Istanbul. A loan around 622 000 TL for ten years repayment period is able to provide a cost effective energy retrofit and after 10 years this retrofit saves money together with the energy saving. Considering that there are 48 owners for 48 flats in the RB, the loan may be around 13 000 TL for every flat owner which is not high for 10 years repayment.

Figure 5.30 presents the payback periods and initial investment costs of the potential NZEB levels for the RB retrofits in Antalya. Similar to Istanbul, payback periods of IN1-W+GL1 and IN1-E+GL1 packages are higher than 20 years in Antalya as well. On the other hand while IN1-E+GL1 package results with 138.3 kWh/m²y primary energy consumption level with 21 years payback period, it is possible to achieve 52.6 kWh/m²y level with maximum 8.9 years payback period by applying the scenario including GL7, VRV, CHW, LED, SP and PV retrofits. However, the initial investment cost of this scenario is higher than IN1-E+GL1 package and therefore it needs financial support in order to be achieved. A loan around 702 000 TL with more than 9 years repayment will encourage the building owners for applying the retrofits in order to increase energy efficiency of their building. The loan required per flat owner is around 14 650 TL for achieving 52.6 kWh/m²y primary energy consumption level.

As presented in Figure 5.31 below, results in Erzurum are more sensitive to different financial scenarios.

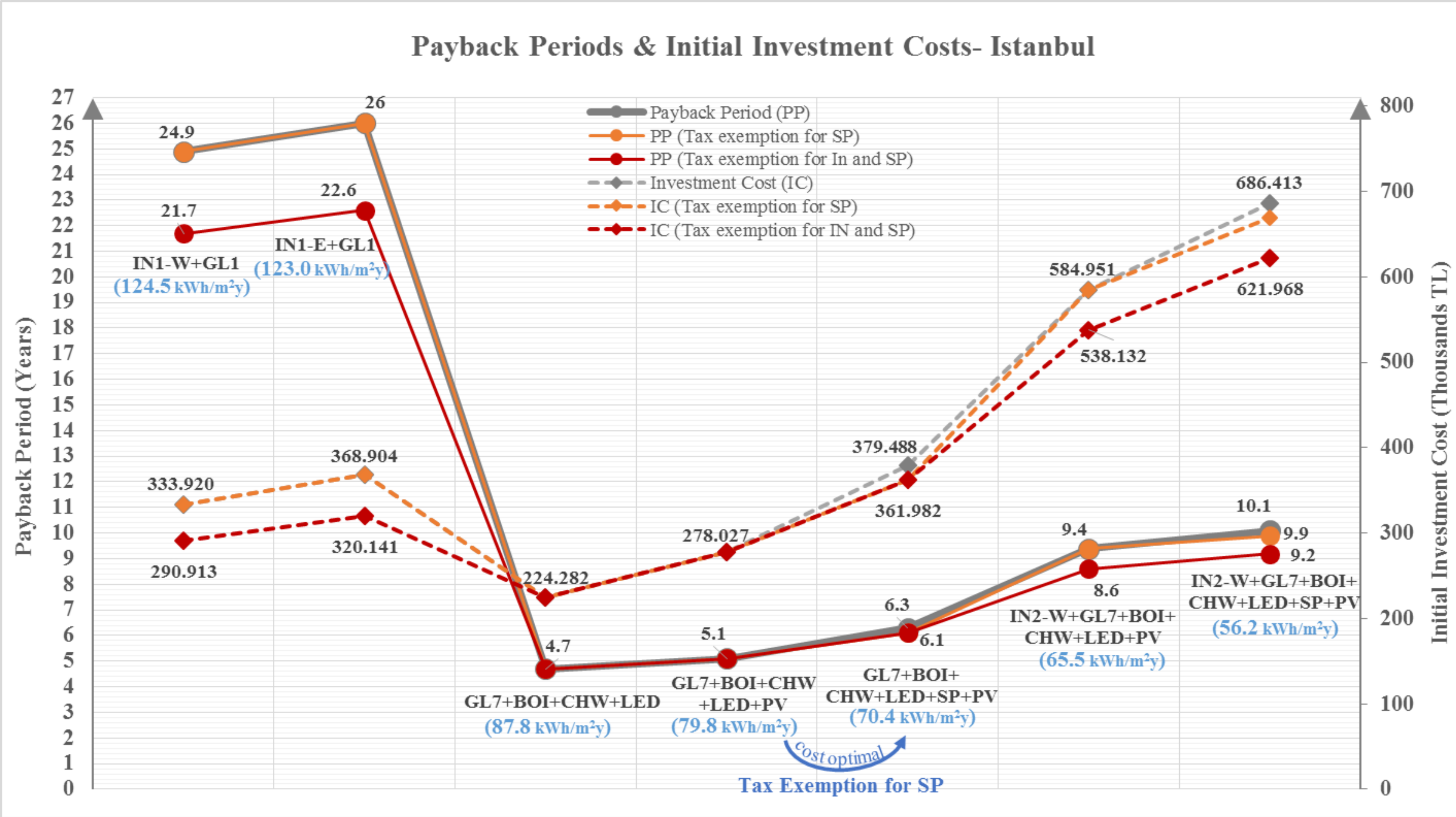


Figure 5.29 : Investment costs and the payback periods of the potential NZEB levels for the RB retrofits in Istanbul.

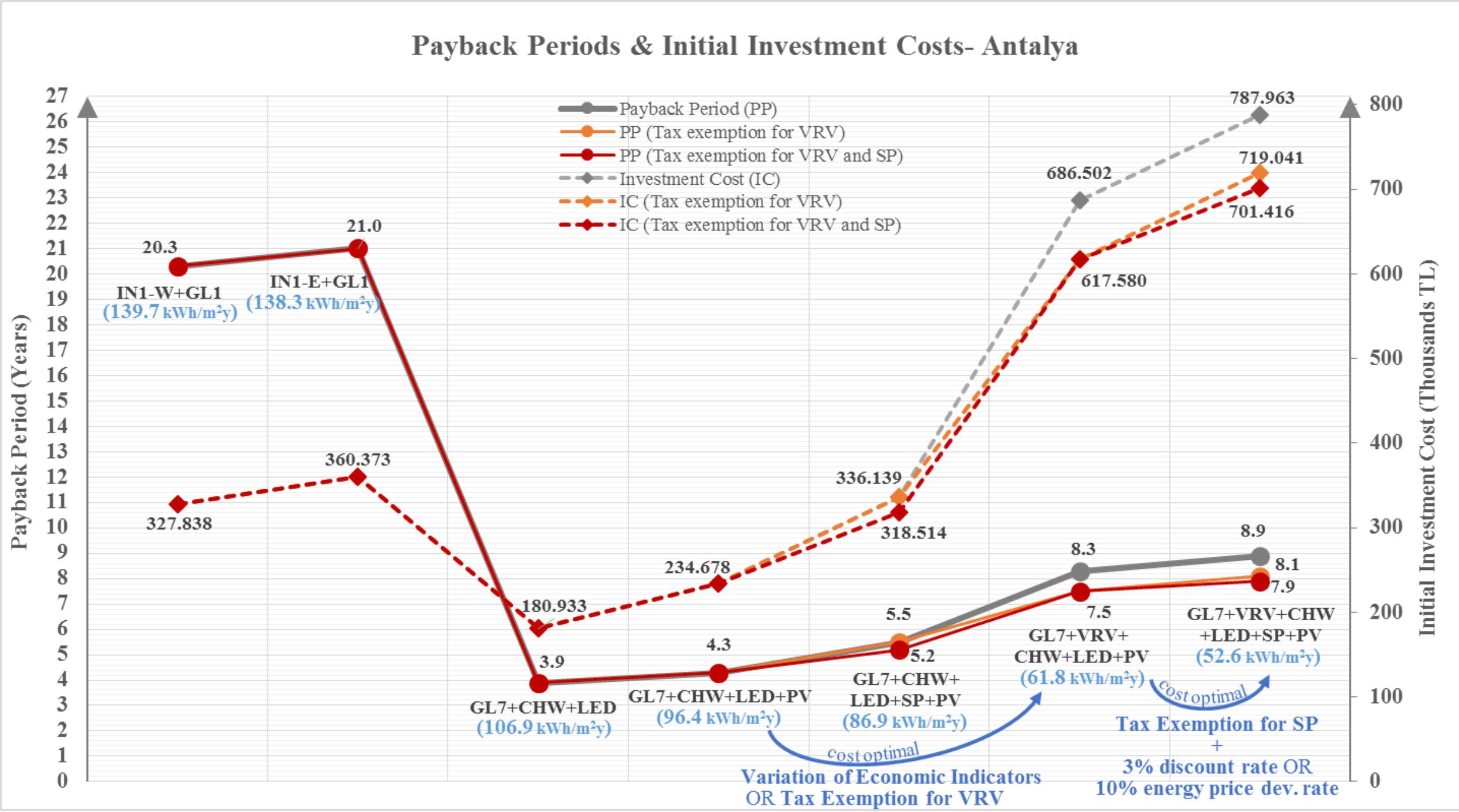


Figure 5.30 : Investment costs and the payback periods of the potential NZEB levels for the RB retrofits in Antalya.

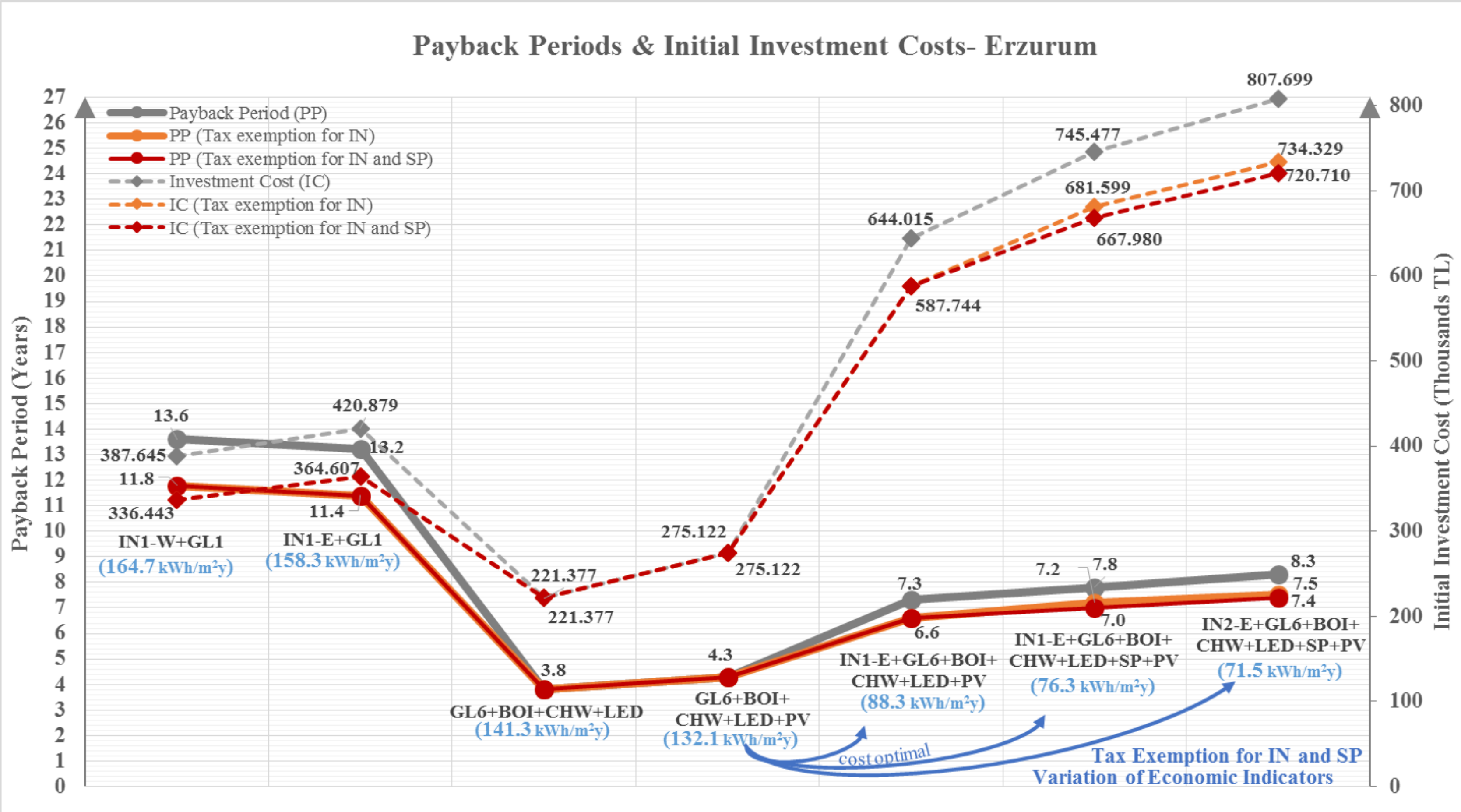


Figure 5.31 : Investment costs and the payback periods of the potential NZEB levels for the RB retrofits in Erzurum.

The cost optimal level moves from 132.1 kWh/m²y to 71.5 kWh/m²y depending on the future scenarios and the possible cost decreases. Contrary to Istanbul and Antalya the payback period of the scenarios representing the national heat insulation standard are between 11 and 13 years in Erzurum. However, by investing on the other scenarios, it is possible to decrease the payback period while increasing the energy performance level of the reference building. If the expectations on the market and economic indicators does not provide the ambitious primary energy consumption levels, tax exemptions should be considered for IN and SP measures and the amount of loan required to achieve 71.5 kWh/m²y is around 721 000 TL with repayment period more than 7.4 years. The share of the loan per flat owner is around 15 000 TL. After this point, the additional global cost difference to achieve the next primary energy consumption level which is 57.2 kWh/m²y is around 30 TL/m².

Nevertheless, being talked about the existing buildings in Turkey, it is important to identify the future lifespan of the building as well. As an example, if the building is not expected to exist for next 10 years, the loan may not be a suitable option and other options are needed to be examined. This is important for the residential buildings in Turkey considering the urban transformation procedure and should be considered for NZEB targets.

5.2.8 Proposals for bridging the gap between cost-optimal and NZEB levels

This step introduces the proposals for NZEB definitions and for bridging the gap between cost-optimal and NZEB levels as the output of overall composition of the outcomes.

The results reveal that, for the retrofit of high-rise apartment buildings in temperate-humid climatic region, as in Istanbul, the achievable future cost-optimal level can be identified between 79.8 kWh/m²y and 56.2 kWh/m²y in terms of primary energy consumption. One of the main factors to be considered for this decision is the expectations on discount rate. If the discount rate is expected to be equal to or higher than 5.78%, the achievable cost-optimal primary energy consumption level is 79.8 kWh/m²y. In order to move towards 70.4 kWh/m²y primary energy consumption level without any support, the discount rate is required to be lower or the investment cost of solar thermal systems should be decreased. Nonetheless, NZEB concept needs further improvements in the building energy performance. As mentioned in BPIE Factsheet on NZEB definitions, NZEB levels defined in EU countries for new residential buildings aim to have a primary energy use lower than 50 kWh/m²y (Buildings Performance

Institute Europe, 2016). Indeed, NZEB levels for existing residential buildings are different than the new buildings; but it is also expected to become lower in time. Therefore, policy-makers should take additional actions to achieve lower energy consumption levels through building retrofits. There are two convenient actions to be considered by policy-makers for closing the financial gap for high-rise apartment building retrofits in tempered-humid climate. These are tax exemptions for heat insulation and especially solar thermal system retrofits and providing low-interest loans for the comprehensive building retrofit actions including heat insulation application, glazing replacement, boiler improvement, use of central hot water system, use of LED for lighting, installation of solar thermal system and PV systems. Using these tools, policy-makers are able to motivate the market and the building owners to retrofit their high-rise residential buildings in temperate-humid climatic region and achieve 56.2 kWh/m²y primary energy consumption level.

Achievable NZEB level for the high-rise apartment building retrofits in hot-humid climate, as in Antalya, ranges between 96.4 kWh/m²y and 52.6 kWh/m²y primary energy consumption level. The discount rate which is equal to or higher than 5.78% leads to an achievable cost-optimal primary energy consumption level of 96.4 kWh/m²y. Lower discount rate, on the other hand, enables to achieve 61.8 kWh/m²y primary energy consumption level cost optimally. Similarly, energy price development rates that are higher than expected also promotes this energy performance level. In order to move towards 52.6 kWh/m²y, cost decreases for solar thermal system and VRV system are only appropriate with low discount rate. If the cost decrease is not expected, the policy-makers ensure this by tax exemptions. Different course of events require additional actions from policy makers such as low-interest loans. The convenient loan amount is 702 000 TL with more than 9 years repayment. Therefore, policy-makers should examine the possibility of these loans.

In cold climatic region of Turkey, as in Erzurum, achievable NZEB level for the retrofit of high-rise apartments is between 132.1 kWh/m²y and 71.5 kWh/m²y in primary energy consumption. This range is higher comparing to temperate-humid and hot-humid region since the RB energy consumption is also higher in this cold climate. Future expectations of policy-makers related to both discount rates and energy price development rates should be effective on identifying achievable NZEB levels for the cold climate. If low discount rates around 3% or high energy price development rates around 10% are expected based on national economy and policy, the achievable NZEB level can move until 76.3 kWh/m²y without any external support. Another probability to autonomously achieve this level is the cost decreases in heat insulation and solar thermal system investments. On the contrary, if these do not take place, the market is required to be supported by policy-makers. The possibility of tax exemption for heat insulation and solar thermal systems enables to set NZEB target as 76.3 kWh/m²y. Moreover, in case of a low discount rate around 3%, 71.5 kWh/m²y is also convenient as NZEB target in cold climate. If the expected discount rate is not that much low, low-interest loan around 721 000 TL may provide to set 71.5 kWh/m²y primary energy consumption level as NZEB target.

As explained above, the useful and convenient encouragement actions refer to different retrofits according to climatic region. Table 5.30 presents these convenient subsidy and loans for different climates. As shown in this table, support in solar thermal panels is required in all three climates. The required low-interest loans range between 622 000 TL and 808 000 TL based on the climatic region and availability of subsidies.

Table 5.30 : Summary of convenient subsidy and loans for different climates.

	Climatic region		
	Tempered-humid (Istanbul)	Hot-humid (Antalya)	Cold (Erzurum)
Retrofit actions which have priority in subsidy and R&D support	Use of solar thermal panels	Use of VRV system for cooling	Application of heat insulation on the building envelope
	-	Use of solar thermal panels	Use of solar thermal panels
Minimum loan amount required for motivating the comprehensive building retrofits in the market (with subsidy)	622 000 TL	702 000TL	721 000 TL
Minimum required payback period of the loan (with subsidy)	10 years	8 years	8 years
Minimum loan amount required for motivating the comprehensive building retrofits in the market (without subsidy)	690 000 TL	790 000TL	808 000 TL
Minimum required payback period of the loan (without subsidy	11 years	9 years	9 years

Results obtained from sample implementation of the second phase of proposed approach reveal that discount rate and energy price development rate are among the main aspects to consider for setting NZEB targets for high-rise apartment retrofits in Turkey. Policy-makers should initially have a reliable examination on the expected economic indicators in order to set NZEB target. Tax exemptions and low-interest loans will be effective to stimulate the market in any case, however, the benefits will be higher if the opportunity is directed at the correct investments by policy-makers considering also the climate.

6. DISCUSSION

In EPBD recast requires that new buildings are NZEBs from 2021 onwards and existing buildings go under cost-effective transformation towards NZEBs (The European Parliament and the Council of the European Union, 2010). Although the highest energy saving potential lies behind the existing building stock (The European Parliament and the Council of the European Union, 2012), NZEB definitions for these buildings have not been progressing with the same acceleration of the NZEB definitions for new buildings (BPIE, 2016) since a deadline for the existing buildings has not been defined yet. Moreover, as explained in Chapter 2, a specific methodology for determining the NZEB targets is not available. Considering the present circumstances, this dissertation has been designed with the aim of introducing an approach to determine achievable NZEB levels for building retrofits.

6.1 Discussion on the Proposed Approach

As previously described in Chapter 2, some of the limited number of available methods and approaches in the literature which focused on NZEB definitions gave the full attention to the requirement of achieving "*very high energy performance level*" without considering the relation with cost-optimality (The European Parliament and the Council of the European Union, 2010; Szalay and Zöld, 2014; Schimschar et. al, 2011). Some other researchers which focused on the cost-effective retrofits in buildings mostly referred to NZEB target within the concluding remarks by linking with their outcomes (Vasconcelos et. al, 2016b). Very few studies, such as presented by Oliveira Panão et al. (2013) and Pikas et al. (2014), considered the direct relation between cost-optimality and NZEB concepts, however, none of these research activities presented a comprehensive approach resulting with the proposals for policy-makers.

The approach proposed in this research fulfil the need of an approach for identifying achievable NZEB targets for building retrofits. Starting from the fact that cost-optimal and NZEB concepts are expected to converge after 2020 (The Commission to the

European Parliament and the Council, 2013), this approach regards the NZEB level as the future cost-optimal level and uses the sensitivity analyses as the main tool to investigate achievability of the future targets related to NZEB. As presented in Chapter 4, the approach involves two main phases which results with proposals for potential NZEB levels with the specific boundary conditions and actions required to provide their achievability or speed up the process. The third phase following these two phases describes the main frame of the assessment procedure for the policy-makers and concludes the whole process by drawing the link between the calculations and NZEB targets.

As indicated by Kuusk et al. (2014) and Pombo et al. (2016) a comprehensive approach referring to deep retrofits is required. The first phase of the approach which includes the national implementation of the cost-optimal methodology meets this demand specified in the literature. This phase combines three main constituents of whole building retrofit by referring to envelope retrofits, building service system retrofits and installation of renewable energy systems. Moreover, it is not only a direct implementation of the cost-optimal approach since it takes the effect of occupant behaviour into account.

The sensitivity analyses already exist in the cost-optimal methodology (The European Commission, 2012a). However, the second phase of the approach proposed in this dissertation attributes an extensive function to the sensitivity analyses and uses them as the main tool to investigate the potential NZEB levels for building retrofits. This tool is supported with payback calculations in order to identify complementary actions to be taken by policy-makers as a part of their plan to increase the number of NZEBs.

With this perspective, the approach proposed in this study constitutes an overall process to define the boundary conditions for NZEB definitions by combining the effect of climate, building properties, occupant behaviour, economic indicators and financial conditions on NZEB definitions. Beyond this, the approach also enables to display the gap between present cost-optimal and potential NZEB levels and develop solutions for bridging this gap in order to guide the policy-makers to plan their actions.

Although the approach was developed for the building retrofits, it can be easily adapted for the new constructions to be used for determining the NZEB targets which are required to be revised periodically by EPBD recast (The European Parliament and the Council of the European Union, 2010).

6.2 Discussion on the Results of Sample Implementation

A sample implementation of the introduced approach is presented in Chapter 5. The results of this implementation came up with both general outcomes and specific suggestions for Turkish policy-makers.

Results of the sample implementation verify that climate is the main aspect affecting the achievable NZEB level. As presented with the results, the same approach followed for the same RB results with different primary energy consumption ranges that were associated with the potential NZEB levels in different climates. In example, the lowest primary energy consumption levels among the potential NZEB targets obtained with sensitivity analyses are 79.8 kWh/m²y in tempered-humid climate (Istanbul), 61.8 kWh/m²y in hot-humid climate (Antalya) and 76.3 kWh/m²y in cold climatic region (Erzurum) of Turkey. Support of incentives moves this lowest primary energy consumption level among potential NZEBs until 70.4 kWh/m²y in tempered-humid climate, 52.6 kWh/m²y in hot-humid climate and 71.5 kWh/m²y in cold climate. Furthermore, the conscious occupant behaviour related to window openings (OB) moves the highest potential NZEB targets towards 50.3 kWh/m²y in tempered-humid climate, 41.8 kWh/m²y in hot-humid climate and 63.3 kWh/m²y in the cold climatic region. The primary energy consumption levels of these different target levels are summarized in Table 6.1 below in order to provide a better understanding on the variations between the climatic regions.

While some research activities focus on improving the skills of building energy professionals in NZEB design, Table 6.1 displays the significant effect of conscious occupant behaviour (Peñalvo-López et. al, 2017). Taking the advantage of conscious occupant behaviour requires training programs also for these occupants as the part of the national action plans.

It is important to note that the table displays the highest energy performance levels among different potential NZEB targets. Correspondingly it represents a positive perspective in terms of economic indicators. However, results of the sensitivity analyses show that potential variations in the economic indicators lead to alteration in the cost-optimal and NZEB levels. Therefore, strong forecasts on the economic indicators are required to ensure that NZEB targets represent the future cost-optimal.

Independent from the economic indicators, subsidy and incentives appear as the most effective and practical actions to be taken and included in the plans for the transformation of existing buildings towards NZEB. Another important fact to consider while discussing the results is that the market costs used in this calculation may not reflect the highest discounts as a consequent of the bargains or the competition between the companies. Therefore the required incentives may be more pleasant for the policy-makers in comparison to the presented results.

Figure 6.1 : Primary energy consumption of different target levels.

	Climatic region		
	Tempered-humid (Istanbul)	Hot-humid (Antalya)	Cold (Erzurum)
Existing cost-optimal primary energy performance level	79.8 kWh/m²y	96.4 kWh/m²y	132.1 kWh/m²y (88.6 kWh/m²y)
Existing cost-optimal primary energy performance level with OB effect	60.4 kWh/m²y	74.3 kWh/m²y	80.7 kWh/m²y
Minimum primary energy consumption level among potential NZEB targets	79.8 kWh/m²y	61.8 kWh/m²y	76.3 kWh/m²y
Minimum primary energy consumption level among potential NZEB targets with incentives	70.4 kWh/m²y	52.6 kWh/m²y	71.5 kWh/m²y
Minimum primary energy consumption level among potential NZEB targets with incentives and OB effect	50.3 kWh/m²y	41.8 kWh/m²y	63.3 kWh/m²y

The primary energy consumption levels of potential NZEB targets identified for the existing high-rise residential buildings in Turkey is between 41.8 kWh/m²y and 96.4 kWh/m²y. Apart from the extreme definitions of Denmark (20 kWh/m²y) and Austria (200 kWh/m²y), this range is not far from the existing NZEB definitions among EU MSs (BPIE, 2016).

The obtained results support the proposed method in terms of recommending comprehensive retrofit concept for investigating NZEB targets. In all climatic regions, the retrofit scenarios which are associated with potential NZEB levels combine the retrofit actions referring to envelope, service systems and renewable energy systems.

The scenarios which are not combining these three fields are not sufficient to achieve potential NZEB levels. On the other hand, the content of these retrofit scenarios achieving potential NZEB levels varies according to the climate since it is the main determinant of NZEB analyses.

Installation of renewable energy systems is a key retrofit action to achieve NZEB levels in the following years. Besides the results showing the necessity of involving the installation of solar thermal and photovoltaic systems within the retrofit scenarios, the expected decrease in the prices of these systems also makes these systems promising (Brown et al., 2011).

Results of the sample implementation are encouraging by showing that very high energy performance levels are achievable for the analysed high-rise residential buildings. Considering that the NZEB levels defined for the new building in EU countries are mainly no more than 50 kWh/m²y, it is significant to display that the potential NZEB target is able to reach a range between 41.8 kWh/m²y and 63.3 kWh/m²y depending on the climatic region (BPIE, 2016). Nevertheless, it is important to bear in mind that achieving these levels are dependent to certain boundary conditions.

It is important to emphasize that, the presented sample implementation followed the individual end user perspective in global cost calculations. However, the governments may prefer using calculations made with macroeceonomic perspective. In this case, higher energy performance levels may result as cost-optimal and future cost-optimal. Moreover, the required amount of subsidy and loans may be lower since the taxes are excluded and carbon prices are included in the calculations. Therefore the cost calculation perspective is also decisive on national actions.

7. CONCLUSION

Precautions referring to the buildings sector are a substantial part of decreasing the worldwide final energy consumption. In this context, NZEB concept of EPBD recast can be regarded as a milestone since it represents binding targets for 28 member countries and drives 5 candidate countries as well. The NZEB concept does not only force the governments to improve energy performance of buildings but also considers their economy by paying significant attention to cost-effectiveness. In this respect, it constitutes applicable and coherent requirements.

NZEB concept of EPBD recast requires to ensure that buildings have a very high energy performance and the very low amount of required energy is met by renewable energy sources. Moreover, NZEB concept should converge with cost-optimal level after 2020. Although NZEB concept is a whole with these three aspects, many studies in the literature focus only the first of the first two aspects when they mention about the NZEB target. Nevertheless, it is very important to take into consideration all these aspects in order to refer NZEB concept certainly and thoroughly. Therefore the approach presented in this dissertation comprises all these three aspects of NZEB concept.

Based on the approach, the sample implementation and the discussion on them which were presented in the previous chapters, this research obtained important remarks for both researchers and policy-makers. Regarding the national decisions on retrofitted NZEBs, the following remarks can be specified:

- Occupant behaviour should be included in the analyses due to their significant effect on achievable NZEB targets
- Both the followed approach and analyses should consider a comprehensive perspective including the retrofits referring to envelope, service systems and renewable energy systems installation
- Sensitivity analyses are beneficial for determining boundary conditions of potential NZEB targets

- Training of the building occupants should be a part of national plans to obtain higher efficiency in buildings

Although the methodology followed by the researchers is definitive on the NZEB decisions, the final decision relies on politic arrangements. Therefore ensuring the reliable transfer of findings into practice is mainly related to policy introduced by the policy-makers participates in the process.

This dissertation demonstrates that national policy-makers should appeal to the subsidy and incentives in order to achieve NZEB targets through a smooth and rapid progress. The proposals obtained by the introduced approach includes convenient actions which are not unrealistic in terms of applicability.

The introduced approach is an instructive guide to achieve EPBD recast targets and requirements of Article 4 of Directive 2012/27/EU. An important action to be taken after the approach has been implemented is to monitor the progress in the market on introduced targets in order to provide the sustainability of the process. Results of the monitoring activity are required for the revision of NZEB targets as future cost-optimal levels in every 5 years.

As a whole, this dissertation exhibits a promising future in terms of great energy and cost savings through building retrofits when the existing building stock is considered. However, this promising development requires deep research, reasonable planning and absolute effort in the following years.

7.1 Further research

Initially, further adaptations of the proposed approach are required. One of the main recommended adaptation is for new buildings to lead the national targets on new constructions. This implementation should also include implementation for different building types.

Besides the adaptation, different implementations of the approach will support the methodology within time. In example, implementations of this approach for different building types or different occupancy patterns would be worthwhile.

Due to the effectiveness of occupancy patterns on building energy performance, future studies may focus on determining reference occupancy patterns for the reference buildings.

The proposed approach in this research can be upgraded by equipping with more details. Integrating also the comfort analyses into the approach would be interesting to provide an extensive point of view.

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APPENDICES

APPENDIX A: Primary energy consumption and global cost results for the RB retrofit scenarios in Istanbul

Table A.1 : Results of envelope retrofit scenarios for Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
BASE	145.3	346.3	**IN3-W+GL3**	114.9	371.1
IN1-W	134.0	380.7	**IN3-W+GL4**	114.0	375.6
IN2-W	131.4	381.8	**IN3-W+GL5**	113.5	370.7
IN3-W	129.0	390.2	**IN3-W+GL6**	114.3	374.3
IN4-W	126.9	451.5	**IN3-W+GL7**	112.0	369.6
IN1-F	144.8	350.8	**IN4-W+GL1**	116.5	439.9
IN2-F	144.7	351.3	**IN4-W+GL2**	116.2	439.9
IN3-F	144.6	350.3	**IN4-W+GL3**	112.2	431.2
IN4-F	144.5	351.0	**IN4-W+GL4**	111.4	430.6
IN1-R	144.3	346.0	**IN4-W+GL5**	111.0	431.2
IN2-R	144.0	345.6	**IN4-W+GL6**	112.0	435.3
IN3-R	143.7	345.6	**IN4-W+GL7**	109.4	430.1
IN4-R	143.4	346.7	**IN1-E+GL1**	123.0	375.2
IN1-E	132.7	385.4	**IN1-E+GL2**	122.4	374.8
IN2-E	129.9	386.8	**IN1-E+GL3**	119.2	367.8
IN3-E	127.2	394.6	**IN1-E+GL4**	118.0	366.7
IN4-E	125.0	458.5	**IN1-E+GL5**	117.4	367.0
GL1	137.1	338.8	**IN1-E+GL6**	118.0	370.0
GL2	136.4	338.2	**IN1-E+GL7**	116.0	365.9
GL3	134.3	333.4	**IN2-E+GL1**	119.7	376.0
GL4	133.1	331.9	**IN2-E+GL2**	119.3	375.8
GL5	132.3	331.8	**IN2-E+GL3**	115.7	368.0
GL6	132.3	333.7	**IN2-E+GL4**	114.8	367.0
GL7	131.0	331.2	**IN2-E+GL5**	114.2	367.5
IN1-W+GL1	124.5	370.9	**IN2-E+GL6**	115.0	371.0
IN1-W+GL2	124.0	370.6	**IN2-E+GL7**	112.7	366.4
IN1-W+GL3	121.1	364.0	**IN3-E+GL1**	116.9	383.1
IN1-W+GL4	120.0	362.8	**IN3-E+GL2**	116.5	383.1
IN1-W+GL5	119.3	363.0	**IN3-E+GL3**	112.5	374.3
IN1-W+GL6	119.8	365.8	**IN3-E+GL4**	111.6	373.7
IN1-W+GL7	117.9	362.1	**IN3-E+GL5**	111.2	374.3
IN2-W+GL1	121.7	371.3	**IN3-E+GL6**	112.3	378.4
IN2-W+GL2	121.2	371.1	**IN3-E+GL7**	109.7	373.2
IN2-W+GL3	117.9	363.8	**IN4-E+GL1**	114.4	446.3
IN2-W+GL4	116.9	362.8	**IN4-E+GL2**	114.1	446.5
IN2-W+GL5	116.4	363.2	**IN4-E+GL3**	109.7	436.9
IN2-W+GL6	117.0	370.8	**IN4-E+GL4**	109.0	436.5
IN2-W+GL7	114.9	362.1	**IN4-E+GL5**	108.7	437.4
IN3-W+GL1	119.0	379.2	**IN4-E+GL6**	110.0	442.1
IN3-W+GL2	118.5	379.1	**IN4-E+GL7**	107.1	436.1

Table A.2 : Results of scenarios including IN, GL, BOI and AC retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
BOI	139.1	346.4	**AC**	133.2	403.5	**BOI+AC**	127.0	403.6
GL5+BOI	126.5	332.5	**GL5+AC**	123.7	396.6	**GL5+BOI+AC**	117.8	397.4
GL6+BOI	126.7	334.9	**GL6+AC**	123.0	397.1	**GL6+BOI+AC**	117.5	398.4
GL7+BOI	125.3	332.0	**GL7+AC**	122.7	396.6	**GL7+BOI+AC**	116.9	397.5
IN2-W+BOI	127.9	386.1	**IN2-W+AC**	118.2	436.4	**IN2-W+BOI+AC**	114.6	440.7
IN3-W+BOI	126.0	395.4	**IN3-W+AC**	115.3	443.9	**IN3-W+BOI+AC**	112.3	449.2
IN4-W+BOI	124.4	457.5	**IN4-W+AC**	112.7	504.2	**IN4-W+BOI+AC**	110.2	510.3
IN2-E+BOI	126.7	391.7	**IN2-E+AC**	116.2	440.7	**IN2-E+BOI+AC**	113.1	445.6
IN3-E+BOI	124.7	400.5	**IN3-E+AC**	113.1	447.3	**IN3-E+BOI+AC**	110.6	453.3
IN4-E+BOI	123.1	465.5	**IN4-E+AC**	110.2	509.8	**IN4-E+BOI+AC**	108.3	516.8
IN2-W+GL7+BOI	111.9	367.3	**IN2-W+GL7+AC**	105.9	426.1	**IN2-W+GL7+BOI+AC**	102.9	431.3
IN3-W+GL4+BOI	111.3	375.9	**IN3-W+GL4+AC**	104.6	433.3	**IN3-W+GL4+BOI+AC**	101.9	439.0
IN3-W+GL5+BOI	111.0	376.7	**IN3-W+GL5+AC**	103.9	433.4	**IN3-W+GL5+BOI+AC**	101.4	439.4
IN3-W+GL7+BOI	109.6	375.7	**IN3-W+GL7+AC**	102.7	433.0	**IN3-W+GL7+BOI+AC**	100.3	439.1
IN4-W+GL4+BOI	109.2	437.2	**IN4-W+GL4+AC**	101.6	492.9	**IN4-W+GL4+BOI+AC**	99.5	499.5
IN4-W+GL5+BOI	109.0	438.1	**IN4-W+GL5+AC**	101.0	493.0	**IN4-W+GL5+BOI+AC**	99.0	499.9
IN4-W+GL7+BOI	107.6	437.1	**IN4-W+GL7+AC**	99.8	492.7	**IN4-W+GL7+BOI+AC**	97.9	499.7
IN2-E+GL7+BOI	110.3	372.3	**IN2-E+GL7+AC**	103.7	429.9	**IN2-E+GL7+BOI+AC**	101.1	435.7
IN3-E+GL4+BOI	109.5	380.1	**IN3-E+GL4+AC**	101.9	435.9	**IN3-E+GL4+BOI+AC**	99.7	442.4
IN3-E+GL5+BOI	109.3	381.0	**IN3-E+GL5+AC**	101.3	436.1	**IN3-E+GL5+BOI+AC**	99.3	442.8
IN3-E+GL7+BOI	107.8	380.0	**IN3-E+GL7+AC**	100.1	435.7	**IN3-E+GL7+BOI+AC**	98.2	442.6
IN4-E+GL4+BOI	107.4	444.0	**IN4-E+GL4+AC**	98.7	497.7	**IN4-E+GL4+BOI+AC**	97.1	505.2
IN4-E+GL5+BOI	107.3	440.2	**IN4-E+GL5+AC**	98.1	498.0	**IN4-E+GL5+BOI+AC**	96.8	500.8
IN4-E+GL7+BOI	105.8	439.0	**IN4-E+GL7+AC**	96.9	497.5	**IN4-E+GL7+BOI+AC**	95.6	500.5

Table A.3 : Results of scenarios including IN, GL, BOI, AC and SHD retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
SHD1	140.9	357.2	**SHD2**	134.2	422.7
GL5+BOI+AC+SHD2	116.3	494.0	**GL5+BOI+SHD2**	124.2	427.5
GL6+BOI+AC+SHD2	115.6	494.0	**GL6+BOI+SHD2**	123.8	428.4
GL7+BOI+AC+SHD2	115.9	495.0	**GL7+BOI+SHD2**	123.6	428.2
IN2-W+GL7+BOI+AC+SHD2	101.7	528.5	**IN2-W+GL7+BOI+SHD2**	110.0	463.0
IN3-W+GL4+BOI+AC+SHD2	100.1	535.0	**IN3-W+GL4+BOI+SHD2**	108.6	470.0
IN3-W+GL5+BOI+AC+SHD2	99.6	535.4	**IN3-W+GL5+BOI+SHD2**	108.3	470.7
IN3-W+GL7+BOI+AC+SHD2	99.0	536.2	**IN3-W+GL7+BOI+SHD2**	107.6	471.2
IN4-W+GL4+BOI+AC+SHD2	97.6	595.3	**IN4-W+GL4+BOI+SHD2**	106.4	530.9
IN4-W+GL5+BOI+AC+SHD2	97.2	595.7	**IN4-W+GL5+BOI+SHD2**	106.2	531.7
IN4-W+GL7+BOI+AC+SHD2	96.6	596.6	**IN4-W+GL7+BOI+SHD2**	105.5	532.2
IN2-E+GL7+BOI+AC+SHD2	99.8	532.8	**IN2-E+GL7+BOI+SHD2**	108.3	467.7
IN3-E+GL4+BOI+AC+SHD2	97.9	538.3	**IN3-E+GL4+BOI+SHD2**	106.7	473.9
IN3-E+GL5+BOI+AC+SHD2	97.4	538.7	**IN3-E+GL5+BOI+SHD2**	106.4	474.7
IN3-E+GL7+BOI+AC+SHD2	96.9	539.5	**IN3-E+GL7+BOI+SHD2**	105.7	475.2
IN4-E+GL4+BOI+AC+SHD2	95.2	595.8	**IN4-E+GL4+BOI+SHD2**	104.4	532.4
IN4-E+GL5+BOI+AC+SHD2	94.8	596.4	**IN4-E+GL5+BOI+SHD2**	104.3	533.4
IN4-E+GL7+BOI+AC+SHD2	94.2	597.3	**IN4-E+GL7+BOI+SHD2**	103.6	534.0

Table A.4 : Results of scenarios including IN, GL, BOI, AC and LED retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
LED	133.4	332.2			
GL5+BOI+AC+LED	106.4	384.6	**GL5+BOI+LED**	114.2	318.1
GL6+BOI+AC+LED	105.9	385.4	**GL6+BOI+LED**	114.4	320.3
GL7+BOI+AC+LED	105.4	384.6	**GL7+BOI+LED**	113.0	317.5
IN2-W+GL7+BOI+AC+LED	90.7	417.3	**IN2-W+GL7+BOI+LED**	98.8	351.2
IN3-W+GL4+BOI+AC+LED	89.6	424.8	**IN3-W+GL4+BOI+LED**	98.1	359.6
IN3-W+GL5+BOI+AC+LED	89.0	425.0	**IN3-W+GL5+BOI+LED**	97.7	360.2
IN3-W+GL7+BOI+AC+LED	87.9	424.7	**IN3-W+GL7+BOI+LED**	96.2	359.1
IN4-W+GL4+BOI+AC+LED	87.0	484.9	**IN4-W+GL4+BOI+LED**	95.7	420.2
IN4-W+GL5+BOI+AC+LED	86.5	485.2	**IN4-W+GL5+BOI+LED**	95.4	421.0
IN4-W+GL7+BOI+AC+LED	85.3	484.7	**IN4-W+GL7+BOI+LED**	93.9	419.8
IN2-E+GL7+BOI+AC+LED	88.9	421.5	**IN2-E+GL7+BOI+LED**	97.1	355.9
IN3-E+GL4+BOI+AC+LED	87.4	427.9	**IN3-E+GL4+BOI+LED**	96.1	363.3
IN3-E+GL5+BOI+AC+LED	86.8	428.2	**IN3-E+GL5+BOI+LED**	95.7	364.0
IN3-E+GL7+BOI+AC+LED	85.7	427.8	**IN3-E+GL7+BOI+LED**	94.2	362.8
IN4-E+GL4+BOI+AC+LED	84.5	490.1	**IN4-E+GL4+BOI+LED**	93.6	426.5
IN4-E+GL5+BOI+AC+LED	84.0	485.7	**IN4-E+GL5+BOI+LED**	93.4	422.5
IN4-E+GL7+BOI+AC+LED	82.8	485.2	**IN4-E+GL7+BOI+LED**	91.9	421.2

Table A.5 : Results of scenarios including IN, GL, BOI, AC and CHW retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL5+ BOI+CHW	101.3	273.6	**GL5+BOI+ AC+CHW**	92.6	338.4
GL6+ BOI+CHW	101.6	276.0	**GL6+BOI+ AC+CHW**	92.3	339.4
GL7+ BOI+CHW	100.1	273.0	**GL7+BOI+ AC+CHW**	91.7	338.5
IN2-W+GL7+ BOI+CHW	86.6	308.1	**IN2-W+GL7+ BOI+AC+CHW**	77.6	372.1
IN3-W+GL4+ BOI+CHW	86.0	316.7	**IN3-W+GL4+ BOI+AC+CHW**	76.6	379.8
IN3-W+GL5+ BOI+CHW	85.7	317.4	**IN3-W+GL5+ BOI+AC+CHW**	76.0	380.1
IN3-W+GL7+ BOI+CHW	84.2	316.4	**IN3-W+GL7+ BOI+AC+CHW**	75.0	379.8
IN4-W+GL4+ BOI+CHW	83.9	377.8	**IN4-W+GL4+ BOI+AC+CHW**	74.1	440.2
IN4-W+GL5+ BOI+CHW	83.7	378.7	**IN4-W+GL5+ BOI+AC+CHW**	73.7	440.6
IN4-W+GL7+ BOI+CHW	82.2	377.7	**IN4-W+GL7+ BOI+AC+CHW**	72.6	440.3
IN2-E+GL7+ BOI+CHW	85.0	313.1	**IN2-E+GL7+ BOI+AC+CHW**	75.8	376.5
IN3-E+GL4+ BOI+CHW	84.2	320.9	**IN3-E+GL4+ BOI+AC+CHW**	74.5	383.2
IN3-E+GL5+ BOI+CHW	84.0	321.8	**IN3-E+GL5+ BOI+AC+CHW**	74.0	383.6
IN3-E+GL7+ BOI+CHW	82.5	320.7	**IN3-E+GL7+ BOI+AC+CHW**	72.9	383.3
IN4-E+GL4+ BOI+CHW	82.2	384.8	**IN4-E+GL4+ BOI+AC+CHW**	71.9	446.0
IN4-E+GL5+ BOI+CHW	82.0	385.9	**IN4-E+GL5+ BOI+AC+CHW**	71.5	446.5
IN4-E+GL7+ BOI+CHW	80.5	384.7	**IN4-E+GL7+ BOI+AC+CHW**	70.3	446.1

Table A.6 : Results of scenarios including IN, GL, BOI, AC and LED retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL5+BOI+ CHW+LED	89.0	259.1	**GL5+BOI+ AC+CHW+LED**	81.2	325.6
GL6+BOI+ CHW+LED	89.2	261.3	**GL6+BOI+ AC+CHW+LED**	80.7	326.4
GL7+BOI+ CHW+LED	87.8	258.5	**GL7+BOI+ AC+CHW+LED**	80.2	325.6
IN2-W+GL7+ BOI+CHW+LED	73.5	291.9	**IN2-W+GL7+BOI+ AC+CHW+LED**	65.4	358.0
IN3-W+GL4+ BOI+CHW+LED	72.7	300.2	**IN3-W+GL4+BOI+ AC+CHW+LED**	64.3	365.5
IN3-W+GL5+ BOI+CHW+LED	72.3	300.8	**IN3-W+GL5+BOI+ AC+CHW+LED**	63.7	365.7
IN3-W+GL7+ BOI+CHW+LED	70.9	299.7	**IN3-W+GL7+BOI+ AC+CHW+LED**	62.6	365.3
IN4-W+GL4+ BOI+CHW+LED	70.4	360.9	**IN4-W+GL4+BOI+ AC+CHW+LED**	61.7	425.5
IN4-W+GL5+ BOI+CHW+LED	70.1	361.6	**IN4-W+GL5+BOI+ AC+CHW+LED**	61.2	425.8
IN4-W+GL7+ BOI+CHW+LED	68.5	360.4	**IN4-W+GL7+BOI+ AC+CHW+LED**	60.0	425.3
IN2-E+GL7+ BOI+CHW+LED	71.8	296.6	**IN2-E+GL7+BOI+ AC+CHW+LED**	63.6	362.2
IN3-E+GL4+ BOI+CHW+LED	70.8	304.1	**IN3-E+GL4+BOI+ AC+CHW+LED**	62.1	368.7
IN3-E+GL5+ BOI+CHW+LED	70.4	304.7	**IN3-E+GL5+BOI+ AC+CHW+LED**	61.5	368.9
IN3-E+GL7+ BOI+CHW+LED	68.9	303.5	**IN3-E+GL7+BOI+ AC+CHW+LED**	60.3	368.4
IN4-E+GL4+ BOI+CHW+LED	68.3	367.2	**IN4-E+GL4+BOI+ AC+CHW+LED**	59.2	430.9
IN4-E+GL5+ BOI+CHW+LED	68.1	368.2	**IN4-E+GL5+BOI+ AC+CHW+LED**	58.7	431.3
IN4-E+GL7+ BOI+CHW+LED	66.5	366.8	**IN4-E+GL7+BOI+ AC+CHW+LED**	57.5	430.8

Table A.7 : Results of scenarios including IN, GL, BOI, AC, CHW, LED and SP retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL5+BOI+ CHW+LED+SP	79.6	263.9	**GL5+BOI+AC+ CHW+LED+SP**	71.8	330.6
GL6+BOI+ CHW+LED+SP	79.8	266.0	**GL6+BOI+AC+ CHW+LED+SP**	71.4	331.3
GL7+BOI+ CHW+LED+SP	78.4	263.2	**GL7+BOI+AC+ CHW+LED+SP**	70.9	330.6
IN2-W+GL7+BOI+ CHW+LED+SP	64.1	296.8	**IN2-W+GL7+BOI+ AC+CHW+LED+SP**	56.2	363.1
IN3-W+GL4+BOI+ CHW+LED+SP	63.4	305.2	**IN3-W+GL4+BOI+ AC+CHW+LED+SP**	55.0	370.6
IN3-W+GL5+BOI+ CHW+LED+SP	63.0	305.8	**IN3-W+GL5+BOI+ AC+CHW+LED+SP**	54.5	370.8
IN3-W+GL7+BOI+ CHW+LED+SP	61.5	304.7	**IN3-W+GL7+BOI+ AC+CHW+LED+SP**	53.3	370.5
IN4-W+GL4+BOI+ CHW+LED+SP	61.0	365.8	**IN4-W+GL4+BOI+ AC+CHW+LED+SP**	52.4	430.7
IN4-W+GL5+BOI+ CHW+LED+SP	60.7	366.6	**IN4-W+GL5+BOI+ AC+CHW+LED+SP**	51.9	431.0
IN4-W+GL7+BOI+ CHW+LED+SP	59.2	365.4	**IN4-W+GL7+BOI+ AC+CHW+LED+SP**	50.7	430.5
IN2-E+GL7+BOI+ CHW+LED+SP	62.5	301.8	**IN2-E+GL7+BOI+ AC+CHW+LED+SP**	54.3	367.5
IN3-E+GL4+BOI+ CHW+LED+SP	61.6	309.3	**IN3-E+GL4+BOI+ AC+CHW+LED+SP**	52.9	374.0
IN3-E+GL5+BOI+ CHW+LED+SP	61.2	310.0	**IN3-E+GL5+BOI+ AC+CHW+LED+SP**	52.3	374.2
IN3-E+GL7+BOI+ CHW+LED+SP	59.7	308.8	**IN3-E+GL7+BOI+ AC+CHW+LED+SP**	51.2	373.8
IN4-E+GL4+BOI+ CHW+LED+SP	59.2	372.6	**IN4-E+GL4+BOI+ AC+CHW+LED+SP**	50.0	436.2
IN4-E+GL5+BOI+ CHW+LED+SP	58.9	373.6	**IN4-E+GL5+BOI+ AC+CHW+LED+SP**	49.5	436.7
IN4-E+GL7+BOI+ CHW+LED+SP	57.4	372.2	**IN4-E+GL7+BOI+ AC+CHW+LED+SP**	48.4	436.2

Table A.8 : Results of scenarios including IN, GL, BOI, CHW, LED, SP and PV retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
PV	137.2	341.1			
GL5+BOI+ CHW+LED+PV	81.1	253.8	**GL5+BOI+ CHW+LED+SP+PV**	71.6	260.2
GL6+BOI+ CHW+LED+PV	81.2	256.0	**GL6+BOI+ CHW+LED+SP+PV**	71.8	262.3
GL7+BOI+ CHW+LED+PV	79.8	253.2	**GL7+BOI+ CHW+LED+SP+PV**	70.4	259.5
IN2-W+GL7+BOI+ CHW+LED+PV	65.5	286.6	**IN2-W+GL7+BOI+ CHW+LED+SP+PV**	56.2	293.2
IN3-W+GL4+BOI+ CHW+LED+PV	64.8	294.9	**IN3-W+GL4+BOI+ CHW+LED+SP+PV**	55.4	301.5
IN3-W+GL5+BOI+ CHW+LED+PV	64.4	295.5	**IN3-W+GL5+BOI+ CHW+LED+SP+PV**	55.0	302.1
IN3-W+GL7+BOI+ CHW+LED+PV	62.9	294.4	**IN3-W+GL7+BOI+ CHW+LED+SP+PV**	53.6	301.0
IN4-W+GL4+BOI+ CHW+LED+PV	62.5	355.6	**IN4-W+GL4+BOI+ CHW+LED+SP+PV**	53.1	362.2
IN4-W+GL5+BOI+ CHW+LED+PV	62.1	356.3	**IN4-W+GL5+BOI+ CHW+LED+SP+PV**	52.8	362.9
IN4-W+GL7+BOI+ CHW+LED+PV	60.6	355.1	**IN4-W+GL7+BOI+ CHW+LED+SP+PV**	51.2	361.7
IN2-E+GL7+BOI+ CHW+LED+PV	63.9	291.3	**IN2-E+GL7+BOI+ CHW+LED+SP+PV**	54.6	298.1
IN3-E+GL4+BOI+ CHW+LED+PV	62.8	298.8	**IN3-E+GL4+BOI+ CHW+LED+SP+PV**	53.6	305.6
IN3-E+GL5+BOI+ CHW+LED+PV	62.5	299.4	**IN3-E+GL5+BOI+ CHW+LED+SP+PV**	53.3	306.3
IN3-E+GL7+BOI+ CHW+LED+PV	60.9	298.2	**IN3-E+GL7+BOI+ CHW+LED+SP+PV**	51.7	305.1
IN4-E+GL4+BOI+ CHW+LED+PV	60.4	361.9	**IN4-E+GL4+BOI+ CHW+LED+SP+PV**	51.2	368.9
IN4-E+GL5+BOI+ CHW+LED+PV	60.2	362.9	**IN4-E+GL5+BOI+ CHW+LED+SP+PV**	51.0	369.9
IN4-E+GL7+BOI+ CHW+LED+PV	58.6	361.6	**IN4-E+GL7+BOI+ CHW+LED+SP+PV**	49.4	368.6

Table A.9 : Results of scenarios including IN, GL, BOI, AC, CHW, LED and RF retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL5+BOI+AC+LED+RF	98.1	444.1	**GL5+BOI+AC+CHW+LED+RF**	68.2	370.4
GL6+BOI+AC+LED+RF	98.2	439.2	**GL6+BOI+AC+CHW+LED+RF**	68.3	372.1
GL7+BOI+AC+LED+RF	97.2	437.6	**GL7+BOI+AC+CHW+LED+RF**	67.3	370.5
IN2-W+GL7+BOI+AC+LED+RF	86.4	476.3	**IN2-W+GL7+BOI+AC+CHW+LED+RF**	57.0	410.4
IN3-W+GL4+BOI+AC+LED+RF	85.9	484.9	**IN3-W+GL4+BOI+AC+CHW+LED+RF**	56.5	418.9
IN3-W+GL5+BOI+AC+LED+RF	85.6	485.6	**IN3-W+GL5+BOI+AC+CHW+LED+RF**	56.2	419.6
IN3-W+GL7+BOI+AC+LED+RF	84.6	485.4	**IN3-W+GL7+BOI+AC+CHW+LED+RF**	55.2	419.4
IN4-W+GL4+BOI+AC+LED+RF	84.2	546.6	**IN4-W+GL4+BOI+AC+CHW+LED+RF**	54.9	480.5
IN4-W+GL5+BOI+AC+LED+RF	84.0	547.4	**IN4-W+GL5+BOI+AC+CHW+LED+RF**	54.6	481.3
IN4-W+GL7+BOI+AC+LED+RF	83.0	547.2	**IN4-W+GL7+BOI+AC+CHW+LED+RF**	53.6	481.1
IN2-E+GL7+BOI+AC+LED+RF	85.0	481.2	**IN2-E+GL7+BOI+AC+CHW+LED+RF**	55.6	415.2
IN3-E+GL4+BOI+AC+LED+RF	84.1	488.7	**IN3-E+GL4+BOI+AC+CHW+LED+RF**	53.8	420.7
IN3-E+GL5+BOI+AC+LED+RF	83.9	489.5	**IN3-E+GL5+BOI+AC+CHW+LED+RF**	54.5	423.4
IN3-E+GL7+BOI+AC+LED+RF	83.3	490.3	**IN3-E+GL7+BOI+AC+CHW+LED+RF**	53.5	423.2
IN4-E+GL4+BOI+AC+LED+RF	82.2	552.6	**IN4-E+GL4+BOI+AC+CHW+LED+RF**	52.9	486.5
IN4-E+GL5+BOI+AC+LED+RF	82.1	548.6	**IN4-E+GL5+BOI+AC+CHW+LED+RF**	52.7	487.4
IN4-E+GL7+BOI+AC+LED+RF	81.0	548.4	**IN4-E+GL7+BOI+AC+CHW+LED+RF**	51.6	487.1

Table A.10 : Results of scenarios including IN, GL, BOI, AC, CHW, LED, RF and SP retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL5+BOI+AC+CHW+LED+RF+SP	52.2	371.2	**GL5+BOI+CHW+LED+RF+SP**	60.1	304.9
GL6+BOI+AC+CHW+LED+RF+SP	52.7	373.5	**GL6+BOI+CHW+LED+RF+SP**	61.2	308.5
GL7+BOI+AC+CHW+LED+RF+SP	51.4	371.5	**GL7+BOI+CHW+LED+RF+SP**	59.1	304.5
IN2-W+GL7+BOI+AC+CHW+LED+RF+SP	44.9	417.3	**IN2-W+GL7+BOI+CHW+LED+RF+SP**	53.1	351.5
IN3-W+GL4+BOI+AC+CHW+LED+RF+SP	44.8	426.5	**IN3-W+GL4+BOI+CHW+LED+RF+SP**	53.4	361.6
IN3-W+GL5+BOI+AC+CHW+LED+RF+SP	44.8	427.6	**IN3-W+GL5+BOI+CHW+LED+RF+SP**	53.6	363.0
IN3-W+GL7+BOI+AC+CHW+LED+RF+SP	43.9	427.6	**IN3-W+GL7+BOI+CHW+LED+RF+SP**	52.3	362.3
IN4-W+GL4+BOI+AC+CHW+LED+RF+SP	43.9	489.3	**IN4-W+GL4+BOI+CHW+LED+RF+SP**	52.8	425.1
IN4-W+GL5+BOI+AC+CHW+LED+RF+SP	43.9	490.4	**IN4-W+GL5+BOI+CHW+LED+RF+SP**	53.0	426.7
IN4-W+GL7+BOI+AC+CHW+LED+RF+SP	43.0	490.4	**IN4-W+GL7+BOI+CHW+LED+RF+SP**	51.7	425.8
IN2-E+GL7+BOI+AC+CHW+LED+RF+SP	44.0	423.1	**IN2-E+GL7+BOI+CHW+LED+RF+SP**	52.3	357.5
IN3-E+GL4+BOI+AC+CHW+LED+RF+SP	43.7	431.5	**IN3-E+GL4+BOI+CHW+LED+RF+SP**	52.5	367.0
IN3-E+GL5+BOI+AC+CHW+LED+RF+SP	43.7	432.5	**IN3-E+GL5+BOI+CHW+LED+RF+SP**	52.7	368.5
IN3-E+GL7+BOI+AC+CHW+LED+RF+SP	42.8	432.5	**IN3-E+GL7+BOI+CHW+LED+RF+SP**	51.4	367.7
IN4-E+GL4+BOI+AC+CHW+LED+RF+SP	42.7	496.7	**IN4-E+GL4+BOI+CHW+LED+RF+SP**	51.9	433.1
IN4-E+GL5+BOI+AC+CHW+LED+RF+SP	42.8	497.9	**IN4-E+GL5+BOI+CHW+LED+RF+SP**	52.2	434.9
IN4-E+GL7+BOI+AC+CHW+LED+RF+SP	41.8	497.9	**IN4-E+GL7+BOI+CHW+LED+RF+SP**	50.9	434.0

Table A.11 : Results of scenarios including IN, GL, BOI, VRV, CHW, LED and SP retrofits in Istanbul**.**

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL5+BOI+VRV+CHW+LED	76.8	304.3	**GL5+BOI+VRV+CHW+LED+SP**	67.5	310.9
GL6+BOI+VRV+CHW+LED	76.0	304.4	**GL6+BOI+VRV+CHW+LED+SP**	66.7	311.0
GL7+BOI+VRV+CHW+LED	76.0	304.6	**GL7+BOI+VRV+CHW+LED+SP**	66.7	311.3
IN2-W+GL7+BOI+VRV+CHW+LED	60.8	336.3	**IN2-W+GL7+BOI+VRV+CHW+LED+SP**	51.6	343.1
IN3-W+GL4+BOI+VRV+CHW+LED	59.5	343.3	**IN3-W+GL4+BOI+VRV+CHW+LED+SP**	50.3	350.1
IN3-W+GL5+BOI+VRV+CHW+LED	58.8	343.2	**IN3-W+GL5+BOI+VRV+CHW+LED+SP**	49.6	350.1
IN3-W+GL7+BOI+VRV+CHW+LED	57.8	343.2	**IN3-W+GL7+BOI+VRV+CHW+LED+SP**	48.6	350.1
IN4-W+GL4+BOI+VRV+CHW+LED	56.7	402.9	**IN4-W+GL4+BOI+VRV+CHW+LED+SP**	47.5	409.8
IN4-W+GL5+BOI+VRV+CHW+LED	56.0	402.9	**IN4-W+GL5+BOI+VRV+CHW+LED+SP**	46.8	409.8
IN4-W+GL7+BOI+VRV+CHW+LED	55.1	402.9	**IN4-W+GL7+BOI+VRV+CHW+LED+SP**	45.9	409.8
IN2-E+GL7+BOI+VRV+CHW+LED	58.8	340.2	**IN2-E+GL7+BOI+VRV+CHW+LED+SP**	49.6	347.1
IN3-E+GL4+BOI+VRV+CHW+LED	57.0	346.0	**IN3-E+GL4+BOI+VRV+CHW+LED+SP**	47.9	353.0
IN3-E+GL5+BOI+VRV+CHW+LED	56.4	346.0	**IN3-E+GL5+BOI+VRV+CHW+LED+SP**	47.2	353.0
IN3-E+GL7+BOI+VRV+CHW+LED	55.4	346.0	**IN3-E+GL7+BOI+VRV+CHW+LED+SP**	46.2	353.0
IN4-E+GL4+BOI+VRV+CHW+LED	53.9	407.6	**IN4-E+GL4+BOI+VRV+CHW+LED+SP**	44.7	414.6
IN4-E+GL5+BOI+VRV+CHW+LED	53.3	407.7	**IN4-E+GL5+BOI+VRV+CHW+LED+SP**	44.1	414.8
IN4-E+GL7+BOI+VRV+CHW+LED	52.3	407.6	**IN4-E+GL7+BOI+VRV+CHW+LED+SP**	43.1	414.7

Table A.12 : Results of scenarios including IN, GL, BOI, VRV, CHW, LED, RF, SP and PV retrofits in Istanbul.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL5+BOI+VRV+CHW+LED+RF+SP	47.7	351.4	GL5+BOI+VRV+CHW+LED+RF+SP+PV	39.8	346.1
GL6+BOI+VRV+CHW+LED+RF+SP	47.9	352.9	GL6+BOI+VRV+CHW+LED+RF+SP+PV	39.9	347.6
GL7+BOI+VRV+CHW+LED+RF+SP	47.1	352.0	GL7+BOI+VRV+CHW+LED+RF+SP+PV	39.2	346.7
IN2-W+GL7+BOI+VRV+CHW+LED+RF+SP	40.3	397.0	IN2-W+GL7+BOI+VRV+CHW+LED+RF+SP+PV	32.3	391.8
IN3-W+GL4+BOI+VRV+CHW+LED+RF+SP	39.9	405.7	IN3-W+GL4+BOI+VRV+CHW+LED+RF+SP+PV	32.0	400.4
IN3-W+GL5+BOI+VRV+CHW+LED+RF+SP	39.7	406.5	IN3-W+GL5+BOI+VRV+CHW+LED+RF+SP+PV	31.8	401.2
IN3-W+GL7+BOI+VRV+CHW+LED+RF+SP	39.0	406.9	IN3-W+GL7+BOI+VRV+CHW+LED+RF+SP+PV	31.1	401.6
IN4-W+GL4+BOI+VRV+CHW+LED+RF+SP	38.8	468.1	IN4-W+GL4+BOI+VRV+CHW+LED+RF+SP+PV	30.9	462.8
IN4-W+GL5+BOI+VRV+CHW+LED+RF+SP	38.7	468.9	IN4-W+GL5+BOI+VRV+CHW+LED+RF+SP+PV	30.7	463.6
IN4-W+GL7+BOI+VRV+CHW+LED+RF+SP	37.9	469.3	IN4-W+GL7+BOI+VRV+CHW+LED+RF+SP+PV	30.0	464.0
IN2-E+GL7+BOI+VRV+CHW+LED+RF+SP	39.3	402.6	IN2-E+GL7+BOI+VRV+CHW+LED+RF+SP+PV	31.3	397.3
IN3-E+GL4+BOI+VRV+CHW+LED+RF+SP	38.7	410.3	IN3-E+GL4+BOI+VRV+CHW+LED+RF+SP+PV	30.7	405.0
IN3-E+GL5+BOI+VRV+CHW+LED+RF+SP	38.5	411.2	IN3-E+GL5+BOI+VRV+CHW+LED+RF+SP+PV	30.6	405.9
IN3-E+GL7+BOI+VRV+CHW+LED+RF+SP	37.8	411.6	IN3-E+GL7+BOI+VRV+CHW+LED+RF+SP+PV	29.8	406.3
IN4-E+GL4+BOI+VRV+CHW+LED+RF+SP	37.4	475.0	IN4-E+GL4+BOI+VRV+CHW+LED+RF+SP+PV	29.4	469.7
IN4-E+GL5+BOI+VRV+CHW+LED+RF+SP	37.3	475.9	IN4-E+GL5+BOI+VRV+CHW+LED+RF+SP+PV	29.3	470.6
IN4-E+GL7+BOI+VRV+CHW+LED+RF+SP	36.5	476.3	IN4-E+GL7+BOI+VRV+CHW+LED+RF+SP+PV	28.6	471.0

APPENDIX B: Primary energy consumption and global cost results for the RB retrofit scenarios in Antalya

Table B.1 : Results of envelope retrofit scenarios in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
BASE	160.9	401.0	**IN3-W+GL2**	136.6	423.7
IN1-W	153.6	435.6	**IN3-W+GL3**	128.5	406.5
IN2-W	152.4	436.8	**IN3-W+GL4**	128.4	406.9
IN3-W	151.1	445.0	**IN3-W+GL5**	128.7	408.5
IN4-W	150.5	501.1	**IN3-W+GL6**	131.9	416.6
F-INS1	160.2	402.7	**IN3-W+GL7**	126.6	405.9
F-INS2	160.0	402.8	**IN4-W+GL1**	135.3	477.9
F-INS3	159.8	401.7	**IN4-W+GL2**	135.7	479.1
F-INS4	159.6	402.1	**IN4-W+GL3**	126.9	460.7
R-INS1	160.1	398.9	**E-INS1+GL1**	138.3	418.4
R-INS2	159.9	398.7	**E-INS1+GL2**	138.4	419.1
R-INS3	159.6	398.4	**E-INS1+GL3**	131.2	403.7
R-INS4	159.4	399.5	**E-INS1+GL4**	130.9	403.6
E-INS1	152.4	439.3	**E-INS1+GL5**	130.9	404.9
IN2-E	151.0	440.5	**E-INS1+GL6**	133.6	411.9
IN3-E	149.5	448.3	**E-INS1+GL7**	129.0	402.5
IN4-E	149.1	506.8	**IN2-E+GL1**	136.4	418.6
GL1	148.0	380.7	**IN2-E+GL2**	136.6	419.5
GL2	147.9	381.0	**IN2-E+GL3**	128.9	403.1
GL3	142.0	368.1	**IN2-E+GL4**	128.7	403.3
GL4	141.5	367.7	**IN2-E+GL5**	128.8	404.7
GL5	141.4	368.7	**IN2-E+GL6**	131.8	412.3
GL6	143.5	374.8	**IN2-E+GL7**	126.8	402.2
GL7	139.8	367.1	**IN4-W+GL6**	131.0	472.1
IN1-W+GL1	139.7	415.1	**IN4-W+GL7**	125.3	460.6
IN1-W+GL2	139.8	415.8	**IN3-E+GL1**	134.3	425.1
IN1-W+GL3	132.8	400.8	**IN3-E+GL2**	134.7	426.2
IN1-W+GL4	132.5	400.7	**IN3-E+GL3**	126.0	408.1
IN1-W+GL5	132.5	401.9	**IN3-E+GL4**	126.1	408.6
IN1-W+GL6	135.0	408.7	**IN3-E+GL5**	126.4	410.5
IN1-W+GL7	130.6	399.6	**IN3-E+GL6**	129.9	419.2
IN2-W+GL1	138.1	415.5	**IN3-E+GL7**	124.3	407.8
IN2-W+GL2	138.3	416.3	**IN4-E+GL1**	133.4	482.5
IN2-W+GL3	130.9	400.5	**IN4-E+GL2**	133.9	484.0
IN2-W+GL4	130.6	400.5	**IN4-E+GL3**	124.4	464.2
IN2-W+GL5	130.7	401.9	**IN4-E+GL4**	124.7	465.2
IN2-W+GL6	133.5	409.2	**IN4-E+GL5**	125.3	467.5
IN2-W+GL7	128.8	399.5	**IN4-E+GL6**	129.4	477.2
IN3-W+GL1	136.4	422.7	**IN4-E+GL7**	123.2	464.7

Table B.2 : Results of scenarios including IN, GL and BOI or AC retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
BOI	159.6	407.3	**AC**	129.8	419.1
GL3+BOI	140.5	375.9	**GL3+AC**	117.8	403.2
GL4+BOI	140.1	375.6	**GL4+AC**	117.3	402.7
GL5+BOI	140.1	376.7	**GL5+AC**	117.0	403.4
GL6+BOI	142.2	382.7	**GL6+AC**	118.0	406.9
GL7+BOI	138.3	374.8	**GL7+AC**	115.9	402.7
IN2-W+BOI	151.9	446.1	**IN2-W+AC**	122.4	459.2
IN3-W+BOI	150.9	454.7	**IN3-W+AC**	121.2	467.5
IN4-W+BOI	150.3	510.9	**IN4-W+AC**	120.5	523.5
IN2-E+BOI	150.6	450.1	**IN2-E+AC**	121.2	463.4
IN3-E+BOI	149.4	458.2	**IN3-E+AC**	119.8	471.2
IN4-E+BOI	149.1	511.7	**IN4-E+AC**	119.3	529.5
IN2-W+GL7+BOI	128.3	403.8	**IN2-W+GL7+AC**	106.7	439.2
IN3-W+GL3+BOI	128.1	410.9	**IN3-W+GL3+AC**	106.4	446.1
IN3-W+GL4+BOI	128.1	411.4	**IN3-W+GL4+AC**	106.1	446.1
IN3-W+GL5+BOI	128.4	413.1	**IN3-W+GL5+AC**	106.2	447.3
IN3-W+GL7+BOI	126.4	410.5	**IN3-W+GL7+AC**	104.9	446.3
IN4-W+GL7+BOI	125.2	465.4	**IN4-W+GL7+AC**	103.7	501.3
IN2-E+GL7+BOI	126.5	406.7	**IN2-E+GL7+AC**	105.1	442.6
IN3-E+GL3+BOI	125.8	412.8	**IN3-E+GL3+AC**	104.3	448.5
IN3-E+GL4+BOI	125.9	413.4	**IN3-E+GL4+AC**	104.2	448.7
IN3-E+GL5+BOI	126.3	415.3	**IN3-E+GL5+AC**	104.3	450.1
IN3-E+GL7+BOI	124.2	412.6	**IN3-E+GL7+AC**	102.9	448.9
IN4-E+GL7+BOI	123.2	469.7	**IN4-E+GL7+AC**	101.9	506.2

Table B.3 : Results of scenarios including IN, GL, BOI and AC retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
BOI+AC	128.6	427.3
GL3+BOI+AC	116.3	411.0
GL4+BOI+AC	115.9	410.6
GL5+BOI+AC	115.7	411.4
GL6+BOI+AC	116.9	415.2
GL7+BOI+AC	114.6	410.8
IN2-W+BOI+AC	122.0	468.6
IN3-W+BOI+AC	120.9	477.1
IN4-W+BOI+AC	120.4	533.3
IN2-E+BOI+AC	120.9	472.9
IN3-E+BOI+AC	119.6	481.1
IN4-E+BOI+AC	119.2	534.4
IN2-W+GL7+BOI+AC	106.3	443.5
IN3-W+GL3+BOI+AC	106.0	450.5
IN3-W+GL4+BOI+AC	105.8	450.6
IN3-W+GL5+BOI+AC	105.9	451.9
IN3-W+GL7+BOI+AC	104.6	450.9
IN4-W+GL7+BOI+AC	103.6	506.0
IN2-E+GL7+BOI+AC	104.8	447.1
IN3-E+GL3+BOI+AC	104.1	453.2
IN3-E+GL4+BOI+AC	104.0	453.5
IN3-E+GL5+BOI+AC	104.2	454.9
IN3-E+GL7+BOI+AC	102.8	453.8
IN4-E+GL7+BOI+AC	101.9	511.2

Table B.4 : Results of scenarios including IN, GL, AC and LED retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL3+LED	128.0	352.3	**GL3+AC+LED**	104.9	387.9
GL4+LED	127.4	351.8	**GL4+AC+LED**	104.4	387.2
GL5+LED	127.3	352.6	**GL5+AC+LED**	104.1	387.8
GL6+LED	129.1	358.0	**GL6+AC+LED**	104.9	391.1
GL7+LED	125.5	350.6	**GL7+AC+LED**	102.9	387.1
IN2-W+GL7+LED	113.7	381.6	**IN2-W+GL7+AC+LED**	92.9	422.2
IN3-W+GL3+LED	113.3	388.4	**IN3-W+GL3+AC+LED**	92.5	428.8
IN3-W+GL4+LED	113.0	388.4	**IN3-W+GL4+AC+LED**	92.1	428.6
IN3-W+GL5+LED	113.2	389.8	**IN3-W+GL5+AC+LED**	92.1	429.6
IN3-W+GL7+LED	111.1	387.1	**IN3-W+GL7+AC+LED**	90.7	428.5
IN4-W+GL7+LED	109.3	440.8	**IN4-W+GL7+AC+LED**	89.1	482.7
IN2-E+GL7+LED	111.5	383.9	**IN2-E+GL7+AC+LED**	91.1	425.3
IN3-E+GL3+LED	110.5	389.4	**IN3-E+GL3+AC+LED**	90.2	430.8
IN3-E+GL4+LED	110.4	389.6	**IN3-E+GL4+AC+LED**	89.9	430.8
IN3-E+GL5+LED	110.6	391.1	**IN3-E+GL5+AC+LED**	89.9	431.9
IN3-E+GL7+LED	108.4	388.3	**IN3-E+GL7+AC+LED**	88.4	430.6
IN4-E+GL7+LED	106.6	443.9	**IN4-E+GL7+AC+LED**	86.9	486.8

Table B.5 : Results of scenarios including GL, CHW, LED and SHD retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
SHD1	151.4	399.7
SHD2	141.9	457.6
GL3+CHW+LED+SHD2	104.5	397.3
GL4+CHW+LED+SHD2	104.2	397.3
GL5+CHW+LED+SHD2	104.0	398.0
GL6+CHW+LED+SHD2	104.5	400.5
GL7+CHW+LED+SHD2	103.2	398.0

Table B.6 : Results of scenarios including IN, GL, AC, CHW and LED retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL3+AC+CHW	99.2	359.2	**GL3+AC+CHW+LED**	86.4	343.8	**GL3+CHW+LED**	109.4	308.2
GL4+AC+CHW	98.7	358.6	**GL4+AC+CHW+LED**	85.8	343.1	**GL4+CHW+LED**	108.8	307.6
GL5+AC+CHW	98.5	359.3	**GL5+AC+CHW+LED**	85.5	343.7	**GL5+CHW+LED**	108.7	308.5
GL6+AC+CHW	99.5	362.8	**GL6+AC+CHW+LED**	86.3	347.0	**GL6+CHW+LED**	110.5	313.9
GL7+AC+CHW	97.3	358.6	**GL7+AC+CHW+LED**	84.3	343.0	**GL7+CHW+LED**	106.9	306.5
IN2-W+GL7+AC+CHW	88.1	395.0	**IN2-W+GL7+AC+CHW+LED**	74.3	377.9	**IN2-W+GL7+CHW+LED**	95.0	337.3
IN3-W+GL3+AC+CHW	87.8	401.9	**IN3-W+GL3+AC+CHW+LED**	73.8	384.6	**IN3-W+GL3+CHW+LED**	94.7	344.1
IN3-W+GL4+AC+CHW	87.5	401.9	**IN3-W+GL4+AC+CHW+LED**	73.5	384.4	**IN3-W+GL4+CHW+LED**	94.4	344.2
IN3-W+GL5+AC+CHW	87.6	403.1	**IN3-W+GL5+AC+CHW+LED**	73.4	385.4	**IN3-W+GL5+CHW+LED**	94.5	345.6
IN3-W+GL7+AC+CHW	86.2	402.0	**IN3-W+GL7+AC+CHW+LED**	72.0	384.2	**IN3-W+GL7+CHW+LED**	92.4	342.9
IN4-W+GL7+AC+CHW	85.1	457.0	**IN4-W+GL7+AC+CHW+LED**	70.5	438.5	**IN4-W+GL7+CHW+LED**	90.6	396.6
IN2-E+GL7+AC+CHW	86.5	398.5	**IN2-E+GL7+AC+CHW+LED**	72.5	381.1	**IN2-E+GL7+CHW+LED**	92.9	339.7
IN3-E+GL3+AC+CHW	85.7	404.4	**IN3-E+GL3+AC+CHW+LED**	71.6	386.7	**IN3-E+GL3+CHW+LED**	91.9	345.3
IN3-E+GL4+AC+CHW	85.6	404.6	**IN3-E+GL4+AC+CHW+LED**	71.3	386.6	**IN3-E+GL4+CHW+LED**	91.8	345.4
IN3-E+GL5+AC+CHW	85.7	406.0	**IN3-E+GL5+AC+CHW+LED**	71.3	387.8	**IN3-E+GL5+CHW+LED**	92.0	347.0
IN3-E+GL7+AC+CHW	84.4	404.8	**IN3-E+GL7+AC+CHW+LED**	69.8	386.5	**IN3-E+GL7+CHW+LED**	89.8	344.1
IN4-E+GL7+AC+CHW	83.3	462.0	**IN4-E+GL7+AC+CHW+LED**	68.3	442.6	**IN4-E+GL7+CHW+LED**	88.0	399.7

Table B.7 : Results of scenarios including IN, GL, AC, CHW, LED and SP retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL3+CHW+LED+SP	99.9	314.6	**GL3+AC+CHW+LED+SP**	77.0	350.4
GL4+CHW+LED+SP	99.4	314.1	**GL4+AC+CHW+LED+SP**	76.4	349.8
GL5+CHW+LED+SP	99.2	314.9	**GL5+AC+CHW+LED+SP**	76.1	350.4
GL6+CHW+LED+SP	101.0	320.2	**GL6+AC+CHW+LED+SP**	76.9	353.6
GL7+CHW+LED+SP	97.5	312.9	**GL7+AC+CHW+LED+SP**	74.9	349.7
IN2-W+GL7+CHW+LED+SP	85.6	343.7	**IN2-W+GL7+AC+CHW+LED+SP**	65.0	384.7
IN3-W+GL3+CHW+LED+SP	85.2	350.5	**IN3-W+GL3+AC+CHW+LED+SP**	65.3	392.5
IN3-W+GL4+CHW+LED+SP	84.9	350.5	**IN3-W+GL4+AC+CHW+LED+SP**	64.1	391.1
IN3-W+GL5+CHW+LED+SP	85.0	351.9	**IN3-W+GL5+AC+CHW+LED+SP**	64.1	392.1
IN3-W+GL7+CHW+LED+SP	82.9	349.1	**IN3-W+GL7+AC+CHW+LED+SP**	62.6	390.8
IN4-W+GL7+CHW+LED+SP	81.1	402.9			
IN2-E+GL7+CHW+LED+SP	83.6	346.5	**IN2-E+GL7+AC+CHW+LED+SP**	63.3	388.0
IN3-E+GL3+CHW+LED+SP	82.7	352.2	**IN3-E+GL3+AC+CHW+LED+SP**	62.4	393.7
IN3-E+GL4+CHW+LED+SP	82.5	352.4	**IN3-E+GL4+AC+CHW+LED+SP**	62.1	393.7
IN3-E+GL5+CHW+LED+SP	82.7	353.9	**IN3-E+GL5+AC+CHW+LED+SP**	62.1	394.8
IN3-E+GL7+CHW+LED+SP	80.6	351.1	**IN3-E+GL7+AC+CHW+LED+SP**	60.6	393.5
IN4-E+GL7+CHW+LED+SP	78.8	406.8			

Table B.8 : Results of scenarios including IN, GL, AC, LED, SHD2 and SP retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL3+AC+SHD2	114.8	496.5	**GL3+AC+CHW+LED+SHD2**	83.1	436.4	**GL3+AC+CHW+LED+SHD2+SP**	73.7	443.1
GL4+AC+SHD2	114.4	496.3	**GL4+AC+CHW+LED+SHD2**	82.7	436.2	**GL4+AC+CHW+LED+SHD2+SP**	73.3	442.9
GL5+AC+SHD2	114.2	496.9	**GL5+AC+CHW+LED+SHD2**	82.4	436.7	**GL5+AC+CHW+LED+SHD2+SP**	73.0	443.4
GL6+AC+SHD2	114.0	498.1	**GL6+AC+CHW+LED+SHD2**	82.4	438.1	**GL6+AC+CHW+LED+SHD2+SP**	73.0	444.8
GL7+AC+SHD2	113.8	497.8	**GL7+AC+CHW+LED+SHD2**	81.9	437.4	**GL7+AC+CHW+LED+SHD2+SP**	72.5	444.1
IN2-W+GL7+AC+SHD2	104.3	533.8	**IN2-W+GL7+AC+ CHW+LED+SHD2**	71.7	471.9	**IN2-W+GL7+AC+ CHW+LED+SHD2+SP**	62.3	478.6
IN3-W+GL3+AC+SHD2	103.0	538.5	**IN3-W+GL3+AC+ CHW+LED+SHD2**	70.2	476.5	**IN3-W+GL3+AC+ CHW+LED+SHD2+SP**	60.9	483.2
IN3-W+GL4+AC+SHD2	102.9	538.8	**IN3-W+GL4+AC+ CHW+LED+SHD2**	70.0	476.6	**IN3-W+GL4+AC+ CHW+LED+SHD2+SP**	60.7	483.3
IN3-W+GL5+AC+SHD2	102.9	539.9	**IN3-W+GL5+AC+ CHW+LED+SHD2**	69.9	477.5	**IN3-W+GL5+AC+ CHW+LED+SHD2+SP**	60.6	484.2
IN3-W+GL7+AC+SHD2	102.4	540.6	**IN3-W+GL7+AC+ CHW+LED+SHD2**	69.2	477.9	**IN3-W+GL7+AC+ CHW+LED+SHD2+SP**	59.9	484.6
IN4-W+GL7+AC+SHD2	101.2	595.4	**IN4-W+GL7+AC+ CHW+LED+SHD2**	67.6	531.8	**IN4-W+GL7+AC+ CHW+LED+SHD2+SP**	58.2	538.5
IN2-E+GL7+AC+SHD2	102.6	537.0	**IN2-E+GL7+AC+ CHW+LED+SHD2**	69.8	474.8	**IN2-E+GL7+AC+ CHW+LED+SHD2+SP**	60.5	481.8
IN3-E+GL3+AC+SHD2	100.8	540.6	**IN3-E+GL3+AC+ CHW+LED+SHD2**	67.4	477.3	**IN3-E+GL3+AC+ CHW+LED+SHD2+SP**	58.6	485.3
IN3-E+GL4+AC+SHD2	100.8	541.1	**IN3-E+GL4+AC+ CHW+LED+SHD2**	67.7	478.5	**IN3-E+GL4+AC+ CHW+LED+SHD2+SP**	58.5	485.6
IN3-E+GL5+AC+SHD2	100.9	542.4	**IN3-E+GL5+AC+ CHW+LED+SHD2**	67.6	479.5	**IN3-E+GL5+AC+ CHW+LED+SHD2+SP**	58.4	486.6
IN3-E+GL7+AC+SHD2	100.4	543.0	**IN3-E+GL7+AC+ CHW+LED+SHD2**	66.9	479.9	**IN3-E+GL7+AC+ CHW+LED+SHD2+SP**	57.8	486.9
IN4-E+GL7+AC+SHD2	99.2	599.9	**IN4-E+GL7+AC+ CHW+LED+SHD2**	65.2	535.6	**IN4-E+GL7+AC+ CHW+LED+SHD2+SP**	56.0	542.8

Table B.9 : Results of scenarios including IN, GL, LED, SP and PV retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
PV	150.3	387.4			
GL3+CHW+ LED+PV	98.9	297.2	**GL3+CHW+ LED+SP+PV**	89.4	303.6
GL4+CHW+ LED+PV	98.3	296.7	**GL4+CHW+ LED+SP+PV**	88.9	303.1
GL5+CHW+ LED+PV	98.1	297.5	**GL5+CHW+ LED+SP+PV**	88.7	303.9
GL6+CHW+ LED+PV	100.0	302.9	**GL6+CHW+ LED+SP+PV**	90.4	309.3
GL7+CHW+ LED+PV	96.4	295.5	**GL7+CHW+ LED+SP+PV**	86.9	301.9
IN4-W+GL7+ CHW+LED+PV	84.5	326.4	**IN2-W+GL7+ CHW+LED+SP+PV**	75.0	332.8
IN3-W+GL3+ CHW+LED+PV	84.1	333.2	**IN3-W+GL3+ CHW+LED+SP+PV**	74.6	339.6
IN3-W+GL4+ CHW+LED+PV	83.9	333.2	**IN3-W+GL4+ CHW+LED+SP+PV**	74.4	339.6
IN3-W+GL5+ CHW+LED+PV	84.0	334.6	**IN3-W+GL5+ CHW+LED+SP+PV**	74.5	341.0
IN3-W+GL7+ CHW+LED+PV	81.9	331.9	**IN3-W+GL7+ CHW+LED+SP+PV**	72.3	338.2
IN4-W+GL7+ CHW+LED+PV	80.1	385.6	**IN4-W+GL7+ CHW+LED+SP+PV**	70.6	391.9
IN2-E+GL7+ CHW+LED+PV	82.4	328.8	**IN2-E+GL7+ CHW+LED+SP+PV**	73.1	335.5
IN3-E+GL3+ CHW+LED+PV	81.4	334.3	**IN3-E+GL3+ CHW+LED+SP+PV**	72.1	341.2
IN3-E+GL4+ CHW+LED+PV	81.2	334.5	**IN3-E+GL4+ CHW+LED+SP+PV**	72.0	341.4
IN3-E+GL5+ CHW+LED+PV	81.4	336.0	**IN3-E+GL5+ CHW+LED+SP+PV**	72.2	343.0
IN3-E+GL7+ CHW+LED+PV	79.3	333.2	**IN3-E+GL7+ CHW+LED+SP+PV**	70.0	340.1
IN4-E+GL7+ CHW+LED+PV	77.4	388.8	**IN4-E+GL7+ CHW+LED+SP+PV**	68.2	395.8

Table B.10 : Results of scenarios including IN, GL, LED, SP and PV retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL3+AC+CHW+ LED+SP+PV	66.5	339.5	**IN2-W+GL7+AC+CHW+ LED+SHD2+SP+PV**	51.7	467.6
GL4+AC+CHW+ LED+SP+PV	65.9	338.8	**IN3-W+GL3+AC+CHW+ LED+SHD2+SP+PV**	50.3	472.2
GL5+AC+CHW+ LED+SP+PV	65.6	339.4	**IN3-W+GL4+AC+CHW+ LED+SHD2+SP+PV**	50.1	472.3
GL6+AC+CHW+ LED+SP+PV	66.4	342.7	**IN3-W+GL5+AC+CHW+ LED+SHD2+SP+PV**	50.0	473.2
GL7+AC+CHW+ LED+SP+PV	64.4	338.7	**IN3-W+GL7+AC+CHW+ LED+SHD2+SP+PV**	49.4	473.6
IN2-W+GL7+AC+ CHW+LED+SP+PV	54.4	373.7	**IN4-W+GL7+AC+CHW+ LED+SHD2+SP+PV**	47.7	527.6
IN3-W+GL3+AC+ CHW+LED+SP+PV	54.7	381.5	**IN2-E+GL7+AC+CHW+ LED+SHD2+SP+PV**	50.0	470.8
IN3-W+GL4+AC+ CHW+LED+SP+PV	53.6	380.1	**IN3-E+GL3+AC+CHW+ LED+SHD2+SP+PV**	48.1	474.4
IN3-W+GL5+AC+ CHW+LED+SP+PV	53.5	381.1	**IN3-E+GL4+AC+CHW+ LED+SHD2+SP+PV**	47.9	474.6
IN3-W+GL7+AC+ CHW+LED+SP+PV	52.1	379.9	**IN3-E+GL5+AC+CHW+ LED+SHD2+SP+PV**	47.9	475.6
IN2-E+GL7+AC+ CHW+LED+SP+PV	52.7	377.1	**IN3-E+GL7+AC+CHW+ LED+SHD2+SP+PV**	47.2	476.0
IN3-E+GL3+AC+ CHW+LED+SP+PV	51.8	382.8	**IN4-E+GL7+AC+CHW+ LED+SHD2+SP+PV**	45.5	531.8
IN3-E+GL4+AC+ CHW+LED+SP+PV	51.5	382.7			
IN3-E+GL5+AC+ CHW+LED+SP+PV	51.5	383.8			
IN3-E+GL7+AC+ CHW+LED+SP+PV	50.1	382.6			

Table B.11 : Results of scenarios including IN, GL, VRV, CHW, LED and SP retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL3+VRV+CHW+LED	74.2	313.8	**GL3+VRV+CHW+LED+SP**	65.0	320.6
GL4+VRV+CHW+LED	73.6	313.1	**GL4+VRV+CHW+LED+SP**	64.3	319.9
GL5+VRV+CHW+LED	73.2	313.5	**GL5+VRV+CHW+LED+SP**	64.0	320.3
GL6+VRV+CHW+LED	73.5	315.5	**GL6+VRV+CHW+LED+SP**	64.2	322.4
GL7+VRV+CHW+LED	72.4	313.4	**GL7+VRV+CHW+LED+SP**	63.1	320.3
IN2-W+GL7+VRV+CHW+LED	63.4	350.7	**IN2-W+GL7+VRV+CHW+LED+SP**	54.2	357.6
IN3-W+GL3+VRV+CHW+LED	62.9	357.3	**IN3-W+GL3+VRV+CHW+LED+SP**	53.7	364.2
IN3-W+GL4+VRV+CHW+LED	62.5	357.0	**IN3-W+GL4+VRV+CHW+LED+SP**	53.3	363.8
IN3-W+GL5+VRV+CHW+LED	62.4	357.7	**IN3-W+GL5+VRV+CHW+LED+SP**	53.1	364.6
IN3-W+GL7+VRV+CHW+LED	61.3	357.3	**IN3-W+GL7+VRV+CHW+LED+SP**	52.1	364.2
IN4-W+GL7+VRV+CHW+LED	60.1	412.2	**IN4-W+GL7+VRV+CHW+LED+SP**	50.8	419.1
IN2-E+GL7+VRV+CHW+LED	61.9	354.4	**IN2-E+GL7+VRV+CHW+LED+SP**	52.7	361.4
IN3-E+GL3+VRV+CHW+LED	61.0	360.1	**IN3-E+GL3+VRV+CHW+LED+SP**	51.8	367.1
IN3-E+GL4+VRV+CHW+LED	60.6	359.8	**IN3-E+GL4+VRV+CHW+LED+SP**	51.4	366.9
IN3-E+GL5+VRV+CHW+LED	60.5	360.7	**IN3-E+GL5+VRV+CHW+LED+SP**	51.3	367.8
IN3-E+GL7+VRV+CHW+LED	59.4	360.3	**IN3-E+GL7+VRV+CHW+LED+SP**	50.3	367.4
IN4-E+GL7+VRV+CHW+LED	58.1	417.0	**IN4-E+GL7+VRV+CHW+LED+SP**	49.0	424.2

Table B.12 : Results of scenarios including IN, GL, VRV, CHW, LED SP and PV retrofits in Antalya.

Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)	Scenario	Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL3+VRV+CHW+LED+PV	63.7	302.8	**GL3+VRV+CHW+LED+SP+PV**	54.4	309.7
GL4+VRV+CHW+LED+PV	63.0	302.1	**GL4+VRV+CHW+LED+SP+PV**	53.8	309.0
GL5+VRV+CHW+LED+PV	62.7	302.5	**GL5+VRV+CHW+LED+SP+PV**	53.4	309.4
GL6+VRV+CHW+LED+PV	63.0	304.6	**GL6+VRV+CHW+LED+SP+PV**	53.7	311.4
GL7+VRV+CHW+LED+PV	61.8	302.5	**GL7+VRV+CHW+LED+SP+PV**	52.6	309.4
IN2-W+GL7+VRV+CHW+LED+PV	52.9	339.7	**IN2-W+GL7+VRV+CHW+LED+SP+PV**	43.6	346.6
IN3-W+GL3+VRV+CHW+LED+PV	52.4	346.3	**IN3-W+GL3+VRV+CHW+LED+SP+PV**	43.1	353.2
IN3-W+GL4+VRV+CHW+LED+PV	52.0	346.0	**IN3-W+GL4+VRV+CHW+LED+SP+PV**	42.7	352.9
IN3-W+GL5+VRV+CHW+LED+PV	51.8	346.8	**IN3-W+GL5+VRV+CHW+LED+SP+PV**	42.6	353.7
IN3-W+GL7+VRV+CHW+LED+PV	50.8	346.4	**IN3-W+GL7+VRV+CHW+LED+SP+PV**	41.5	353.3
IN4-W+GL7+VRV+CHW+LED+PV	49.5	401.3	**IN4-W+GL7+VRV+CHW+LED+SP+PV**	40.2	408.2
IN2-E+GL7+VRV+CHW+LED+PV	51.4	343.5	**IN2-E+GL7+VRV+CHW+LED+SP+PV**	42.2	350.5
IN3-E+GL3+VRV+CHW+LED+PV	50.4	349.1	**IN3-E+GL3+VRV+CHW+LED+SP+PV**	41.2	356.2
IN3-E+GL4+VRV+CHW+LED+PV	50.1	348.9	**IN3-E+GL4+VRV+CHW+LED+SP+PV**	40.9	356.0
IN3-E+GL5+VRV+CHW+LED+PV	50.0	349.8	**IN3-E+GL5+VRV+CHW+LED+SP+PV**	40.8	356.9
IN3-E+GL7+VRV+CHW+LED+PV	48.9	349.3	**IN3-E+GL7+VRV+CHW+LED+SP+PV**	39.7	356.4
IN4-E+GL7+VRV+CHW+LED+PV	47.6	406.1	**IN4-E+GL7+VRV+CHW+LED+SP+PV**	38.4	413.2
			IN4-W+GL7+VRV+CHW+ LED+SP+SHD2+PV	38.2	503.3
			IN4-E+GL7+VRV+CHW+ LED+SP+SHD2+PV	36.2	508.1

APPENDIX C: Primary energy consumption and global cost results for the RB retrofit scenarios in Erzurum

Table C.1 : Results of envelope retrofit scenarios in Erzurum.

	Primary Energy (kWh/m²y)	Global Cost (TL/m²)		Primary Energy (kWh/m²y)	Global Cost (TL/m²)
BASE	216.3	437.4	**IN3-W+GL3**	153.5	469.2
IN1-W	173.5	437.0	**IN3-W+GL4**	150.2	465.0
IN2-W	168.8	440.3	**IN3-W+GL5**	147.9	462.9
IN3-W	163.9	479.4	**IN3-W+GL6**	145.7	461.8
IN4-W	160.3	511.8	**IN3-W+GL7**	145.9	461.4
IN1-F	213.2	437.7	**IN4-W+GL1**	150.7	503.7
IN2-F	212.8	437.4	**IN4-W+GL2**	148.7	501.5
IN3-F	212.5	437.3	**IN4-W+GL3**	149.4	500.7
IN4-F	212.2	437.7	**IN4-W+GL4**	146.1	496.6
IN1-R	213.0	434.2	**IN4-W+GL5**	143.9	494.6
IN2-R	212.6	434.7	**IN4-W+GL6**	141.6	493.4
IN3-R	212.3	434.7	**IN4-W+GL7**	141.9	493.1
IN4-R	212.0	434.9	**IN1-E+GL1**	158.3	427.5
IN1-E	167.6	435.0	**IN1-E+GL2**	156.3	425.1
IN2-E	162.2	438.8	**IN1-E+GL3**	157.4	425.3
IN3-E	156.9	478.2	**IN1-E+GL4**	154.1	421.0
IN4-E	152.8	511.6	**IN1-E+GL5**	151.8	418.8
GL1	209.3	434.3	**IN1-E+GL6**	149.2	417.0
GL2	207.1	431.5	**IN1-E+GL7**	149.8	417.3
GL3	209.8	434.9	**IN2-E+GL1**	152.6	430.7
GL4	206.3	430.3	**IN2-E+GL2**	150.7	428.4
GL5	203.9	427.7	**IN2-E+GL3**	151.4	427.9
GL6	200.5	424.3	**IN2-E+GL4**	148.2	423.8
GL7	202.1	426.7	**IN2-E+GL5**	145.9	421.7
IN1-W+GL1	164.7	430.4	**IN2-E+GL6**	143.5	420.3
IN1-W+GL2	162.7	427.9	**IN2-E+GL7**	143.8	420.1
IN1-W+GL3	164.1	428.8	**IN3-E+GL1**	146.9	469.4
IN1-W+GL4	160.8	424.4	**IN3-E+GL2**	145.0	467.3
IN1-W+GL5	158.4	422.1	**IN3-E+GL3**	145.4	465.9
IN1-W+GL6	155.6	419.9	**IN3-E+GL4**	142.2	461.9
IN1-W+GL7	156.4	420.7	**IN3-E+GL5**	140.0	460.0
IN2-W+GL1	159.8	433.2	**IN3-E+GL6**	137.8	459.1
IN2-W+GL2	157.7	430.7	**IN3-E+GL7**	137.9	458.4
IN2-W+GL3	158.9	431.2	**IN4-E+GL1**	142.5	502.2
IN2-W+GL4	155.6	426.8	**IN4-E+GL2**	140.7	500.2
IN2-W+GL5	153.3	424.6	**IN4-E+GL3**	140.7	498.2
IN2-W+GL6	150.7	422.7	**IN4-E+GL4**	137.6	494.4
IN2-W+GL7	151.3	423.2	**IN4-E+GL5**	135.5	492.6
IN3-W+GL1	154.6	471.7	**IN4-E+GL6**	133.5	492.2
IN3-W+GL2	152.6	469.4	**IN4-E+GL7**	133.3	490.9

Table C.2 : Results of scenarios including IN, GL, BOI or AC retrofits in Erzurum.

	Primary Energy (kWh/m²y)	Global Cost (TL/m²)		Primary Energy (kWh/m²y)	Global Cost (TL/m²)
BOI	197.1	423.0	**AC**	212.2	510.6
GL6+BOI	183.1	412.5			
GL7+BOI	184.3	414.3			
IN1-W+BOI	161.5	427.8	**IN1+AC**	168.1	507.1
IN2-W+BOI	157.6	433.7	**IN2-W+AC**	163.1	509.9
IN3-W+BOI	153.7	474.1	**IN3-W+AC**	157.9	548.3
IN4-W+BOI	150.7	507.6	**IN4-W+AC**	154.0	580.1
IN1-E+BOI	156.6	428.8	**IN1-E+AC**	161.7	504.2
IN2-E+BOI	152.3	434.1	**IN2-E+AC**	156.0	507.2
IN3-E+BOI	147.9	474.9	**IN3-E+AC**	150.2	545.7
IN4-E+BOI	144.7	509.5	**IN4-E+AC**	145.7	578.2
IN1-W+GL6+BOI	145.5	414.9	**IN1-W+GL6+AC**	151.9	493.9
IN2-W+GL6+BOI	141.4	419.0	**IN2-W+GL6+AC**	146.7	496.2
IN2-W+GL7+BOI	141.6	418.8	**IN2-W+GL7+AC**	148.2	498.4
IN3-W+GL5+BOI	139.0	459.5	**IN3-W+GL5+AC**	144.4	537.2
IN3-W+GL6+BOI	137.2	459.0	**IN3-W+GL6+AC**	141.3	534.3
IN3-W+GL7+BOI	137.2	458.4	**IN3-W+GL7+AC**	142.6	536.1
IN4-W+GL5+BOI	135.6	492.3	**IN4-W+GL5+AC**	140.1	568.5
IN4-W+GL6+BOI	134.0	492.1	**IN4-W+GL6+AC**	137.2	565.8
IN4-W+GL7+BOI	133.8	491.1	**IN4-W+GL7+AC**	138.3	567.3
IN1-E+GL6+BOI	140.2	413.7	**IN1-E+GL6+AC**	145.1	490.2
IN2-E+GL6+BOI	135.5	418.4	**IN2-E+GL6+AC**	139.1	492.7
IN2-E+GL7+BOI	135.4	417.6	**IN2-E+GL7+AC**	140.3	494.5
IN3-E+GL5+BOI	132.4	458.7	**IN3-E+GL5+AC**	135.9	533.2
IN3-E+GL6+BOI	130.9	458.8	**IN3-E+GL6+AC**	133.1	530.7
IN3-E+GL7+BOI	130.5	457.4	**IN3-E+GL7+AC**	134.0	532.0
IN4-E+GL5+BOI	128.7	492.5	**IN4-E+GL5+AC**	131.1	565.1
IN4-E+GL6+BOI	127.4	493.1	**IN4-E+GL6+AC**	128.4	562.9
IN4-E+GL7+BOI	126.8	491.2	**IN4-E+GL7+AC**	129.1	563.8

Table C.3 : Results of scenarios including IN, GL, BOI and AC retrofits in Erzurum.

	Primary Energy (kWh/m²y)	**Global Cost (TL/m²)**
BOI+AC	193.2	496.5
GL6+BOI+AC	180.5	488.8
GL7+BOI+AC	182.2	491.7
IN1-W+BOI+AC	156.1	499.3
IN2-W+BOI+AC	151.9	503.3
IN3-W+BOI+AC	147.6	543.0
IN4-W+BOI+AC	144.4	575.8
IN1-E+BOI+AC	150.7	497.9
IN2-E+BOI+AC	146.0	502.4
IN3-E+BOI+AC	141.2	542.4
IN4-E+BOI+AC	137.6	576.1
IN1-W+GL6+BOI+AC	141.8	488.9
IN2-W+GL6+BOI+AC	137.5	492.5
IN2-W+GL7+BOI+AC	138.5	494.0
IN3-W+GL5+BOI+AC	135.4	533.8
IN3-W+GL6+BOI+AC	133.0	531.9
IN3-W+GL7+BOI+AC	133.8	533.1
IN4-W+GL5+BOI+AC	131.9	566.1
IN4-W+GL6+BOI+AC	129.6	564.4
IN4-W+GL7+BOI+AC	130.2	565.3
IN1-E+GL6+BOI+AC	136.2	486.9
IN2-E+GL6+BOI+AC	131.1	490.9
IN2-E+GL7+BOI+AC	131.9	492.0
IN3-E+GL5+BOI+AC	128.3	531.9
IN3-E+GL6+BOI+AC	126.1	530.4
IN3-E+GL7+BOI+AC	126.7	531.1
IN4-E+GL5+BOI+AC	124.3	565.0
IN4-E+GL6+BOI+AC	122.3	563.8
IN4-E+GL7+BOI+AC	122.6	564.1

Table C.4 : Results of scenarios including IN, GL, BOI, CHW or LED retrofits in Erzurum.

	Primary Energy (kWh/m²y)	Global Cost (TL/m²)		Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL6+BOI+CHW	152.1	337.5			
GL7+BOI+CHW	153.2	336.5			
IN1-W+GL6+BOI+CHW	114.3	339.6	**IN1-W+GL6+BOI+LED**	134.1	401.5
IN1-W+GL7+BOI+CHW	114.7	339.7	**IN1-W+GL7+BOI+LED**	134.7	402.0
IN2-W+GL6+BOI+CHW	110.2	343.7	**IN2-W+GL6+BOI+LED**	129.9	405.3
IN2-W+GL7+BOI+CHW	110.4	343.4	**IN2-W+GL7+BOI+LED**	130.3	405.5
IN3-W+GL5+BOI+CHW	107.7	384.1	**IN3-W+GL5+BOI+LED**	127.5	446.0
IN3-W+GL6+BOI+CHW	105.9	383.6	**IN3-W+GL6+BOI+LED**	125.5	444.9
IN3-W+GL7+BOI+CHW	105.9	382.9	**IN3-W+GL7+BOI+LED**	125.7	444.8
IN4-W+GL5+BOI+CHW	104.4	416.8	**IN4-W+GL5+BOI+LED**	124.1	478.5
IN4-W+GL6+BOI+CHW	102.8	416.7	**IN4-W+GL6+BOI+LED**	122.2	477.8
IN4-W+GL7+BOI+CHW	102.6	415.6	**IN4-W+GL7+BOI+LED**	122.2	477.2
IN1-E+GL6+BOI+CHW	109.0	338.5	**IN1-E+GL6+BOI+LED**	128.7	399.9
IN1-E+GL7+BOI+CHW	109.1	338.0	**IN1-E+GL7+BOI+LED**	129.0	399.9
IN2-E+GL6+BOI+CHW	104.3	343.2	**IN2-E+GL6+BOI+LED**	123.8	404.3
IN2-E+GL7+BOI+CHW	104.2	342.3	**IN2-E+GL7+BOI+LED**	123.9	403.9
IN3-E+GL5+BOI+CHW	101.2	383.4	**IN3-E+GL5+BOI+LED**	120.7	444.7
IN3-E+GL6+BOI+CHW	99.7	383.5	**IN3-E+GL6+BOI+LED**	118.9	444.2
IN3-E+GL7+BOI+CHW	99.3	382.1	**IN3-E+GL7+BOI+LED**	118.8	443.3
IN4-E+GL5+BOI+CHW	97.5	417.3			
IN4-E+GL6+BOI+CHW	96.3	417.8	**IN4-E+GL6+BOI+LED**	115.3	478.1
IN4-E+GL7+BOI+CHW	95.6	415.9			

Table C.5 : Results of scenarios including IN, GL, BOI, CHW, LED and SP retrofits in Erzurum.

	Primary Energy (kWh/m²y)	Global Cost (TL/m²)		Primary Energy (kWh/m²y)	Global Cost (TL/m²)
GL6+BOI+CHW+LED	141.3	321.4	**GL6+BOI+CHW+LED+SP**	129.4	327.1
GL7+BOI+CHW+LED	142.6	323.4	**GL7+BOI+CHW+LED+SP**	130.7	329.2
IN1-W+GL6+BOI+CHW+LED	102.9	326.1	**IN1-W+GL6+BOI+CHW+LED+SP**	91.1	328.1
IN1-W+GL7+BOI+CHW+LED	103.4	326.5			
IN2-W+GL6+BOI+CHW+LED	98.6	329.9	**IN2-W+GL6+BOI+CHW+LED+SP**	86.8	331.9
IN2-W+GL7+BOI+CHW+LED	99.0	330.0	**IN2-W+GL7+BOI+CHW+LED+SP**	87.3	332.1
IN3-W+GL5+BOI+CHW+LED	96.2	370.5	**IN3-W+GL5+BOI+CHW+LED+SP**	84.4	372.6
IN3-W+GL6+BOI+CHW+LED	94.2	369.5	**IN3-W+GL6+BOI+CHW+LED+SP**	82.4	371.5
IN3-W+GL7+BOI+CHW+LED	94.4	369.2	**IN3-W+GL7+BOI+CHW+LED+SP**	82.6	371.4
IN4-W+GL5+BOI+CHW+LED	92.8	403.0	**IN4-W+GL5+BOI+CHW+LED+SP**	81.0	405.1
IN4-W+GL6+BOI+CHW+LED	90.9	402.3	**IN4-W+GL6+BOI+CHW+LED+SP**	79.1	404.3
IN4-W+GL7+BOI+CHW+LED	90.9	401.7	**IN4-W+GL7+BOI+CHW+LED+SP**	79.2	403.8
IN1-E+GL6+BOI+CHW+LED	97.4	324.6	**IN1-E+GL6+BOI+CHW+LED+SP**	85.5	326.5
IN1-E+GL7+BOI+CHW+LED	97.8	324.6			
IN2-E+GL6+BOI+CHW+LED	92.6	329.0	**IN2-E+GL6+BOI+CHW+LED+SP**	80.7	330.9
IN2-E+GL7+BOI+CHW+LED	92.7	328.5	**IN2-E+GL7+BOI+CHW+LED+SP**	80.8	330.5
IN3-E+GL5+BOI+CHW+LED	89.5	369.3	**IN3-E+GL5+BOI+CHW+LED+SP**	77.6	371.2
IN3-E+GL6+BOI+CHW+LED	87.7	368.9	**IN3-E+GL6+BOI+CHW+LED+SP**	75.8	370.8
IN3-E+GL7+BOI+CHW+LED	87.6	367.9	**IN3-E+GL7+BOI+CHW+LED+SP**	75.7	369.9
IN4-E+GL5+BOI+CHW+LED	85.6	402.7	**IN4-E+GL5+BOI+CHW+LED+SP**	73.7	404.7
IN4-E+GL6+BOI+CHW+LED	84.0	402.7	**IN4-E+GL6+BOI+CHW+LED+SP**	72.1	404.7
IN4-E+GL7+BOI+CHW+LED	83.6	401.3	**IN4-E+GL7+BOI+CHW+LED+SP**	71.7	403.3

Table C.6 : Results of scenarios including IN, GL, BOI, CHW, LED, SP and PV retrofits in Erzurum.

	Primary Energy (kWh/m²y)	Global Cost (TL/m²)		Primary Energy (kWh/m²y)	Global Cost (TL/m²)
PV	207.1	416.3			
GL6+BOI+CHW+LED+PV	132.1	313.4	**GL6+BOI+CHW+LED+SP+PV**	120.2	319.1
GL7+BOI+CHW+LED+PV	133.4	315.5	**GL7+BOI+CHW+LED+SP+PV**	121.6	321.3
IN1-W+GL6+BOI+CHW+LED+PV	93.7	318.2	**IN1-W+GL6+BOI+CHW+LED+SP+PV**	81.9	320.2
IN1-W+GL7+BOI+CHW+LED+PV	94.3	318.6			
IN2-W+GL6+BOI+CHW+LED+PV	89.5	321.9	**IN2-W+GL6+BOI+CHW+LED+SP+PV**	77.7	323.9
IN2-W+GL7+BOI+CHW+LED+PV	89.9	322.1	**IN2-W+GL7+BOI+CHW+LED+SP+PV**	78.1	324.2
IN3-W+GL5+BOI+CHW+LED+PV	87.1	362.5	**IN3-W+GL5+BOI+CHW+LED+SP+PV**	75.3	364.6
IN3-W+GL6+BOI+CHW+LED+PV	85.1	361.5	**IN3-W+GL6+BOI+CHW+LED+SP+PV**	73.2	363.6
IN3-W+GL7+BOI+CHW+LED+PV	85.3	361.3	**IN3-W+GL7+BOI+CHW+LED+SP+PV**	73.5	363.4
IN4-W+GL5+BOI+CHW+LED+PV	83.6	395.0	**IN4-W+GL5+BOI+CHW+LED+SP+PV**	71.8	397.1
IN4-W+GL6+BOI+CHW+LED+PV	81.7	394.3	**IN4-W+GL6+BOI+CHW+LED+SP+PV**	69.9	396.4
IN4-W+GL7+BOI+CHW+LED+PV	81.8	393.7	**IN4-W+GL7+BOI+CHW+LED+SP+PV**	70.0	395.9
IN1-E+GL6+BOI+CHW+LED+PV	88.3	316.7	**IN1-E+GL6+BOI+CHW+LED+SP+PV**	76.3	318.5
IN1-E+GL7+BOI+CHW+LED+PV	88.6	316.6			
IN2-E+GL6+BOI+CHW+LED+PV	83.4	321.0	**IN2-E+GL6+BOI+CHW+LED+SP+PV**	71.5	323.0
IN2-E+GL7+BOI+CHW+LED+PV	83.5	320.6	**IN2-E+GL7+BOI+CHW+LED+SP+PV**	71.6	322.5
IN3-E+GL5+BOI+CHW+LED+PV	80.3	361.4	**IN3-E+GL5+BOI+CHW+LED+SP+PV**	68.4	363.3
IN3-E+GL6+BOI+CHW+LED+PV	78.6	360.9	**IN3-E+GL6+BOI+CHW+LED+SP+PV**	66.6	362.9
IN3-E+GL7+BOI+CHW+LED+PV	78.4	360.0	**IN3-E+GL7+BOI+CHW+LED+SP+PV**	66.5	362.0
IN4-E+GL5+BOI+CHW+LED+PV	76.4	394.8	**IN4-E+GL5+BOI+CHW+LED+SP+PV**	64.5	396.8
IN4-E+GL6+BOI+CHW+LED+PV	74.9	394.8	**IN4-E+GL6+BOI+CHW+LED+SP+PV**	63.0	396.8
IN4-E+GL7+BOI+CHW+LED+PV	74.5	393.4	**IN4-E+GL7+BOI+CHW+LED+SP+PV**	62.6	395.4

Table C.7 : Results of scenarios including IN, GL, BOI, CHW, LED, RF, SP and PV retrofits in Erzurum.

	Primary Energy (kWh/m²y)	**Global Cost (TL/m²)**
IN1-W+GL6+BOI+CHW+LED+RF+SP+PV	61.2	354.0
IN2-W+GL6+BOI+CHW+LED+RF+SP+PV	58.7	360.6
IN2-W+GL7+BOI+CHW+LED+RF+SP+PV	57.9	358.9
IN3-W+GL5+BOI+CHW+LED+RF+SP+PV	56.6	401.7
IN3-W+GL6+BOI+CHW+LED+RF+SP+PV	56.1	403.1
IN3-W+GL7+BOI+CHW+LED+RF+SP+PV	55.1	401.0
IN4-W+GL5+BOI+CHW+LED+RF+SP+PV	54.5	436.3
IN4-W+GL6+BOI+CHW+LED+RF+SP+PV	54.2	438.0
IN4-W+GL7+BOI+CHW+LED+RF+SP+PV	53.0	435.6
IN1-E+GL6+BOI+CHW+LED+RF+SP+PV	57.2	354.7
IN2-E+GL6+BOI+CHW+LED+RF+SP+PV	54.2	362.0
IN2-E+GL7+BOI+CHW+LED+RF+SP+PV	53.3	359.9
IN3-E+GL5+BOI+CHW+LED+RF+SP+PV	51.6	403.0
IN3-E+GL6+BOI+CHW+LED+RF+SP+PV	51.3	404.9
IN3-E+GL7+BOI+CHW+LED+RF+SP+PV	50.1	402.3
IN4-E+GL5+BOI+CHW+LED+RF+SP+PV	49.1	438.7
IN4-E+GL6+BOI+CHW+LED+RF+SP+PV	49.1	440.9
IN4-E+GL7+BOI+CHW+LED+RF+SP+PV	47.7	437.9

Table C.8 : Results of scenarios including IN, GL, BOI, CHW, LED, RF and SP retrofits in Erzurum.

	Primary Energy (kWh/m²y)	Global Cost (TL/m²)		Primary Energy (kWh/m²y)	Global Cost (TL/m²)
IN1-W+GL6+BOI+CHW+LED+RF	82.2	359.6	**IN1-W+GL6+BOI+CHW+LED+RF+SP**	70.3	362.0
IN1-W+GL7+BOI+CHW+LED+RF	81.6	358.2			
IN2-W+GL6+BOI+CHW+LED+RF	79.7	366.2	**IN2-W+GL6+BOI+CHW+LED+RF+SP**	67.8	368.5
IN2-W+GL7+BOI+CHW+LED+RF	78.9	364.5	**IN2-W+GL7+BOI+CHW+LED+RF+SP**	67.1	366.8
IN3-W+GL5+BOI+CHW+LED+RF	77.6	407.2	**IN3-W+GL5+BOI+CHW+LED+RF+SP**	65.7	409.6
IN3-W+GL6+BOI+CHW+LED+RF	77.2	408.7	**IN3-W+GL6+BOI+CHW+LED+RF+SP**	65.3	411.0
IN3-W+GL7+BOI+CHW+LED+RF	76.2	406.6	**IN3-W+GL7+BOI+CHW+LED+RF+SP**	64.3	409.0
IN4-W+GL5+BOI+CHW+LED+RF	75.5	441.9	**IN4-W+GL5+BOI+CHW+LED+RF+SP**	63.7	444.3
IN4-W+GL6+BOI+CHW+LED+RF	75.2	443.6	**IN4-W+GL6+BOI+CHW+LED+RF+SP**	63.3	446.0
IN4-W+GL7+BOI+CHW+LED+RF	74.1	441.2	**IN4-W+GL7+BOI+CHW+LED+RF+SP**	62.2	443.6
IN1-E+GL6+BOI+CHW+LED+RF	78.3	360.3	**IN1-E+GL6+BOI+CHW+LED+RF+SP**	66.4	362.7
IN1-E+GL7+BOI+CHW+LED+RF	77.5	358.6			
IN2-E+GL6+BOI+CHW+LED+RF	75.3	367.6	**IN2-E+GL6+BOI+CHW+LED+RF+SP**	63.4	369.9
IN2-E+GL7+BOI+CHW+LED+RF	74.3	365.5	**IN2-E+GL7+BOI+CHW+LED+RF+SP**	62.4	367.8
IN3-E+GL5+BOI+CHW+LED+RF	72.7	408.6	**IN3-E+GL5+BOI+CHW+LED+RF+SP**	60.8	411.0
IN3-E+GL6+BOI+CHW+LED+RF	72.4	410.4	**IN3-E+GL6+BOI+CHW+LED+RF+SP**	60.5	412.8
IN3-E+GL7+BOI+CHW+LED+RF	71.2	407.9	**IN3-E+GL7+BOI+CHW+LED+RF+SP**	59.3	410.3
IN4-E+GL5+BOI+CHW+LED+RF	70.2	444.2	**IN4-E+GL5+BOI+CHW+LED+RF+SP**	58.3	446.6
IN4-E+GL6+BOI+CHW+LED+RF	70.1	446.5	**IN4-E+GL6+BOI+CHW+LED+RF+SP**	58.2	448.9
IN4-E+GL7+BOI+CHW+LED+RF	68.7	443.5	**IN4-E+GL7+BOI+CHW+LED+RF+SP**	56.8	445.9

Table C.9 : Results of scenarios including IN, GL, BOI, CHW, LED, RF, SP and PV retrofits in Erzurum.

	Primary Energy (kWh/m²y)	Global Cost (TL/m²)		Primary Energy (kWh/m²y)	Global Cost (TL/m²)
IN1-E+GL6+BOI+CHW+LED+RF+SP+AC	62.9	437.0	**IN1-E+GL6+BOI+CHW+LED+RF+SP+SHD2**	64.4	458.0
IN2-E+GL6+BOI+CHW+LED+RF+SP+AC	59.6	443.7	**IN2-E+GL6+BOI+CHW+LED+RF+SP+SHD2**	61.2	462.9
IN2-E+GL7+BOI+CHW+LED+RF+SP+AC	59.5	443.4	**IN2-E+GL7+BOI+CHW+LED+RF+SP+SHD2**	61.3	463.1
IN3-E+GL5+BOI+CHW+LED+RF+SP+AC	57.3	485.5	**IN3-E+GL5+BOI+CHW+LED+RF+SP+SHD2**	59.2	507.2
IN3-E+GL6+BOI+CHW+LED+RF+SP+AC	56.4	485.9	**IN3-E+GL6+BOI+CHW+LED+RF+SP+SHD2**	58.1	507.3
IN3-E+GL7+BOI+CHW+LED+RF+SP+AC	56.1	485.2	**IN3-E+GL7+BOI+CHW+LED+RF+SP+SHD2**	58.1	507.2
IN4-E+GL5+BOI+CHW+LED+RF+SP+AC	54.6	520.5	**IN4-E+GL5+BOI+CHW+LED+RF+SP+SHD2**	56.6	542.5
IN4-E+GL6+BOI+CHW+LED+RF+SP+AC	53.7	521.2	**IN4-E+GL6+BOI+CHW+LED+RF+SP+SHD2**	55.6	542.9
IN4-E+GL7+BOI+CHW+LED+RF+SP+AC	53.3	520.2	**IN4-E+GL7+BOI+CHW+LED+RF+SP+SHD2**	55.5	542.6

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