ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A NEW APPROACH TO INCREASE ENERGY EFFICIENCY OF LUXURY HIGH-RISE RESIDENTIAL BUILDINGS THROUGH AN ADVANCED FACADE COMPONENT

PhD THESIS

Gözde TAŞÇI

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

YÜKSEK KATLI LÜKS KONUT BİNALARININ ENERJİ VERİMLİLİĞİNİ GELİŞMİŞ BİR CEPHE BİLEŞENİ İLE ARTIRMAK ÜZERE YENİ BİR YAKLAŞIM ÖNERİSİ

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KASIM 2017

Gözde GALİ TAŞÇI, a Ph.D. student of ITU Graduate School of Science Engineering and Technology student ID 502112070, successfully defended the thesis/dissertation entitled "A NEW APPROACH TO INCREASE ENERGY EFFICIENCY OF LUXURY HIGH-RISE RESIDENTIAL BUILDINGS THROUGH AN ADVANCED FACADE COMPONENT", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my spouse and dear cat,

FOREWORD

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November 2017 Gözde TAŞÇI
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ABBREVIATIONS

ASIEPI	: Assessment and Improvement of the EPBD Impact (for new buildings and building renovation)
AUT	: Apartment Unit Types
BEP-TR	: Building Energy Performance – Turkey
DoE	: US Department of Energy
EU	: European Union
EPBD	: Energy Performance of Buildings Directive
HVAC	: Heating Ventilation Air-Conditioning
IEE	: Intelligent Energy Europe
MAT	: Mean Air Temperature
MS	: Member States
nZEB	: Nearly Zero Energy Buildings
PNFC	: Proposed New Façade Component
PV	: Photovoltaic
TABULA	: Typology Approach for Building Stock Energy Assessment
TARP	: Thermal Analysis Research Program
TUBITAK	: The Scientific and Technological Research Council of Turkey
TUIK	: Turkish Statistical Institute
UH	: Uncomfortable Hours
UNFCCC	: United Nations Framework Convention on Climate Change

SYMBOLS

SHGC **:** Solar Heat Gain Coefficient
T_{vis} **:** Visible Transmittance
U **:** Heat Transfer Coefficient

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A NEW APPROACH TO INCREASE ENERGY EFFICIENCY OF LUXURY HIGH-RISE RESIDENTIAL BUILDINGS THROUGH AN ADVANCED FACADE COMPONENT

SUMMARY

Researches on reducing building originated yearly energy demand is one of the top issues in every country. Global warming threatens the life of all species and the Earth. One of the top reasons of global warming is greenhouse gases sourced by buildings.

There are crucial developments in EU in order to provide energy efficiency in buildings. The most important improvement in EU is EPBD – Energy Performance of Buildings Directive and its enforcements. There are obligatory articles for Member States to provide performance improvement in new and existing buildings. Turkey as a member state candidate follows the developments in EU and therefore the enforcements of EPBD. Building energy performance has a high level of importance since Turkey is heavily foreign-dependent in terms of energy sources. So, improving building energy efficiency will provide reduction in required energy amount.

Since, the developments in EU are followed in Turkey, EPBD 2010/31/EU became the lead document to direct Turkish building energy policy. According to EPBD 2010/31/EU, until 2020 overall greenhouse gas emmission will be at least 20% below 1990 levels, Union's energy consumption will be 20 % reduced and in this obligation the renewable energy use portion will be increased. This is a very clear enforcement. Turkey took this Directive as a base and National Energy Efficiency Action Plan was prepared. In accordance with this plan, the same obligation is valid until 2023. So, until 2023 energy consumption will be reduced 20% together with increasing renewable energy portion in Turkey. The Directive presents a methodology framework in order to provide this article. Basically, reference buildings should be defined, energy efficiency measures for reference buildings should be defined, final and primary energy need of reference buildings and measures should be assesed, costs of the energy efficiency measures should be calculated. Therefore, in order to adapt this methodology a national research project supported by TUBITAK was done in Turkey. This thesis study bases on the results of that national research.

The research was took place in Istanbul climate because of the variation in building typology in Istanbul. To this aim, the density of the residential buildings within existing and new buildings was considered and the pilot building type was selected as residential buildings. Also, the Directive suggests to start from residential buildings. Three common residential types were designated through surveys by statistical data sourced by TUIK (Turkish Statistical Institute): single family houses, standard apartments, luxury high-rise residential buildings. Within this residential building types there is one different type distinguished from the common types that is

called “residence” in Turkey. In this study, as a brief explanation, this type was named as “luxury high-rise residential buildings”.

This building type became popular in metropolises of Turkey in the last years. That is because of the rising land prices in the city center and the varied demands of the upper-middle and upper income group. The existing samples of this residential building type meets the building envelope thermal transmittance requirements in accordance with the related standards, also meets the HVAC requirements, however still have high energy demand. As a finding of the mentioned national research project, unlike the standard residential building types, standard retrofit measures does not have an important effect on energy performance improvement of luxury high-rise residential buildings.Therefore, instead of standard measures advanced retrofit measures are suggested for this building typology. Finally, it is obvious that advanced retrofits are more effective. In this thesis study, an advanced façade retrofit was developed and investigated to be used on luxury high-rise residential buildings.

According to the investigations, there are lots of research projects proposing different methods to improve the energy performance of the buildings and so to reduce the greenhouse gas emmissions in different countries. However, there is not any research specifically focuses on advanced retrofits when the standard ones are not effective for luxury high-rise residential buildings. And also, there is not any other investigation with the façade component that is proposed within this study.

The approach in this thesis study offers a different perspective on building envelope retrofits by thinking the building construction as a renewable energy system itself while reaching EU’s 2020 target especially to increase renewable energy portion in building construction and 2023 targets of Turkish National Action Plan. Therefore, a new exterior wall component detail that increases the solar gain and ventilation rate through façade according to the climatic conditions were proposed and theoretical investigations were concluded on example buildings to reveal if the facade detail serves for the purpose. To this aim, three case study residential buildings was chosen. The first one is an existing building, the second one is a virtual building that suits with passive design parameters and the last one is the same building with the second one with more storey. Thus, the importance of the design conditions is also revealed.

In addition, in studies about adopting the methodology of EPBD 2010/31/EU or reaching EU’s 2020 target, the focus is mostly only on reducing the yearly energy demand, however thermal comfort of indoor environment is a very important aspect to designate the most proper suggestions for reaching the target. Especially, in these kinds of studies while proposing a new construction component as in this thesis study, it is very important to evaluate the energy performance of the proposed component together with its effect on thermal comfort. Therefore, after energy performance analyzes, thermal comfort analyzes were done by calculating uncomfortable hours.

As a conclusion, it was shown that the proposed exterior wall component detail has big potential to reduce yearly primary energy demand of luxury high-rise residential buildings in comparison to the standard retrofit actions. Additionally, in the cases with the proposed component, uncomfortable hours are less than the base cases. Moreover, Turkey is one of the representative country of Mediterranean climatic countries with a wide variety in terms of climatic conditions. Therefore, researches in Turkey would effect the applications in other Mediterranean countries as reverse. And since this building type and its variations locates also in other Mediterranean countries, the research could be a reference for potential use of the countries with Mediterranean climate.

Within the scope of the thesis; in the first part the purpose of the thesis study, the unique value, literature review and hypothesis, in the second part the progress in the field of building energy efficiency both in EU and Turkey, in the third part the approach to decrease yearly primary energy demand of luxury high-rise residential buildings and comprehensive explanation of the methodology, in the forth part application of the explained approach on three case study buildings, in the fifth part discussion of the study and in the sixth part conclusion of the study take place.

YÜKSEK KATLI LÜKS KONUT BİNALARININ ENERJİ VERİMLİLİĞİNİ GELİŞMİŞ BİR CEPHE BİLEŞENİ İLE ARTIRMAK ÜZERE YENİ BİR YAKLAŞIM ÖNERİSİ

ÖZET

Günümüzde, yaklaşık olarak tüm ülkelerde binalardan kaynaklı yıllık enerji ihtiyacını azaltmaya yönelik araştırmalar yapılmakta ve bu araştırmalar öncelik taşımaktadır. Bilindiği üzere, küresel ısınma hem dünyayı hem de dünyada yaşayan canlıların yaşamını tehdit etmektedir. Küresel ısınmanın bilinen en önemli sebeplerinden biri binalardan kaynaklı sera gazı salınımıdır.

Avrupa Birliği'nde, binalarda enerji verimliliğini sağlamaya yönelik çok önemli gelişmeler olmaktadır. Bu gelişmeler içerisinde en önemlisi "EPBD – Binalarda Enerji Performansı Direktifi" ve yaptırımlarıdır. Üye ülkelerin yeni ve mevcut binalarda enerji performansını artırmalarına yönelik zorunlu maddeler içermektedir. Türkiye, üye ülke adayı olarak Avrupa Birliği'ndeki bu gelişmeleri ve EPBD'nin yaptırımlarını takip etmektedir. Türkiye enerji kaynaklarını sağlama bakımından yüksek oranda dışa bağımlı olduğu için bina enerji performansını artırmak büyük önem taşımaktadır. Bu sayede ihtiyaç duyulan enerji miktarı azalabilecektir.

Avrupa Birliği'ndeki gelişmeler Türkiye tarafından takip edildiği üzere, bu gelişmeler ülkeye uyarlanmaktadır. Son olarak yayınlanan ve tüm üye ülkelerin bina enerji performansı iyileştirmeleri için uygulaması zorunlu olan maddeleri içeren direktif EPBD 2010/31/EU Türkiye'de bina enerji tedbirlerini yönlendiren ana kaynak olmuştur. EPBD 2010/31/EU kapsamında 2020 yılına kadar tüm AB'nin enerji tüketimi 1990 yılındaki seviyelerin % 20 altına düşecektir ve tüm enerji tüketimi % 20 azaltılacaktır. Bu hususta yenilenebilir enerji kullanım oranı da artırılacaktır. Bu net karar sonrası Türkiye bu direktifi bir temel olarak kabul ederek Ulusal Enerji Verimliliği Eylem Planı'nı hazırladı. Bu plan kapsamında aynı zorunluluk 2023 yılına kadar olacak şekilde belirlendi. Yani, Türkiye'de de 2023'e kadar toplam enerji tüketiminin % 20 oranında azaltılacağı ve bunda yenilenebilir enerji kaynaklarının kullanılmasının da önemli bir payı olacağı öngörüldü. Baz alınan Direktif bu yaptırımı sağlamak amacı için bir metodoloji sistemi önermiştir. Bu sistem kısaca; referans binaların tanımlanması, referans binalarda enerji verimliliği tedbirlerinin belirlenmesi, referans binaların ve enerji verimliliği tedbirlerinin son ve birincil enerji ihtiyaçlarının belirlenmesi, enerji verimliliği tedbirlerinin maliyetlerinin belirlenmesidir. Türkiye'de bu metodolojiyi ülke koşullarına uyarlamak amacı ile TUBITAK destekli bir ulusal araştırma projesi geliştirilmiştir. Tez çalışması da bu projeyi temel almaktadır. Çalışmalar, barındırdığı bina tipolojisi çeşitliliği göz önünde bulundurularak ve yapılan çalışmaların uygulanırlığı ele alınarak İstanbul ikliminde yapılmıştır. Bu amaçla, Türkiye'de bulunan mevcut bina tipleri ve yeni yapılmakta olan bina tipleri içerisindeki yoğunluğu değerlendirilerek, başlangıç olarak konut binaları seçilmiştir. Aynı zamanda Direktif de çalışmalara konut binalarından başlanmasını öngörmektedir. Türkiye İstatistik Kurumu'ndan (TÜİK) alınan veriler doğrultusunda konut binaları 3

tipolojiye ayrılmıştır: tekil aile konutları, standart apartmanlar, lüks yüksek konut binaları Bu bina tipolojileri arasında bir tanesi diğerlerinden farklılaşmıştır. Bu tipoloji Türkiye'de "rezidans" olarak adlandırılmaktadır. Bu tez çalışması kapsamında kısa bir tanımlayıcılık katarak bu bina tipolojisi "lüks yüksek konut binaları (luxury high-rise residential buildings)" olarak adlandırılmıştır.

Bu bina tipi son yıllarda Türkiye'de, özellikle metropollerinde çok popüler olmuştur. Bunun sebebi artan arsa fiyatları ve orta-üst ve üst kesimin değişen ve artan konut binası içi ihtiyaçlarıdır. Bu bina tipolojisinin mevcut örnekleri ilgili standartlarda bina kabuğu için belirlenen ısıl geçirgenlik gereksinimlerini karşılamakta ve hatta daha üzerine çıkmaktadır. Ayrıca mekanik tesisat sistemleri için belirlenen kriterleri de karşılamaktadır, fakat enerji ihtiyacı yine de yüksektir. Ulusal projenin bir bulgusu olarak standart konut binalarının (diğer 2 tipoloji) aksine lüks yüksek konut binalarında geleneksel cephe iyileştirme önlemleri bina enerji performansının iyileştirilmesinde etkili olmamaktadır. Bu sebeple, bu bina tipolojisi için standart iyileştirme tedbirleri yerine ileri iyileştirme tedbirleri önerilmektedir. Sonuç olarak da ileri iyileştirme tedbirlerinin bu bina tipolojisi üzerinde daha etkili olduğu belirlenmiştir. Bu tez kapsamında, lüks yüksek konut binalarında enerji performansını artırmak amacı ile ileri bir cephe bileşeni geliştirilmiş ve kullanımı ve etkileri test edilmiştir.

Araştırmalar kapsamında, farklı ülkelerde bina enerji performansını geliştirmeye ve sera gazı salınımlarını azaltmaya yönelik pek çok farklı yöntem önerisi içeren araştırma çalışmaları yapıldığı bulgusuna ulaşılmıştır. Ancak spesifik olarak standart iyileştirme tedbirlerinin etkisiz olduğu yerde ileri iyileştirme tedbirlerinin sunulmasını içeren, lüks konut binaları için bu konuyu ele alan ve bu tez kapsamında geliştirilen cephe bileşenini test eden herhangi bir araştırma bulunamamıştır.

Tez çalışmasındaki yaklaşım, bina cephe bileşenlerinin birebir kendilerini bir yenilenebilir enerji sistemi gibi değerlendirmeyi öngörerek bina cephe iyileştirmelerine farklı bir bakış açısı önermektedir. Öte yandan, binalarda yenilenebilir enerji kullanım oranını arttırarak Avrupa Birliği'nin EPBD 2010/31/EU direktifinde tanımlı 2020 hedefleri ile Türkiye'nin bu direktife göre geliştirdiği Ulusal Eylem Planı'nda yer alan 2023 hedeflerine ulaşabilmesi için bir yöntem önerisi sunar. Bu doğrultuda, güneş kazançlarını ve havalandırma oranını iklimsel koşullara uygun olarak cephe yoluyla arttıran yeni bir dış duvar bileşeni önerilmiştir ve bu cephe detayının amaca uygunluğunun testleri için örnek binalar üzerinde teorik araştırmalar yapılmıştır. Bu amaçla 3 adet örnek/referans bina belirlenmiştir. Bu binalardan ilki İstanbul'da mevcut bir binadır, ikincisi pasif tasarım parametrelerine uygun sanal bir binadır, üçüncüsü ise ikinci binanın aynısı olup kat sayısı daha fazladır. Bu yöntemle geliştirilen cephe bileşeninin verimliliği üzerinde tasarım koşullarının da etkisi ortaya konmuştur.

Genel olarak EPBD 2010/31/EU içerisinde yer alan metodolojinin ülke koşullarına adapte edilmesini öneren çalışmalarda veya Avrupa Birliği'nin 2020 hedeflerine ulaşmak için geliştirilen çalışmalarda yalnızca yıllık enerji ihtiyacının azaltılmasının üzerinde durulur. Oysa iç mekan koşullarının kalitesi için ısıl konfor çok önemlidir ve enerji ihtiyacının düşürülmesiyle ısıl konforu da arttıran öneriler hedeflere ulaşmada en uygun öneriler olarak belirlenmelidir. Özellikle, bu çalışmada olduğu gibi yeni bir bina elemanı önerilen çalışmalarda enerji performansı ile birlikte ısıl konfor da mutlaka değerlendirilmelidir. Bu sebeple, bu tez kapsamında enerji performansı analizlerinden sonra konforsuz saatlerin hesaplanması ile ısıl konfor analizleri de yapılmıştır.

Sonuç olarak, önerilen dış duvar bileşeni detayının lüks yüksek konut binalarının yıllık birincil enerji ihtiyacını düşürmede geleneksel iyileştirme önerilerine göre çok etkili olduğu belirlenmiştir. Ayrıca önerilen cephe elemanının kullanıldığı durumlarda konforsuz saatler de elemanın kullanılmadığı baz durumlara göre oldukça azalmıştır. Bunlara ek olarak, Türkiye, barındırdığı farklı iklim bölgeleri ile birlikte Akdeniz ikliminin temsili ülkelerinden biridir. Bu sebeple, Türkiye'de yapılan araştırmalar ve sonucunda elde edilen bulguların uygulanması Akdeniz iklimine sahip diğer ülkelere de katkıda bulunacaktır. Bu bina tipi ve benzerleri diğer Akdeniz iklimine sahip ülkelerde de bulunmaktadır. Böylece, geliştirilen ve etkisi test edilen yeni bina elemanı diğer ülkelerde de potansiyel kullanıma ve etkiye sahip olabilecektir.

Tez kapsamında;

- Birinci bölüm: tezin amacı, özgün değeri, literatür araştırması ve hipotez
- İkinci bölüm: Avrupa Birliği ve Türkiye'de bina enerji verimliliği konusunda olan gelişmeler
- Üçüncü bölüm: lüks yüksek konut binalarında yıllık birincil enerji ihtiyacını azaltmaya yönelik bir yaklaşım önerisi ve metodolojisinin detaylı anlatımı
- Dördüncü bölüm: üçüncü bölümde önerilen yaklaşımın örnek konut binalarına (3 adet) uygulanması
- Beşinci bölüm: çalışma hakkında tartışma
- Altıncı bölüm: çalışmanın sonuçları ve öneriler

konularını içermektedir.

1. INTRODUCTION

This thesis study bases on the improvements about building energy efficiency both in EU and in Turkey. The research mainly focuses on reducing yearly primary energy demand of luxury high-rise residential buildings by proposing an advanced building envelope component that will also lead the study to be compatible to EU’s 2020 and Turkey’s 2023 renewable energy targets. In addition to this perspective, the study also discusses on uncomfortable hours analyzes and reducing the number of uncomfortable hours together with the yearly primary energy demand. This research study is very important to explain the importance of different strategies for different building typologies since the main focus is an advanced facade retrofit instead of standard facade retrofit.

1.1 Purpose of the Thesis

The Earth and all species are under the treath of global warming that can cause harm. The most important reason of global warming is greenhouse gases that covers the Earth’s surface as a coat. Greenhouse gases are mostly caused by energy sources that we use for our needs. According to the studies and research, buildings constitute 30% of the total energy consumption and they are the second at this subject after industry with 39%.

Therefore, building energy efficiency is one of the most important subjects in Europe for European Union’s (EU) 2020 Strategy of saving 20% of its primary energy consumption and emissions of greenhouse gases and other pollutants. Nearly 40% of EU’s final energy consumption is caused by building sector [COM, 2011, 109 final]. Thus, energy efficiency improvement studies should start from building sector. To this aim, Energy Performance of Buildings Directive (EPBD) 2002/91/EC was published and with total transposition of this directive EU’s energy saving and greenhouse gas emission targets were planned to be achieved [EU Commission, 2002]. The directive came into force in 4 January 2003 and all EU Member States (MS) were obliged to implement this directive until 4 January 2006. Turkey as an EU candidate country was following the related legislations and essential legal arrangements were taken in since 2007 [Energy Performance of Buildings Regulation, 2008; Energy Efficiency Law, 2007]. As a further step, in consideration of EPBD 2002/91/EC for energy certification of the buildings and generating a building stock, Turkish National Building Energy Performance Calculation Method (BEP-TR) was developed in convenience with simple hourly method of EN 13790 [Building Energy Performance Calculation Method, 2010; CEN, 2008].

Subsequently published EPBD 2010/31/EU is the amended version of EPBD 2002/91/EC and includes further substantive amendments. EPBD 2010/31/EU is a guideline for achieving energy efficiency measures for 2020 target of EU. The building sector is expanding, which is bound to increase its energy consumption from 40% to more. Therefore, reduction of energy consumption and the use of energy from renewable sources in the building sector constitute important measures to reduce the Union's energy dependency and greenhouse gas emissions. In accordance with EPBD 2010/31/EU, MS should lay down a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements. This methodology should require defining reference buildings, defining energy efficiency measures of reference buildings, assess the final and primary energy need of the reference buildings, and calculate the costs of the energy efficiency measures for designating cost-optimal level [EU Commission, 2010]. Defining the reference buildings is a crucial starting step for energy efficiency development in building sector. A supplementary directive was published by EPBD. In this document, net present value method is defined for long term calculations [EU Commission Delegated Regulation, 2012]. The cost-optimal level of energy efficient buildings is the key point to reach nearly Zero Energy Building (nZEB) that is defined as a target in EPBD 2010/31/EU.

Additionally, together with an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the Union to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). The European Council of March 2007 reaffirmed the Union's commitment to the Union-wide development of energy from renewable sources by endorsing a mandatory target of a 20% share of energy from renewable sources by 2020. Directive 2009/28/EC establishes a common framework for the promotion of energy from renewable sources [EU Commission, 2010; EU Commission 2009]. Individual EU countries have different available resources and their own unique energy markets. Therefore, each will follow a different path to meet the obligations under the Renewable Energy Directive, including their legally binding 2020 targets. Each country release its own national action plans on a database [Url-1]. According to EU Strategy on Heating and Cooling, heating and cooling consume half of the EU's energy and much of it is wasted. Buildings are the first consumers of heating and cooling. Developing a strategy to make heating and cooling more efficient and sustainable is a priority for EU. Although the heating and cooling sector is moving to clean low carbon energy, 75% of the fuel it uses still comes from fossil fuels. A smarter and more sustainable use of heating and cooling is within reach as the technology is available [COM, 2016, 51 final]. Therefore, benefitting from renewable energy was become a critical point while reaching 2020 targets.

In parallel with these developments in EU, the Ministry of Energy and Natural Resources of Turkish Republic published Energy Efficiency National Action Plan in consideration of EU's 2020 target and related directives. According to the investigations, energy supply in Turkey equals to 78.3% of imported primary energy. In addition, primary energy consumption rate increased 36% in 2014 in comparison to 2005. Also, current account balance of Turkey in foreign currency follows a negative path in last years and net energy import is one of the biggest reasons of this situation. Energy density decreased 4.8% in 2009-2014 term [Turkish National Energy Efficiency Action Plan, 2016]. Therefore, adaptation of related EU directives became inevitable. Targets of the action plan basically includes the implementation of former related laws and regulations of Turkish Republic, decreasing the energy density 20% until 2023, and decreasing primary energy supply 20% and achieving these goals through EU's legislative framework [EU Commission 2002, EU Commission 2010, EU Commission, 2009; Turkish National Energy Efficiency Action Plan, 2016; EU Commission, 2012]. In specific to building sector, Energy Efficiency Strategy Paper 2012-2023 was prepared. Briefly, in accordance with the paper at least 25% of the building stock in 2010 will be sustainable buildings until 2023, the number of eco-friendly buildings that benefit from renewable energy sources will increase to decrease energy needs and carbon emissions of the buildings, and the use of renewable energy sources will be promoted [Turkish National Energy Efficiency Action Plan, 2016].

This thesis study bases on the mentioned methodology in EPBD 2010/31/EU and a national TUBITAK project that is an adaptation research of the methodology framework in EPBD 2010/31/EU. The approach in this study starts with step-by-step implementation of the methodology to the residentail buildings, then specifically implementation on a current popular building typology called “residence” in Turkey which are “luxury high-rise residential buildings”. According to the related research by the implementation of the methodology framework in the Directive, the building envelope thermo-physical properties of luxury high-rise residential buildings are high-standard and better performed than common standard apartments. Therefore, application of standard retrofit measures does not effect the builiding energy performance of this building typology. Thus, advanced retrofit measures is a necessity for this building typology as a difference from the others. As an originality of this thesis study, there is not any other research that bases on this kind of evidence that directs the study to advanced retrofit measures. To this aim, a unique solution was defined. The widest area of the building was designated in order to gain benefit from renewable energy the most. Than a unique advanced façade component was defined. Then, investigations was done by implementing this proposed façade component on different case study buildings. As another originality of this research, thermal comfort was evaluated together with the building energy performance criteria.

1.2 Literature Review

Since building energy efficiency is a key subject, there are many research studies. The research studies are mainly in the light of EPBD 2010/31/EU and most of them are at national level while there are some important projects at international base. The researches are mainly about the adaptation of the methodology in EPBD 2010/31/EU. As the residential building type is the most common building type, especially the research studies on adaptation of the methodology starts from them. There are three very important research projects about this subject.

One of them is IEE TABULA (Intelligent Energy Europe - Typology Approach for Building Stock Energy Assessment) which is an IEE funded project between the years of 2009 – 2012. The project was focused on residential buildings and typologies were developed for 13 countries in EU. Each national typology consists of a classification scheme grouping buildings according to their size, age and further parameters and a set of exemplary buildings representing the building types. They were published by the project partners in national "Building Typology Brochures", written in their respective languages. As a common element all brochures contain double page “Building Display Sheets” for all example/reference buildings on which energy related features and the effects of refurbishment measures are illustrated graphically. To exchange information on the European level the "TABULA WebTool" provides an online calculation of the exemplary/reference buildings from all countries, displaying their energy related features and the possible energy savings by implementing refurbishment measures. Basis of the TABULA WebTool is a simple and transparent reference procedure for calculating the energy need, the energy use by energyware and the energyware assessment (primary energy, carbon dioxide, costs). Apart from the reference calculation used for cross-country comparison a calibration of the calculated energy use to the typical levels of actual consumption is foreseen with the intention to enable a realistic assessment of energyware and heating costs savings. Based on the residential building typologies building stock models have been created for seven countries which enable a projection of the actual national building stock consumption and the energy saving potentials [Loga et al., 2010]. The other EU project is IEE ASIEPI (Intelligent Energy Europe – Assesment and Improvement of the EPBD Impact) is another important project in accordance with EPBD 2010/31/EU requirements. The main goal of ASIEPI was to provide support to Member States and the European Commission on EPBD related aspects that may present potential problems when implementing the EPBD:

- How to compare the energy performance requirements across Europe?
- What's the actual impact of the EPBD?
- How to organise control and compliance?
- How to effectively handle thermal bridges?
- How to stimulate good building and duct airtightness?
- How to assess innovative systems?

- How to stimulate good summer comfort conditions? [Spiekman, M. (editor), 2010].

Another research project for defining the reference buildings and designating the cost-optimal energy efficiency level was developed in Turkey as a Scientific and Technological Research Council of Turkey (TUBITAK) 1001 project. The project entitled as “Determination of Turkish Reference Residential Buildings and National Method for Defining Cost Optimum Energy Efficiency Level of Buildings”. The project focuses on residential buildings. Residential building typologies were generated and reference values together with final and primary energy consumptions of reference buildings were defined for those buildings. The research study was concluded by developing energy efficiency retrofits at cost-optimal level [Yılmaz, et al. (project team), 2015]. As a difference to residential building typology definitions of other countries, there is a different typology in Turkey’s project which is luxury high-rise residential buildings. The reason of having this typology is the rapid rise of the land prices in the city center, population growth and changing social needs of the occupants. These buildings host the residential areas and social functions in the same building. Formerly, those functions were in the same land in separate buildings, but after the high land prices the horizontal settlement type was converted into vertical settlement. Luxury high-rise residential buildings mostly locate in metropolises of Turkey and reflects the preferred residential building typology in metropolis cities. Moreover, their energy consumption level is much higher than the standard residential building types due to their central HVAC system. According to the results of the national TUBITAK research project in Turkey, standard retrofit measures are very effective in other residential building types while advanced retrofit actions are required for luxury high-rise residential building type. Because the thermo-physical properties of the building facade of these buildings are very effective and more efficient than the national legislations’ suggestions while the building facade of the other residential building types barely providing the limit values of the national legislations.

The research studies on reaching EU’s 2020 targets by the implementation of EPBD 2010/31/EU are mostly for reducing the yearly energy demand of standard buildings through traditional methods and with lower budget. As in this study, there are also lots of advanced façade research with existing renewable energy systems and high-tech materials in the market both for the application of the methodology in the Directive or only for providing an energy efficient level to the buildings. For example Fong et al. (2012) presented using building integrated solar collectors and PV panels on an office building for solar cooling with Hong Kong climate. Sun et al. (2012) presented the effects of shading type building integrated photovoltaic claddings on energy saving and the effect of surface azimuth angles on this systems efficiency. Li et al. (2016) explored building integrated wind turbines on a high-rise building for power generation. Passer et al. (2016) investigated two types of façade refurbishments (minimum and high quality) for the International Energy Agency and European Commission’s global emission target of 2050. Based on the results of the study, the optimal type of refurbishment was designated as high-quality refurbishment of the thermal envelope using prefabricated facade elements, solar thermal collectors and PV panels. The result of this example research is very similar to the base reason of this thesis study. According to the results of the research minimum refurbishments are not as effective as high quality advanced refurbishments on improving the energy performance of case study residential building, therefore the study was resulted to the efficiency of the advanced refurbishments. Favoino et al. (2015) investigated adaptive transparent building facades on an office building case to achieve nZEB objectives of EPBD 2010/31/EU. According to the results high energy savings were achievable by adapting the transparent part of the building envelope alone and this study could provide a tool to assess the full energy saving potential of next generation smart glazing and to guide the product development of more innovative adaptive transparent façade technologies. Pikas et al. (2014) presented possible office building façade suggestion on reaching EU’s 2020 nZEB target. The cases were analyzed both on energy efficiency and cost optimality points of views. PV panel integration to the building envelope was investigated too.

Researches summarized above are related with advanced façade retrofits. However, all of them includes existing technologies or high-tech materials. Whereas in this thesis study the advanced façade retrofit introduces a new façade component and investigates the effects of it. There are researches like this but the number of this kind of research is not very high as the others. Addtionally, since the advanced component in this thesis study is a newly designed component within the scope of this thesis study, there is not any other research on it. The example researches about innovative solutions are with different components, but mostly configuring an existing renewable energy system in the market in a different way than the traditional methods. Luo et al. (2016) introduced an active building envelope suggestion that is photovoltaic thermoelectric wall system. This system could use the electric power converted from solar energy by PV cells directly serves for the operation of thermoelectric radiant panel. This active system was highly self-adaptive to ambient thermal environment and could reduce heat gain by considerable scale. The basic structure of the system was very similar to Trombe Wall. The system was compared to a traditional wall system and resulted as very effective. Connelly et al. (2016) presented building integrated concentrating PV, smart window system consisting of a thermo-tropic layer with integrated PVs was treated as an electricity-generating smart window or glazed façade as a new concept. The system automatically responded to climatic conditions by varying the balance of solar energy reflected to the PV for electricity generation and transmitted through the system into the building for provision of light and heat. Favoino et al. (2014) presented in another study a new multifunctional façade module that would be applicable on reaching EU's 2020 nZEB target. Within the scope of the paper in the framework of a research activity on advanced integrated facades, a new multifunctional facade module, called ACTRESS (ACTive, RESponsive and Solar) has been conceived and a prototype built for analyzing the energy performance and the potentialities of such envelope components.

The explained studies above mostly focusing on energy performance improvement methods basing on set-point temperatures of heating and cooling periods. However, it is very important to consider thermal comfort of the indoor environment while reducing the energy demand. Research studies focusing on EPBD mostly don't take into account thermal comfort analyzes, but especially in these kinds of studies while concentrating on advanced façade retrofits, especially introducing a new advanced component, evaluating thermal comfort is very important to direct the research. Ascione et al. (2016) discourses on giving secondary importance to thermal comfort or usually neglecting it. While the research focuses on energy performance of residential buildings in Mediterranean climate, also considers thermal comfort basing on ASHRAE 55-2004. Penna et al. (2015) discussed about targeting energy and cost efficient nZEBs according to EPBD 2010/31/EU but neglecting thermal comfort on this path. According to the research, it is possible to reach energy and cost efficiencies at the same time, but thermal comfort results are worsening at this point. There could be other solutions to reach more efficient buildings in terms of energy savings and indoor thermal comfort, but not cost-optimum. Also, in the scope of cost-optimal level, advanced retrofit actions would increase the initial investment cost of the other standard residential building types where the income of the occupants is comparatively lower to afford the cost. However, considering higher income level of the building owners and higher energy consumption of the building, advanced retrofit actions for building facade are more appropriate than the standard ones for luxury high-rise residential buildings. Therefore, distinctly from other residential building types, for these buildings an alternative advanced façade approach could be effective on reaching EU's 2020 and Turkey's 2023 renewable energy use target. So, as in the result of the research study of Penna et al. (2015), in some cases cost-optimality is in secondary importance level in order to provide energy efficiency and thermal comfort together. Attia et al. (2015) investigated the effects of different thermal comfort methods on nZEBs (residential) in hot climates (in this study Cairo). The study showed the importance of selected thermal comfort model on defining building energy consumption. Figueiredo et al. (2016) presented the application of Passive House standard on the buildings locate in Mediterranean climate and analyzed cost optimization too for the convenience to EPBD 2010/31/EU. Finally, energy performance, cost optimization and thermal comfort of the case study residential building have been evaluated together.

Thermal comfort analyzes also were done for advanced façade retrofits. In these researches mostly energy perforamnce and thermal comfort were evaluated together without cost analyzes. Hweij et al. (2017) explored the performance of an evaporatively cooled window driven by solar chimney attached to external facades of an office building in dry climate for energy efficiency and thermal comfort at the same time. The research resulted with improved thermal comfort together with 10% of energy performance improvement. Serra et al. (2010) investigated climate adaptive façade for a highly glazed façade. The effects of the façade on energy performance and thermal comfort have been evaluated for heating and cooling periods. Barbosa et al. (2015) presented the thermal comfort analyses for naturally ventilated double skin façade office building. Hengstberger et al. (2016) investigated maintaining thermal comfort while there are building integrated solar thermal collectors on building façade. To this aim, phase change materials have been tested to use into the absorber insulation. Thermal comfort analysis could be done with free-running mode. For example, Ascione et al. (2017) in another research investigated an office building that is convenient to German standards but has discomfort hours. Passive strategies have been developed to provide thermal comfort while considering cost-optimality according to the new applications.

1.3 Hypothesis

This thesis study bases on Directive 2010/31/EU and mentioned national research project supported by TUBITAK. According to the results of the TUBITAK project standard retrofit measures are not effective on reducing yearly energy demand of luxury high-rise residential buildings while advanced retrofit measures are the only way to reduce the yearly energy demand of this building type. Starting from this point, developing an advanced façade component and application of that advanced retrofit action was investigated.

Façade area constitutes the largest area of luxury high-rise residential buildings. Therefore, necessary constructional changes on façade area will directly affect the energy performance of the building. There are various advanced façade systems that benefits from renewable energy sources and there are several research studies on utilization from these systems. Whereas, especially architects may design the building façade construction as a renewable energy system instead of an addition to the facade. Therefore, it is possible to develop different renewable energy system components by investigating the effects on building energy performance.

This thesis study introduces a theoretical approach and application of the approach on three case studies for a new advanced façade component proposition. The proposed façade component increases the renewable energy utilization portion in the buildings by increasing solar gains during heating period through selective surface application within the component and increasing the ventilation rate within the façade during cooling period through the inlet and outlet vents on the exterior surface of the component. In order to analyze this component, three building projects were generated with different specialities. One of the buildings is an existing building and the others are specifically designed for this thesis study. The façade thermo-physical properties and boundary conditions of the buildings were generated by benefitting from the gathered data of the existing building project together with the obtained data in TUBITAK project. The first case study building represents an existing condition, the second case study building adds the effects of passive design parameters to the investigation and the third case study building represents taller buildings. All three case study buildings have same façade components and boundary conditions in order to compare the effects of façade retrofit measures.

Additionally, the occupant profile in luxury high-rise residential buildings is high income group (middle-upper and upper). So, they have purchasing power and prefer quality investments. Advanced retrofit measures may increase the initial investment cost of the buildings. However, the most problematic subject for the luxury high-rise residential building occupants is monthly energy costs and the occupant group would buy the apartment units even the prices are high when the monthly dues are less. Therefore, reducing the yearly energy demand will be more important than increasing the initial investment cost in this building type. Cost calculations were done under Turkish national market conditions. There are cost optimality analyzes for all three case study buildings in order to meet the requirements of the methodology in EPBD 2010/31/EU, however the main focus is not reaching a cost optimal solution for luxury high-rise residential buildings, but determining the most effective proposals to reduce the yearly primary energy demand of the buildings.

As can be seen in literature summary, there are research studies about advanced façade tehcnologies field. Most of them are by using the existing renewable energy systems or high-tech materials. However, this thesis study focuses on developing a new façade component, additionally this component does not benefit from existing systems but a totally new system being generated in the scope of climatic characteristics. This new façade component forms the original part of the thesis study.

The proposed façade component in this study is unique both by being not existed and not tested before and benefitting from climatic features. So, this component is totally new and special for this thesis study. It is not a system as the other building integrated renewable energy systems. It is a building component and architectural constituent. Therefore, this component is not being used on a façade material, it is a façade construction itself. The second most important property of the proposed component that it is not a mechanically working system. It only benefits from the climatic conditions. The component works in harmony with solar radiation and air circulation. This work functions in a passive way. Therefore, this is also a very important difference of the proposed component from the other building integrated advanced façade systems. Actually, it is not correct to call the proposed façade component as a "building integrated component", because it is a building construction element as the other components of the building.

Finally, this thesis study aims to develop mentioned façade component as a possible suggestion for EU's 2020 and Turkey's 2023 renewable energy targets by increasing renewable energy use ratio in luxury high-rise residential building type.

2. PROGRESS IN THE FIELD OF BUILDING ENERGY EFFICIENCY IN EUROPEAN UNION AND TURKEY

This thesis study bases on the improvements in the building energy efficiency field both in EU and Turkey. Therefore, it is crucial to investigate these improvements in detail in order to understand the reason and the base of this thesis study. The unique idea of this thesis study directly sourced from the results of the TUBITAK project that is a project for adaptation of the methodology framework in EPBD 2010/31/EU for nearly zero building concept to Turkey. Thus, the terms that are explained in this part forms the roots of this thesis study.

2.1 Progress in EU in Building Energy Efficiency and Policies

Buildings account for 40% of total energy consumption in the Union. Therefore, reduction of energy consumption and the use of energy from renewable sources in the building sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions. One of the most important development is the Energy Performance Buildings Directive (EPBD), which was developed and will be implemented with following milestones [Url-2]:

- December 2002: EU adopts Energy Performance Buildings Directive (EPBD) EPBD 2002.
- January 2006: Deadline for transposing the directive into national law.
- November 2008: Commission proposes revision of EPBD.
- April 2009: Parliament adopts first-reading position.
- November 2009: EU reaches political agreement on Directive.
- May 2010: Parliament approves new legislation.
- May 2010: EU adopts/approves the recast/revised EPBD 2010.
- End of 2018: Public buildings to have to be nearly zero energy standards.

- End of 2020: All new buildings to be nearly zero energy (20% reduction in the Union's total energy consumption with the support of renewable energy use).

2.1.1 EPBD 2002/91/EC

This Directive was the first agreement on establishing common goals on building energy performance in EU. Within the scope of the Directive, the common calculation methodology should include all the aspects which determine energy efficiency and not just the quality of the building's insulation. This integrated approach should take into account of aspects such as heating and cooling installations, lighting installations, the position and orientation of the building, heat recovery, etc. The minimum standards for buildings are calculated on the basis of the below methodology. The Member States are responsible for setting the minimum standards [Url-3]:

- A common methodology for calculating the integrated energy performance of buildings;
- Minimum standards on the energy performance of new buildings and existing buildings that are subject to major renovation;
- Systems for the energy certification of new and existing buildings and for public buildings, prominent display of this certification and other relevant information. Certificates must be less than five years old;
- Regular inspection of boilers and central air-conditioning systems in buildings and in addition an assessment of heating installations in which the boilers are more than 15 years old.

The Directive concerned both residential and non-residential buildings except historic buildings and industrial sites, etc. Energy certification of the buildings was the key point of this Directive. It was crucial to start the energy certification from public buildings in order to provide example to the public and show the certificate on a visible place.

The Directive forms part of the Community initiatives on climate change (commitments under the Kyoto Protocol) and security of supply (the Green Paper on security of supply). Firstly, the Community is increasingly dependent on external energy sources and secondly, greenhouse gas emissions are on the increase. The Community can have little influence on energy supply but can influence energy demand. One possible solution to both the above problems is to reduce energy consumption by improving energy efficiency. Energy consumption for buildings-related services accounts for approximately one third of total EU energy consumption. The Commission considers that, with initiatives in this area, significant energy savings can be achieved, thus helping to attain objectives on climate change and security of supply. Community-level measures must be framed in order to deal with such community-level challenges.

This Directive is a follow-up to the measures on boilers (92/42/EEC), construction products (89/106/EEC) and SAVE programme provisions on buildings. Though there was already a directive on the energy certification of buildings (Directive 93/76/EEC repealed by Directive 2006/23/32/EC), it was adopted in a different political context before the Kyoto agreement and the uncertainties with the security of energy supply in the Union. It does not have the same objectives as Directive 2002/91/EC. The latter is an additional instrument, proposing concrete action to fill any existing gaps [Url-3].

2.1.2 EPBD 2010/31/EU on Energy Performance of Buildings (EPBD-Recast)

EPBD 2010/31/EU that the amended version of EPBD 2002/91/EC aims to promote the improvement of the energy performance of residential and non-residential buildings within the Union, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

The coverage of this Directive is expanded in comparison to 2002/91/EC. Therefore, MS should comply with the requirements of this Directive and not only 2002/91/EC. The matter of this Directive should be transposed to the national law of MS. As in the “Article I” of the Directive, the requirements are as follows:

- The common general framework for a methodology for calculating the integrated energy performance of buildings and building units.
- The application of minimum requirements to the energy performance of new buildings and new building units.

- The application of minimum requirements to the energy performance of: existing buildings, building units and building elements that are subject to major renovation; building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced; and technical building systems whenever they are installed, replaced or upgraded.
- National plans for increasing the number of nearly zero- energy buildings.
- Energy certification of buildings or building units.
- Regular inspection of heating and air-conditioning systems in buildings.
- Independent control systems for energy performance certificates and inspection reports.

The EU has taken several actions to honour both its long term commitment to maintain the global temperature rise below 2 °C, and its commitment to reduce, by 2020, overall greenhouse gas emissions by at least 20% below 1990 levels, and by 30% in the event of an international agreement being reached. Reduced energy consumption and an increased use of energy from renewable sources also have an important part to play [EU Commission, 2010].

The comparative methodolgy framework to identify cost-optimal levels of energy performance requirements for buildings and building elements takes place in "Annex III" of the Directive. The comparative methodology framework shall enable Member States to determine the energy performance of buildings and building elements and the economic aspects of measures relating to the energy performance, and to link them with a view to identifying the cost-optimal level. The comparative methodology framework shall allow for taking into account use patterns, outdoor climate conditions, investment costs, building category, maintenance and operating costs (including energy costs and savings), earnings from energy produced, where applicable, and disposal costs, where applicable and it should be based on relevant European standards. The comparative frame methodology is as below:

- Define reference buildings that are characterised by and representative of their functionality and geographic location, including indoor and outdoor climate conditions. The reference buildings shall cover residential and non-residential buildings, both new and existing ones.

- Define energy efficiency measures to be assessed for the reference buildings. These may be measures for individual buildings as a whole, for individual building elements, or for a combination of building elements.
- Assess the final and primary energy need of the reference buildings and the reference buildings with the defined energy efficiency measures applied.
- Calculate the costs (i.e. the net present value) of the energy efficiency measures (as referred to in the second indent) during the expected economic lifecycle applied to the reference buildings (as referred to in the first indent) by applying the comparative methodology framework principles.

In accordance with the Directive nearly zero energy building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. Cost-optimal level means the energy performance level which leads to the lowest cost during the estimated economic lifecycle. Cost-optimal gap and example graph is shown in Figure 2.1.

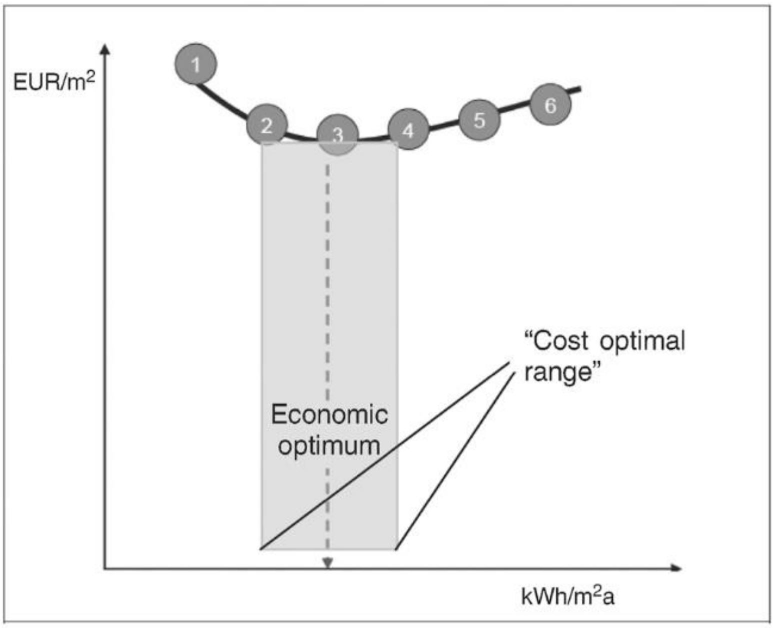


Figure 2.1 : Different variants within the graph and position of the cost-optimal range [EU Commission Notices, 2012].

2.1.2.1 Reference building

According to supplementing Directive 2010/31/EU Article 2, reference building is a hypothetical or real reference building that represents the typical building geometry and systems, typical energy performance for both building envelope and systems, typical functionality and typical cost structure in the Member States and is representative of climatic conditions and geographic location.

There are three different methods to define reference buildings; Real building method, Example building method, Virtual building method [Corgnati et al., 2013].

2.1.2.2 Primary energy

According to EPBD 2010/31/EU Article 2, primary energy means energy from renewable and non-renewable sources which has not undergone any conversion or transformation process. In order to define the primary energy demand of a building yearly energy demand should be multiplied to the related conversion factor. Following equation 2.1 should be used in order to calculate the primary energy demand:

$$PED_f = T_f \; x \; Cf_f \tag{2.1}$$

Where:

- PED_f is primary energy demand for any fuel,
- T_f is sum of total energy demand of any fuel,
- Cf_f is conversion factor of any fuel.

2.1.2.3 Energy efficiency measure

According to supplementing Directive 2010/31/EU Article 2, energy efficiency measure means a change to a building resulting in a reduction of the building's primary energy need. Additionally, retrofit measures should be start from most common and basic solutions then move towards to more innovative solutions.

2.1.2.4 Global cost calculation in terms of net present value

According to the comparative methodology in Directive 2010/31/EU Member States shall require to calculate the costs (i.e. the net present value) of the energy efficiency measures during the expected economic lifecycle applied to the reference buildings by applying the comparative methodology framework principles. EU Regulation supplementing Directive 2010/31/EU provides two alternatives for the cost calculation levels. The first one is financial global cost calculation and the second one is macroeconomic global cost calculation. The financial cost calculation method supports individual benefits while macroeconomic calculation method supports societal benefits [EU Commission Delegated Regulation, 2012].

According to supplementing Directive 2010/31/EU Article 2, global cost means the sum of the present value of the initial investment costs, sum of running costs, and replacement costs (referred to the starting year), as well as disposal costs if applicable. Therefore, in order to calculate the global cost in terms of net present value, separate cost categories should be defined. The supplementing Directive gives the calculation period as fixed equal to 20 years for non-residential buildings and 30 years for residential buildings and cost calculations consider only costs of elements which are effective on building energy performance and are different for the various cases. The cost categories to calculate the global cost are shown in Figure 2.2.

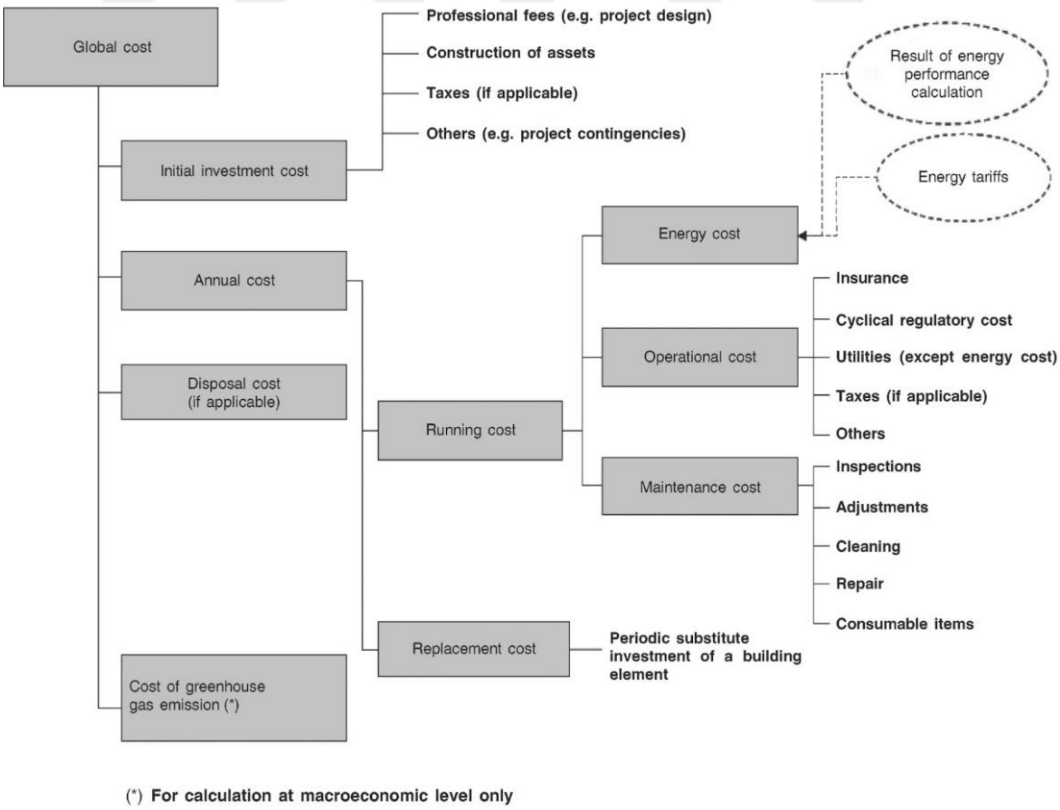


Figure 2.2 : Cost categorization according to the framework methodology [EU Commission Notices, 2012].

Initial Investment Cost: According to supplementing Directive 2010/31/EU Article 2, initial investment cost is all costs incurred up to the point when the building or the building element is delivered to the customer, ready to use. These costs include design, purchase of building elements, connection to suppliers, installation and commissioning processes. Initial investment cost is calculated with equation 2.2.

$$C_I = C_{I(p)}\ x \left(1 + \frac{R_d(i)}{100}\right)^{\tau} \qquad (2.2)$$

Where:

- C_I is initial investment cost for measure or set of measures
- $C_{I(p)}$ is present value of initial investment cost
- $R_d(i)$ is discount rate (for year i)
- τ is calculation period.

Discount rate depends on the real interest rate R_R and on the year p of the considered costs and is calculated with equation 2.3 [CEN, 2007].

$$R_d = \left(\frac{1}{1 + R_R}\right)^{p} \qquad (2.3)$$

Where:

- R_d is discount rate
- R_R is real interest rate.

Real interest rate depends on the market rate R and on the inflation rate R_i (which both may depend on the year i, but here are assumed constant), it is calculated with the equation 2.4.

$$R_R = \frac{R - R_i}{1 + R_i} \qquad (2.4)$$

Where:

- R_R is real interest rate
- R_i is market interest rate.

Annual costs: Annual cost is the sum of running costs and replacement costs paid in a certain year.

Running costs is annual maintenance costs, operational costs and energy costs and are calculated with the following equation 2.5.

$$C_r = C_e + C_o + C_m \quad (2.5)$$

Where:

- C_r is running costs
- C_e is energy costs
- C_o is operational costs
- C_m is maintenance costs during the calculation period.

Energy costs are directly related to the energy demand or end-use energy consumption and should be calculated through one of these. Energy costs are calculated through the following equation 2.6.

$$C_e = C_e(i) x P_v(e,n) \quad (2.6)$$

Where:

- C_e is energy cost
- C_e(i) is energy cost (for year i)
- P_v(e,n) is present value factor of energy (for calculation period n)

Operational costs are all costs linked to the operation of the building including annual costs for insurance, utility charges and other standing charges and taxes [EU Commission Delegated Regulated, 2012].

Maintenance costs are annual costs for measures for preserving and restoring the desired quality of the building or building element. This includes annual costs for inspection, cleaning, adjustments, repair and consumable items [EU Commission Delegated Regulated, 2012]. Standard EN 15459 Annex A consists maintenance costs for energy system components and products. These given values should be multiplied with the initial investment cost of each component in order to designate yearly maintenance cost for each component. Yearly maintenance cost amount should be multiplied with the present value factor the component for the calculation period of n. Present value factor is calculated with the equation 2.7.

$$p_v(c,n) = \frac{1-\left(1+\frac{R_I}{100}\right)^{-n}}{\frac{R_I}{100}} \tag{2.7}$$

Where:

- $p_v(c,n)$ is present value factor of the component (for calculation period n)
- R_I is real interest rate

Real interest rate is related to market interest rate and inflation rate and they both may differ in the year of i in comparison to the current rate. However, EN 15459 counts them as constant.

Replacement cost means a substitute investment for a building element, according to the estimated economic lifecycle during the calculation period [EU Commission Delegated Regulated, 2012].

Replacement costs are calculated throughout the calculation period based on timing and costs for replacement of systems and components. Present value factor or discount rate is used to refer costs starting year [CEN, 2007]. It is calculated with the following equation 2.8.

$$C_R(i) = C_I \; x \left(1+\frac{R_d(i)}{100}\right)^{Lp} \tag{2.8}$$

Where:

- $C_R(i)$ is the replacement cost (for year i)
- C_I is initial investment cost (for measure or set of measures)
- $R_d(i)$ is the discount rate for the application year i
- Lp is lifespan of the product.

There are given lifespan values for energy system components and products in EN 15459, Annex A.

Global cost: Calculation of global cost consists of summing all of the related costs as; initial investment cost, replacement cost, running costs, energy costs also taxes (VAT) and applying to these the discount rate by means of a discount factor so as to express them in terms of value in the starting year, plus the discounted residual value as in equation 2.9. Costs should be market or related legislation based and should be in convenience with the time and location parameters.

Global cost term can be called as lifecycle cost analysis. Global costs calculations result in a net present value of costs incurred during a defined calculation period, taking into account residual values of equipment with longer lifetimes. Projections for energy costs and interest rates can be limited to the calculation period.

$$C_g(\tau) = C_I + \sum_j \left(\sum_{i=1}^{\tau} \left(C_{a,i}(j) x R_d(i) \right) - V_{f,\tau}(j) \right) \qquad (2.9)$$

Where:

- τ means the calculation period
- $C_g(\tau)$ means global cost (referred to starting τ_0) over the calculation period
- C_I means initial investment costs for measure of set of measures j
- $C_{a,i}(j)$ means annual cost during year i for measure of set of measures j
- $V_{f,\tau}(j)$ means residual value of measure of set of measures j at the end of the calculation period (discounted to the starting year τ_0)
- $R_d(i)$ means discount factor for year i based on discount rate r.

According to the economic lifetime of the variable (building or building element) residual value should be discounted. Calculation graph of residual value of a building element that has a longer lifetime than the building is shown in Figure 2.3. Additionally, if a building element has shorter lifetime than the building, thus replacement costs added to the calculations for this specific element. The calculation of this kind of residual value is shown in Figure 2.4.

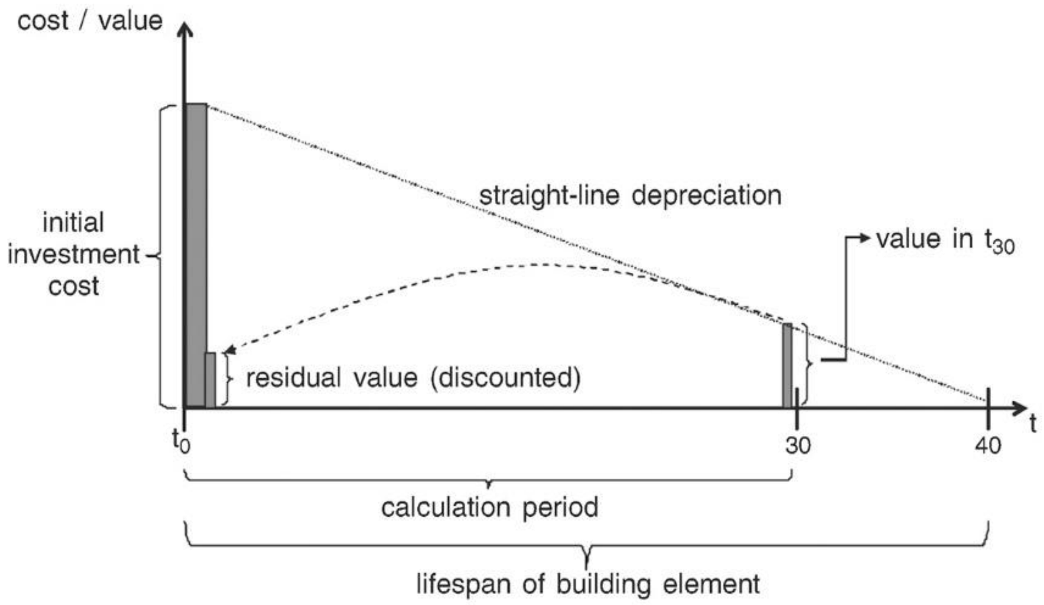


Figure 2.3 : Calculation of the residual value of a building element which has a longer lifetime than the calculation period [EU Commission Notices, 2012].

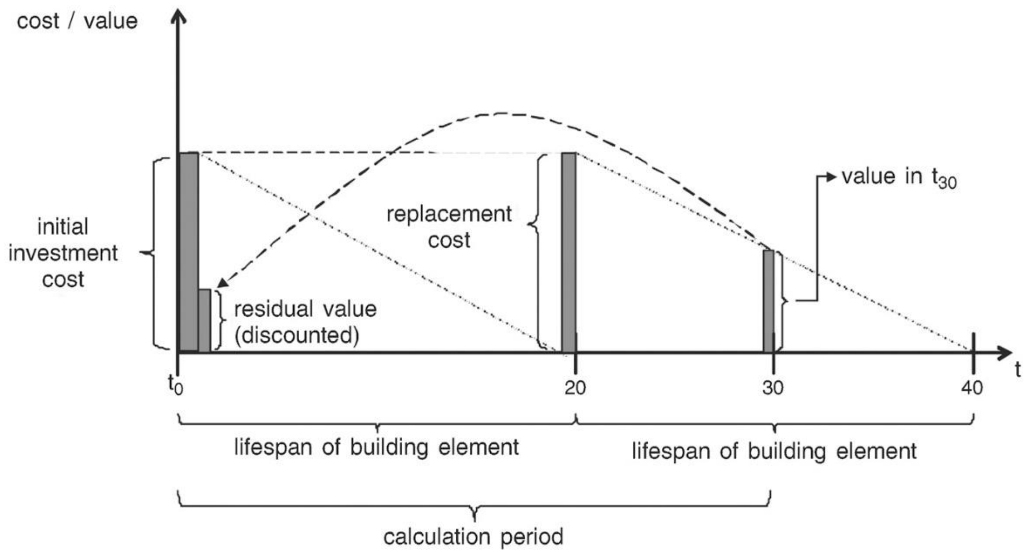


Figure 2.4 : Calculation of the residual value of a building element which has a shorter lifetime than the calculation period [EU Commission Notices, 2012].

While calculating global costs, costs of the following can be excluded [EU Commission Delegated Regulation, 2012];

- Costs that are the same for all assessed measures/variants/packages,
- Costs related to building elements which have no influence on the energy performance of a building.

2.1.3 Commission Delegated Regulation (EU) No 244/2012

This regulation includes supplementing articles to EPBD 2010/31/EU. In consistent with Article 5 and Annexes I and III of EPBD 2010/31/EU, this Regulation fixes a comparative methodology framework to be used by Member States for calculating cost-optimal levels of minimum energy performance requirements for new and existing buildings and building elements [EU Commission Delegated Regulation, 2012].

The methodology framework specifies rules for comparing energy efficiency measures, measures incorporating renewable energy sources and packages and variants of such measures, based on the primary energy performance and the cost attributed to their implementation. It also stresses on the way of implementing these rules to the selected reference buildings with the aim of designating cost-optimal levels of minimum energy performance requirements.

2.1.4 Directive 2012/27/EU

This Directive is the amended version of directives 2009/125/EC and 2010/31/EU. The scope of this Directive is to form a common framework of measures for the promotion of energy efficiency levels in order to provide the 2020 20% target of the Union and for further energy efficiency improvements beyond that date. The Directive focuses on the energy market and stresses on providing arrangements on supply and use of energy.

2.2 Progress in Turkey in Building Energy Efficiency and Policies

Turkey as a candidate of EU Member States follows all the improvements on building energy performance in EU and directs the country's energy policies accordingly.

Turkey mainly focuses on adapting the requirements that MS should comply with in consistent with EPBD Directives.

2.2.1 5627 Energy Efficiency Law

This Law was published in 2 May 2007 in Republic of Turkey Official Gazette. The aim of this Law is providing efficient use of energy, prevent of wastage, mitigating the burden of energy costs on economy, increasing the efficiency of energy resources and the use of energy to protect the environment.

This Law includes the development of energy consciousness in society as a whole and discourses on the importance of organizing activities and trainings in order to create awareness. Also, it covers the rules for the way of benefitting from renewable energy sources. Additionally contains enhancement and support of energy efficiency during the production, transmission, distribution and consumption of energy, in industrial enterprises, in electricity energy production facilities, in transmission and distribution networks and in transportation.

2.2.2 Building Energy Performance Regulation

This Regulation was formed by basing on 5627 Energy Efficiency Law and 3194 Construction Law and EPBD 2002/91/EC. It was published in 5 December 2008 in Republic of Turkey Official Gazette. The aim of this Regulation is to define below requirements by taking into account outside environmental climatic conditions, indoor requirements, local conditions and cost effectiveness:

- The calculation methodology that provides all kinds of energy use of buildings,
- Classification of the buildings in the scope of primary energy and carbon dioxide emission,
- Designation of minimum energy performance requirements of new and existing buildings with major renovation.
- Evaluation of applicability of renewable energy sources.
- Control of heating and cooling systems.
- Limiting greenhouse gas emissions.
- Determination of building performance criteria and application rules.
- Environmental protection.

This regulation includes the following enforcements to be used in new and existing residential, commercial and public buildings: minimum performance criteria of architectural design, HVAC installations, lighting appliances, electricity installation, fixed equipments for buildings consuming electricity; energy performance calculation methods; preparation of energy identity certificates; organization to authorize independent bodies to prepare and audit the controls of the buildings and energy identity certificates; necessary research for the formation of the country energy policy; collection of information of experiments.

2.2.3 Building Energy Performance Calculation Methodology (BEP-TR)

BEP-TR was developed mostly basing on the requirements in EPBD 2002/91/EC. The part that directs to obligate MS to develop an energy certification methodology influenced Republic of Turkey Ministry of Environment and Urbanization.

While preparing building energy performance calculation methodology EN 15217 is the dependant standard. The methodology includes five main title; Net Energy Demand Calculation for Heating and Cooling, Lighting Energy Demand Calculation, Energy Demand Calculation for Mechanical Systems, Reference Building Designation Method, and Simplified Method for Existing Buildings.

The model bases on Simple Hourly Calculation method of EN 13790. The method is based on an equivalent resistance-capacitance (R-C) model and uses an hourly time step and all building and system input data can be modified each hour using schedule tables (in general, on a weekly basis) [CEN, 2008]. During the calculation process, BEP-TR makes the calculations by taking into account heat transfer through transmission, heat transfer by ventilation, internal gains, and solar gains. This method meets the base equation of ‘Energy Use for Space Heating and Cooling’ of EN ISO 13790.

Application of this methodology provides a certificate at the end that includes the energy performance and CO_2 emission levels of the building in comparison to related reference building. Energy identity certificate expresses the document that includes energy demand and energy classification, insulation properties, efficiency of heating and cooling systems of the building at minimum.

2.2.4 TUBITAK 1001 project: determination of Turkish reference buildings and national method for defining cost-optimum energy efficiency level of buildings

This project was developed by a project team of Istanbul Technical University and supported by Republic of Turkey Ministry of Environment and Urbanization and TUBITAK (The Scientific and Technological Research Council of Turkey). The project code is 113M596. It bases on EPBD 2010/31/EU and the methodology framework that took place in “Annex III” of the Directive. The project mainly includes adaptation of the calculation methodology for Turkey.

As a starting point of the research, residential buildings was selected as the building type to be analyzed since they consist the major building type and also EPBD predicts residential buildings as the first level. Istanbul was selected as the pilot region because of having variation in residential building typologies and occupant profiles. Istanbul represents warm and humid climate type in Turkey.

First necessity was to designate residential building typologies. Therefore, through investigations in between residential building typologies a distinguishment was formed. These typologies are as follow: Single Family Houses, Standard Apartments (below 2000 m^2), Standard apartments (above 2000 m^2), Residences (Luxury High-Rise Residential Buildings). The reason of the distinguishment between standard apartments is that in accordance with the Building Energy Performance Regulation central heating system is an obligation in buildings that are more than 2000 m^2. However, this article of the Regulation includes only new buildings starting from 2009, therefore for the residential buildings that were constructed before 2009 there are 3 building typologies as: Single Family Houses, Standard Apartments, Residences. So there is not any distinguisment in Standard Apartment type for that period.

Accordingly, in order to define reference buildings a building stock was a necessity. The data was provided from Turkish Statistical Institute (TUIK) and are mainly: the number of floors, general area, structural system, construction materials, heating systems and fuel types, domestic hot water and fuel types. Other information for example the plan form of building typologies, apartment unit number of building typologies, transparency ratio, cooling system, etc. were gathered from academicians in the field via meetings and through project investigations. Therefore, with this information reference buildings of each residential building typology were formed.

Heat transfer coefficient values were decided in accordance with the given values in Turkish Heat Insulation Standard (TS 825). Therefore the building construction years were designated in accordance with the years TS 825 was updated. So, in addition to divide in building typologies, all typologies were divided in between construction years of 1985-1999, 2000-2008, 2009-2012.

Occupant profiles and schedules were decided in accordance with “Population and Housing Consensus” and “Income and Living Conditions Survey” of TUIK [TUIK, 2011; TUIK, 2012]. According to those researches average household member in Turkey is 3.6 which means couple and 2 children. Therefore, all scenarios were prepared considering this data, however for luxury high-rise residential buildings 2 person family (only couple) which is the second common household member number in accordance with the researches additionally considered. Electrical household appliances were defined through investigations in the market [Url-4; Url-5; Url-6]. National and international standards, regulations and TUIK database were used to designate power, efficiency value, lighting level and operational schedules of artificial lighting systems [Yılmaz et al. (project team), 2015].

Finally, 26 reference buildings were defined for four building typologies and construction periods. All of them were simulated in order to define their yearly energy consumption level and configure energy performance improvement retrofits. The simulation models were generated through DesignBuilder simulation tool and input data were entered and simulations were run through EnergyPlus. Both of them are scientifically proven tools. They are in the category of detailed dynamic simulation tool in EN 13790. According to the general results, standard retrofit measures are very effective to reduce the yearly energy consumption of single family houses and standard apartment units. However, in the case of luxury high-rise residential buildings standard retrofits are not enough to reduce the yearly energy consumption and advanced retrofit measures become a necessity. The striking point in the results is adding heat insulation to the facade was not effective and the yearly energy consumption of the building was not changing by this retrofit. That is because the existing façade components of luxury high-rise residenatial buildings are better performed than the limits (required values) in the standards (related TS 825).

2.2.5 Energy Efficiency Strategy Paper, 2012

The paper presents strategic guidelines and actions for creating energy efficiency in the building, transportation and industrial sectors in Turkey. It plans to enhance energy efficiency, preventing unconscious use and dissipation, and decreasing energy density either within the sectorial base or at the macro level. These guidelines form important components of the Turkish national energy policy, in all its stages from energy production and transmission to final consumption.

Purpose and main plan of the paper is to determine a political set supported with result focused and concrete targets and to define the to be made activities necessary for reaching targets together with the enterprises responsible for making these activities; to act in the framework of a collaboration and participatory approach of public and private sector and NGOs. It is targeted with this document to decrease at least 20% of amount of energy consumed per GDP of Turkey in the year 2023 (energy intensity).

2.2.6 Republic of Turkey National Renewable Energy Action Plan, 2014

The plan bases on the Directive 2009/28/EC of The European Parliament and of The Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC sets.

The intention of Turkey’s renewable energy action plan is to have at least 20% of renewable energy sources for its general energy consumption in 2023.

2.2.7 Republic of Turkey National Energy Efficiency Action Plan, 2016

The national action plan is mainly based on supplementing Directive 2012/27/EU and the reason of providing a national action plan is Annex XIV, Part 2: General framework for national energy efficiency action plans of the same Directive.

The plan also bases on EPBD 2010/31/EU, 2009/125/EC, 2010/30/EU. The plan was prepared for 2015-2023. According to the plan, energy inputs to the country is very few and expensive. This condition creates a very hard position for Turkey. Therefore the basic targets of this plan are the provision of supply security needs to be foregrounded, reducing the risks associated with import dependency, providing sustainable energy costs, increasing the effectiveness of struggle with climate change and protecting the environment.

Energy supply in Turkey equals to 78.3% of imported primary energy which is a high ratio of dependency. EU targets reducing primary energy need 20% until 2020. Turkey targets the same reduction until 2023.

The plan includes targets for different sectors. The energy efficiency measures for buildings in the national action plan are as following:

- Action plan for sustainable operation and supply
  - Adaptation of the EU Directive to the national legislation
  - Creation of a database including energy consumption data for buildings
- Energy identity certificate (EKB) / Building certificate
  - Application of energy identity certificates (EKB)
  - Increasing green certificate practice in buildings
- Residential building entrepreneurs
  - Enhancing energy efficiency in mass housing
- Energy Manager / Studies
  - Energy study funds towards building: Financial support for energy efficiency measures in buildings
  - Execution of the Best Practices Handbook for material and technology used in the construction sector
- Renovation plans / Subsidies
  - Rehabilitation and improvement of existing buildings: lighting, building insulation, replacing heating and ventilation systems.
- Energy production integration
  - Integration of renewable energy and cogeneration technologies into the building sector.

3. A NEW APPROACH TO DECREASE THE YEARLY PRIMARY ENERGY DEMAND OF LUXURY HIGH-RISE RESIDENTIAL BUILDINGS

In this part a new approach was introduced that bases on the developments that were explained in the preivous part. This approach was formed by the harmonization of the directives and plans of EU and Turkey, also since it is a unique approach on this scope necessary literature investigation was done in order to be sure not to be similar to any approach that was defined before. It aims to propose a guideline for the applications in order to reduce the yearly primary energy demand of luxury high-rise residential buildings.

3.1 Purpose

This part is to define the methodology of the thesis study. The thesis study includes lots of data based on the explained Directive (EPBD 2010/31/EU) and national Project (TUBITAK 1001) in the previous part. Calculation methodology is very important to reach reliable results.

As briefly explained in part 2.2.4, there is a specific residential building typology that the energy performance of it cannot be increased through standard retrofit measures and advanced retrofit measures are required. This building typology has high performed building envelope and their building envelope insulated more than the required level of the related standard, however due to the central mechanical heating, cooling and ventilating systems their energy consumption is still high. Therefore, reducing the loads on HVAC system would be the solution in order to reduce the yearly primary energy demand of this building typology and this could be done by improving the building envelope. However, since the envelope is already high performed in comparison to the requirements of the standards, advanced retrofits that are benefitting from renewable energy would be appropriate to apply in order to improve the architectural characteristics of the building. The main focus of this study is to provide an energy efficient solution to reduce the primary energy demand of luxury high-rise residential buildings. This building typology is a new and popular type in Turkey. The explained TUBITAK 1001 project was dealt with the yearly primary energy consumption of this building typology and it is concluded as stated that standard retrofit measures are not effective on reducing the primary energy consumption of luxury high-rise residential buildings since their building envelope is high performed according to the limit levels of the related standards. Therefore, advanced retrofits are crucial to implement on this building typology.

According to the literature review, there is not any research dealing with reducing the primary energy demand of luxury high-rise residential buildings through application of the methodology framework of EPBD 2010/31/EU, designating the importance of advanced façade retrofit measures when standard ones are not effective on this typology and investigating or proposing an advanced retrofit measure through its energy efficiency and thermal comfort levels. Then, there is a deficiency of an approach for reducing primary energy demand of luxury high-rise residential buildings. This typology has a fast growing number in the market. Therefore, reducing the energy demand of that typology will affect the current energy demand condition (country-based) very closely.

The approach has a general aspect and is adaptable to different building typologies and it is flexible to be applied both to new and existing buildings. This method is based on the methodology framework of EPBD 2010/31/EU that explained in part 2.1.2.

3.2 Steps of the Approach

This approach gets the methodology in EPBD 2010/31/EU and the steps are as following:

1. Determination of case study (reference) buildings and definition of reference building parameters
2. Calculation of primary energy demand of base case residential buildings
3. Determination of the advanced retrofit case and verification simulations if necessary
4. Determination of all retrofit measures
5. Calculation of primary energy demand of retrofit measures

6. Calculation of global costs in terms of net present value for base case and retrofitted cases and calculation of primary energy demand for all global cost analyzes
7. Investigation of thermal comfort condition
8. Analization of the effects of all retrofit measures on the base case energy performance

3.3 Determination of Reference Buildings and Definition of Reference Building Parameters

Reference buildings are very important to compare the energy performance retrofit measures and reveal the effects of the measures. In order to designate reference buildings, detailed data is necessary. The data for building location, form, floor area, building envelope thermo-physical properties, window-to-wall ratio, HVAC system components, DHW components, lighting appliances are requirements together with operational schedules for occupancy, electrical household appliances, lighting systems. Additionally, detailed information about operational schedules of HVAC systems are important parameters.

The list of the most important data/parameters for reference building definition in this approach as follows; climatic data, operation hours of the building, location, direction, geometry, surroundings, building envelope thermo-physical and optical characteristics, internal environmental quality conditions (boundary conditions), set-point temperatures (thermostat values). In terms of building envelope, only thermo-physical and optical properties of the building element/elements that are subject of the retrofit measures are necessary.

Basically, reference buildings are assumed that meeting the minimum requirements in the related standards for each category. For example for building envelope thermo-physical properties data in TS 825 Heat Insulation Standard should be met. For electrical household appliances ASHRAE Fundamentals 2009 requirements can be an important guidance, also data from the market is acceptable. For lighting appliances, the design values should met the required data in EN 12464 and EN 15193 or if there is a prepared project for lighting system it should be used. Also building energy performance calculation method of Turkey, BEP-TR considers these standards for national building energy certification calculations.

Within the scope of adapted calculation methodology and TUBITAK project, reference buildings were defined by virtual building method. This method is used when there is not any representative real building in the building stock, so a virtual building could be created. This building should contain all representative data related with its category and construction year. A reference building within the research studies could be the base condition of the case study building and retrofit measures could be compared with it. In this approach, reference buildings are defined as base condition of the case study buildings both for existing and virtual buildings. In this case, building envelope thermo-physcial and optical properties represent the existing building's data.

In order to compare different case study buildings climatic condition, building envelope thermo-physical and optical properties, boundary conditions data and operational schedules, thermostat values and operational schedules should be the same in between them (Single or multiple of them could be variable in accordance with the subject of the analyzes).

3.4 Calculation of Primary Energy Demand of Base Case Study (Reference) Buildings

In this proposed approach, the primary energy demand of the base case study also represents the reference value.

There are three methods to define the energy performance of the buildings in accordance with EN 13790:

- Measurement
- Manual
- Computational
    - Simple Hourly Method
    - Monthly/Seasonal Method
    - Detailed Dynamic Method

It is possible to gather energy consumption data of an existing building through measurement, however retrofits cannot be measured. Moreover, if the case study building is not a real building, manual or computational calculations are necessary. Frankly, measurement and manual calculation are waste of time and not reliable. Especially with the following step in energy performance calculations of retrofit measures. It is not possible to designate all of them (retrofit measures) through these methods. For reliable results computational calculations are necessary.

In order to reach dependable analysis results building energy performance simulation tools developed by US Department of Energy (DoE) can be used in the scope of this approach. DesignBuilder and EnergyPlus tools are tested and accuracy verified simulation tools by other research studies several times. Both of them base on detailed dynamic method of EN 13790. In detailed dynamic simulation methods, the input data (on heat transmission elements, heat transfer by infiltration and ventilation) are more detailed than for the monthly or simple hourly methods [CEN, 2008]. Briefly, the calculation shall be performed according to partitioning into zones; transmission heat transfer characteristics; ventilation heat transfer characteristics; internal heat gains; solar heat gains; dynamic parameters; internal conditions. The calculation also includes dynamic heat transfer via the ground, including thermal bridges; non-adiabatic internal walls and floors; linear thermal bridges; air flows between building zones; solar shading by, and reflection from overhangs, fins and external obstacles; angle-dependent solar properties of windows; hourly calculation of air infiltration [Gali, 2011].

DesignBuilder uses EnergyPlus as a calculation algorithm, so for calculations and data entrance EnergyPlus is better to be used. However, DesignBuilder is more user-firendly. Therefore, the simulation models of the case study buildings (3D building models) are composed in DesignBuilder, then are exported to EnergyPlus and all input data about reference parameters and variations for retrofit measures are entered in EnergyPlus. Finally, simulations should be run afterwards in EnergyPlus.

Within the scope of this approach energy performance calculations are done for yearly primary energy demand and not for consumption. Because the focus in the study is on advanced measures and in order to see the pure effect of retrofit measures on building energy performance there should be no intervention of HVAC system. So as to provide this type of calculation, HVAC system is modelled as Ideal Loads System under EnergyPlus simulation tool. This component can be thought of as an ideal unit that mixes air at the zone exhaust condition with the specified amount of outdoor air and then adds or removes heat and moisture at 100% efficiency in order to produce a supply air stream at the specified conditions [US DoE, 2014]. This method provides a model for an ideal HVAC system without any loss.

Primary energy demand calculation is done with the implementation of equation 2.1 in part 2.1.2.2 into the country conditions. For Turkey, revealed primary energy conversion factors by Turkish Ministry of Environment and Urbanization and indicated factors in Green Building Certification Guide can be used [ÇEBDİK, 2013]. The factors are 2.36 and 1 for electricity and other type of fuels respectively. Following equations 3.1, 3.2 and 3.3 should be used to calculate the primary energy demand in Turkey:

$$PED_e = T_{electricity} \; x \; 2.36 \tag{3.2}$$

$$PED_o = T_{other} \; x \; 1 \tag{3.2}$$

$$TPED = PED_e + PED_o \tag{3.3}$$

Where:

- PED_e is primary energy demand for electricity,
- $T_{electricity}$ is sum of total electricity energy demand,
- PED_o is primary energy demand for other fuel types,
- T_{other} is sum of total other fuel types energy demand,
- TPED is total primary energy demand.

3.5 Determination of the Advanced Retrofit Case and Verification Simulations (If Necessary)

This part is to create possible solutions for improving building energy performance of luxury high-rise residential buildings. As mentioned before, in order to improve the energy performance of this building typology, advanced retrofits are required. In addition, within the scope of EPBD 2010/31/EU and Turkish National Action Plan, increasing renewable energy use portion within the buildings is the common target. Therefore, an advanced retrofit that benefits from renewable energy should be defined. Advanced retrofit proposals could be both by applying existing advanced technologies or high-tech materials to the building envelope and testing their performance on specified case study building or defining a new advanced technology or component and applying it to the case study building and investigating the effects. While determining the most appropriate advanced retrofit the following parameters are effective:

- Building typology
- Climatic conditions
- Location
- Direction
- Building part that has the largest outdoor area
- Existing envelope components' thermo-physical and optical properties
- Occupant profile

The parameters above are the determinative and guiding information to decide the retrofit.

<u>Building typology:</u> The building heating and cooling demand requirements change in acordance with the building typology. So, for two buildings in the same area while in one of them an advanced retrofit for cooling is a necessity, for the other one an advanced retrofit for heating can be necessary.

<u>Climatic conditions:</u> The climate region that the building locates is very important to designate what kind of advanced retrofit is necessary. For example, if the building locates in a cold climate the proposal would be different than when the building locates in an area with high sunshine percentage.

<u>Location:</u> This parameter is important both to determine the climatic conditions of the building and the building surroundings.

<u>Direction:</u> This parameter is to define the main direction of the building. As it is known, design for each direction in the scope of façade, layout, etc. is different than the other and using South direction properly is very important (for the North hemisphere).

<u>Building part that has the largest outdoor area:</u> The advanced retrofit should include the largest outdoor area in order to benefit as possible as from renewable energy and

to be efficient the most. The largest outdoor area will be the most exposed area from solar radiation or wind depending on the climatic region. Also, applying a technology on a wide area will be more effective than applying it to a small area. Wide area would have effect on more internal zones because it will be in contact (sharing a building part) with as many as possible.

Existing envelope components' thermo-physical and optical properties: Mainly thermo-physical properties of building envelope should meet the minimum values in the related standards. If the envelope performance is better than the standards the level of being advanced of the retrofit should be increased in a parallel direction with the existing envelope performance. Because, retrofit measure focuses to improve the building energy performance in comparison to the base condition.

Occupant profile: It is a decisive feature in terms of cost. When the occupant profile is average the advancing level of the measure should stay in the lower limit that the occupants can afford. As the financial situation of the occupants increases the advancing level rises in a parallel direction. That means, when the occupant profile is in the upper group, the advancing level can be in the upper limit with high initial investment costs which causes high global costs.

If the advanced retrofit consists proposing a new component/system it is necessary to verify if the component/system serves as efficient as in theory. The verification analyzes can be done with EnergyPlus simulation tool. These simulation tests should be done through applying the proposed component/system directly on the base case study building and running the simulations for designated representative days for each season (These days may be 21st of January, April, July, October). The simulations should be hourly based for 1 year. During the verification simulations, HVAC system should be assumed as not exist, so the simulations should be run in free-running mode. The reason of this is to see the effect of newly designed advanced component/system alone. Hourly mean air temperature of the zones without (base case) and with the proposed component/system application should be compared to see if it answers and is effective. In order to provide comparative analyzes graphs should be drawn consisting hourly mean air temperature of the base condition and advanced retrofit for 8760 hours. If the mean air temperature is reduced in comparsion to the base case that means the proposed component/system is effective.

In order to continue with the verification analyzes parts of the proposed new component/system should be tested by omitting them step by step.

When it is determined that the proposed component/system works correctly and is efficient to reduce the mean air temperature of the zones, it may possible to determine the retrofit measures.

3.6 Determination of Retrofit Measures

The retrofit measures should be defined in accordance with the condition of the reference or base building. That means the level of basic solutions should be determined in accordance with the building's envelope thermo-physical properties, HVAC system condition and lighting system efficiency level. In the scope of this approach, only building envelope thermo-pyhsical properties are considered. Therefore, the level of basic is changeable.

There are two types of retrofit measures; Standard and Advanced.

Standard retrofit measures are related to architectural, mechanical or lighting systems. These measures are mostly in the basic level such as variation in building envelope heat transfer coefficient value (U value) both for opaque and transparent components. This can be alteration suggestions or heat insulation additions in building envelope components. Efficiency level modifications in HVAC system components or lighting appliances could be other standard retrofit proposals.

Advanced retrofit measures are related innovative and technological suggestions. These kinds of measures mostly consist of application of existing renewable energy systems or as a minority application of new systems that provide renewable energy use. This measure type should be preferred where standard retrofit measures are not effective on improving the base case building's energy performance level.

Measures can be single or a combination of single measures as a package.

3.7 Calculation of Primary Energy Demand of Retrofit Measures

The primary energy demand calculation of each case are done through the equations 3.1, 3.2 and 3.3 as in part 3.4. For the analyzes same building energy performance simulation tools are used.

According to the common general framework for the calculation of energy performance of buildings that was explained in Directive 2010/31/EU, the energy performance of a building shall be expressed in a transparent manner and shall include an energy performance indicator and a numeric indicator of primary energy use, based on primary energy factors per energy carrier, which may be based on national or regional annual weighted averages or a specific value for on-site production. The methodology for calculating the energy performance of buildings should take into account European standards and shall be consistent with relevant Union legislation, including Directive 2009/28/EC. Moreover, according to the comparative methodology in Directive 2010/31/EU Member States shall require to assess the final and primary energy need of the reference buildings and the reference buildings with the defined energy efficiency measures applied.

As this methodology aims to proceed in the scope of the Directive, first the annual energy demands for each retrofit case (expressed in terms of ideal loads) of case study buildings should be assessed by means of the dynamic energy simulation software EnergyPlus. Then, in order to develop an analysis in convenient to the Directive, primary energy demand of each case should be estimated considering an HVAC system with an ideal efficiency equal to 1 to focus on the sole effect of the retrofit measures.

3.8 Calculation of Global Costs in Terms of Net Present Value for Base Case (Reference) and Retrofitted Cases and Calculation of Primary Energy Demand for All Global Cost Analyzes

This approach follows financial cost calculation concerning individual perspective of the owner.

Net present value represents the current worth of a cash flow over time [Olson et al., 2009]. This cost estimation method considers time value of the money by converting all future incomes and outcomes to the present value using a discount rate.

In order to calculate the global cost different cost categories should be calculated as explained in part 2.1.2.4. In this approach, global cost includes initial investment cost, running costs, replacement costs, energy costs and residual value.

3.8.1 Calculation of initial investment cost

Initial investment cost directly depends on the market conditions. In order to gather reliable information recent architectural and constructional projects, constructional firms, material firms in the market together with the provided info by related government body can be considered. Information exchange between sectoral firms is crucial.

Initial investment costs include material, transportation, labor, scaffolding costs and all of them are variable in accordance with the city of the project, required amount of the material, prestige of the project and experience level of the bidder. Therefore, in order to determine the initial investment costs it is better to receive tender from around three different material firms if possible and assume the average number of the total as the tender.

Another possible designation method is to receive tender for the related subject from a dominant company in the market or a third method is providing the costs from the designated values of the related governmental body; for example in Turkey Construction and Installation Unit Prices of Ministry of Environment and Urbanization. Transportation and labor costs could be provided from material firms, if it is not possible then these costs should be gathered separately.

TAXs should be added into the gathered costs.

Initial investment costs should be calculated in accordance with the equation 2.2 in part 2.1.2.4.

3.8.2 Calculation of annual costs

Annual costs include two different cost categories: running costs, replacement costs. In order to calculate annual costs both of them should be considered.

3.8.2.1 Calculation of running costs

Running costs include maintenance costs, operational costs and energy costs. Within the scope of this approach only the energy costs are calculated and calculated with the adaptation of equation 2.6 in part 2.1.2.4.

In order to calculate energy costs for Turkey, natural gas unit price is taken 0.1097754 TL/kWh, electricity unit price is taken 0.36637 TL/kWh considering 2015 values including TAX [Url-7, Url-8]. Through multiplying this values with the related energy demand of each component, yearly cost of energy demand of the starting year would be defined. The increase in energy costs was assumed as equal to the inflation rate.

3.8.2.2 Calculation of replacement costs

Replacement costs includes the replacement of building elements within the scope of this approach. Because HVAC system components are not included the scope of this approach. The system is modelled as 100% efficient by defining it as Ideal Loads.

Therefore lifespan information of building construction elements are necessary. This info cannot be gathered from the related standard. The data for the products should be gathered from the market. Also, related material and product firms can provide this information. Replacement cost is calculated with the adaptation of equation 2.8 in part 2.1.2.4.

3.8.3 Calculation of global cost

Global cost is the sum of the above explained costs together with the residual value in accordance with the lifespan of the element and the lifetime of the building. Global cost is calculted in accordance with the equation 2.9 in part 2.1.2.4. The inflation rate is taken as 8.05%, according to the statistics of Turkish Republic Central Bank’s last 5 years’ average value. Market rate of interest rate is 14.3% [Url-9].

3.8.4 Primary energy demand – global cost analyzes

After calculating primary energy demand and global cost for base case and retrofit measures, simultaneous comparison of primary energy demand and global cost results is used to define the cost-optimum measures. Therefore, in order to provide this comparison, a graph should be drawn while yearly primary energy demand (kWh/m².y) locating on X axis, global cost (currency/m²) locates on Y axis. The case/cases that provide cost-optimum energy efficiency level can be determined by monitoring the changes in global cost and primary energy demand for the retrofit measures through this graphical plot.

In case if the measures are not cost-optimum then the most energy efficient measures should be taken into account if possible.

3.9 Investigation of Thermal Comfort Condition

It is very important to evaluate the effects of retrofit measures on thermal comfort. The indicator to define the most efficient improvement case is the energy saving level together with improvement in thermal comfort conditions that means the measure providing highest energy efficiency level.

Within the scope of this approach, thermal comfort of the base case buildings and retrofit measures are evaluated through calculating uncomfortable hours. In order to define limit levels, first of all comfort level expectation of the building should be defined. The following Table 3.1 shows the comfort level expectations that are described in EN 15251 [BSI, 2008].

After designating the category the recommended design values for related category should be selected from EN 15251, Annex A, "Table A.2: Examples of recommended design values of the indoor temperature for design of buildings and HVAC systems" and "Table A.3: Temperature ranges for hourly calculation of cooling and heating energy in three categories of indoor environment".

Table 3.1 : Comfort categories according to EN 15251.

Category	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

After designating the limit design values, base case building and each retrofit measure are run in free-running mode (without HVAC installation definitions) and hourly operative temperatures for 1 year are designated. Then, a table is formed. Microsoft Excel can be used for providing table view. In the table, two columns for each case should be provided. The first column includes operative temperatures in hourly based, so there will be 8760 rows for each case. The second column is necessary to show the operative temperature values that are below heating design value or above cooling design value. If the operative temperature at in an hour is below the heating design value, a number of “1” is written in the second column against the related hour. If the operative temperature at in an hour is above the cooling design value, a number of “1” is written to the second column against the related hour. A partial example for four different hours when the design values are assumed for heating is 21 °C and for cooling is 25 °C is shown in Table 3.2.

This table should be done in a consecutive order for the whole year (8760 hours). At the end of the table the number “1”s in the right column are summed and this summation gives the total number of uncomfortable hours. If the total number of uncomfortable hours of a retrofit measure is less than base case’s that means the related retrofit measure is improved the comfort level; if the total number of uncomfortable hours of a measure is more than base case’s then this means the related retrofit measure is belove the comfort level.

Table 3.2 : Uncomfortable hours calculation table.

Hours of the Year (Month/Day/Hour)	Case I Operative Temperature (°C)	Case I Uncomfortable Hours Count
01/24 13:00:00	16	1
04/14 12:00:00	22	-
07/30 15:00:00	33	1
11/10 11:00:00	25	-

3.10 Analization of the Effects of All Retrofit Measures on the Base Case Energy Performance

In this part primary energy demand, global cost and thermal comfort level results of the measures are compared and the most effective measures are determined. A retrofit measure should improve at least 1 of these parameters in respect to the base case, in order to be counted as effective. However, providing energy saving and thermal comfort together is crucial in the case of advanced retrofits.

4. APPLICATION OF THE SUGGESTED APPROACH TO DIFFERENT CASE STUDY BUILDINGS IN ORDER TO REDUCE THEIR PRIMARY ENERGY DEMAND AND INCREASE THERMAL COMFORT LEVEL

This part of the study is to show the applicability of the approch that was explained in part 3. As mentioned, standard measures are not effective on reducing the yearly primary energy demand of luxury high-rise residential buildings. Therefore, the approach was developed for the application of advanced retrofit measures.

Advanced measures could be in two ways as application of an existing component/system or proposing a new component/system. Within the scope of this thesis study proposing an advanced new facade component was handled. It should be a totally new construction component that was not investigated before in any research study.

Detailed analyzes were performed on three different case study buildings with different plan schemes and layouts in order to analyze the effects of proposed new advanced facade component through proposed method in different situations. The first case study building represents an existing case with complex conditions in the scope of location, direction, etc. The second case study building represents the condition of the building when it is in convenience with the passive design parameters. The third case study building represents the buildings with more storey.

Application of the approach on the case study buildings is explained separately in order to be clear. Climatic conditions, building envelope thermo-physical and optical properties, boundary conditions (mostly) and proposed advanced facade component features are the same for all three case study buildings. That is because to reveal the effect of the proposed advanced facade component on different buildings and in order to do this the only variant should be the building layouts. Additionally, it is important to show how the methodology can be applied on different buildings, therefore the application of the approach takes part in different chapters for separate case study buildings.

4.1 Application of the Suggested Approach on First Case Study Building

4.1.1 Definition of first case study residential building and reference parameters

This part contains the necessary data about the first case study building. This data as explained in part 3.3 in detail is required to define the first reference building for this study and also crucial for the investigations.

4.1.1.1 Climatic condition of the first case study building

Proposal of a new advanced component will be varied for different climatic areas. Therefore, it is important to designate an average climatic region that represents the common conditions. Istanbul is in the warm-humid climatic region of Turkey and very close to the Mediterranean climatic conditions. Winters are cool with low temperatures averaging 1–4 °C. Springs and autumns are mild, but often rainy and unpredictable. Summers are hot during the daytime while evenings are usually cooler and windy. With this specialities, climatic condition of Istanbul also represents other Mediterranean countries in EU. Since the thesis study mainly depends on the directives of EU, the applicability of the proposed component in other Mediterranean countries is crucial. Therefore, Istanbul climatic region is very suitable to investigate the proposed advanced component because of the applicability in different countries.

The weather data for simulations was obtained from weather data source of EnergyPlus [Url-10].

4.1.1.2 Location, direction and geometry of the first case study building

First case study building is a representative existing luxury high-rise residential building in Istanbul. The building was selected in accordance with the common characteristic properties of luxury high-rise residential buildings that were defined in TUBITAK project. Therefore, the first case study building is one block of Kanyon Residence which is residential block of mixed functioned building complex. The case study building is shown in Figure 4.1 in red colored rectangle. The main direction of the building is East. As in Figure 4.1 there is a high-rise building very close to the case study building block shown in blue colored rectangle (on the West direction of the case study building). This building was considered in all simulation tests as surrounding that causes shading effect on the case study building.

Figure 4.1 : First case study building.

There are 5 more adjacent residential building blocks next to the case study building. This condition is shown in Figure 4.2 in an open formatted vertical section of the building blocks.

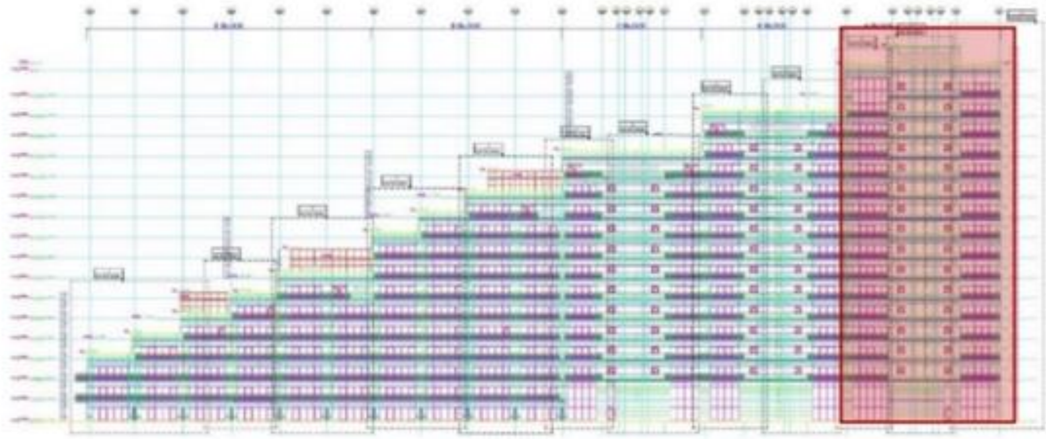


Figure 4.2 : Architectural vertical section of all blocks.

The red colored rectangle shows the case study building block. South facade of the case study building is adjacent as in Figure 4.2, thus it was modeled as adiabatic in the simulation tests. Additionally, there are other functions under the residential floors, therefore the floor of first residential floor was modeled as adiabatic too. The main subject is facade components in this thesis study, therefore the other building envelope components are not in the scope of this thesis.

All floor functions and adiabatic surfaces are shown in Figure 4.3. As it can be seen in the figure, there are 12 more floors under the first residential floor and 8 of them are in underground level. Undermost 4 floors are storage areas. Upper 5 floors are shop areas and uppermost 3 floors are city club. Then, there are 15 residential floors. First seven floors have four apartment units in each floor. Only in the second floor on the right side there is one apartment unit instead of two according to the owner's request. In the upper 8 floors there are two apartment units in each floor. The unit interior layout is differed in 14th and 15th floors on the left side and on the right side there is a duplex unit. These differentiations are depend on the owner's requests.

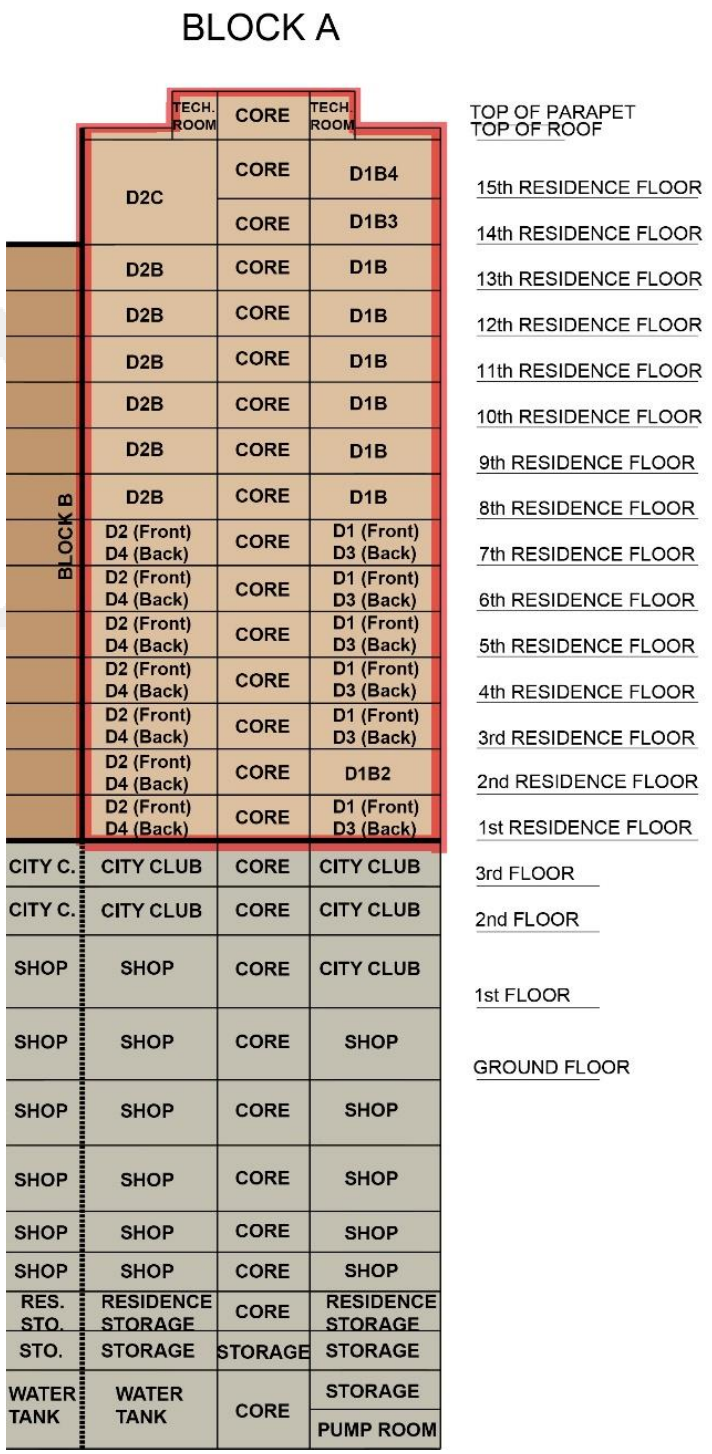


Figure 4.3 : Architectural vertical section of first case study building.

This case study building is a good example for the strictions in the location, direction and surroundings. Because the metropolises that this building typology is very common are very crowded and it is very important to show the effects of this condition. This doesn’t mean that luxury high-rise residential buildings always locate on crowded areas, but it is a case example with the level as complex as it can be.

This case study building represents the variations in the apartment unit layout of luxury high-rise residential buildings. Because, unlike standard residential buildings, there is not any generalization for apartment unit layout and number of occupants (room numbers) for this building type.

The researches and surveys on the number of household members present the general apartment unit layout. Additionally, the researches on existing luxury high-rise buildings show the differentiation of layout (necessary room numbers) in comparison to the standard residential buildings. According to the Population and Housing Survey 2011 results of TUIK, the average household size in Turkey was announced 3.8 and in Istanbul 3.6 [TUIK, 2011]. According to TUIK Income and Living Conditions Research, in 2012, 54% of households constitute core families consisting of couples with children [TUIK, 2012]. For this reason, while the usage pattern was determined each residential building type was assumed as used by a quadruple family. However, as a difference from the other residential building typologies for the apartment units with 1+1 layout in luxury high-rise residential buildings, the household acceptance was made of couples without children followed by a percentage of 15.8% of the household consisting of the couples with children according to the data of TUIK. Therefore, as in this case study building 1+1 layout is very common in luxury high-rise residentail buildings as distinct from standard residential buildings.

There are different apartment unit types within this block as explained. The apartment unit differentiations and net areas of each floor is shown in Table 4.1.

Table 4.1 : Apartment unit types (AUT) in first case study building.

	AUT	Number of Rooms	Area (m²)	Type
Between 1st and 7th residence floors	D1 D2	1+1	108.06 m²	Type 1
	D3 D4	1+1 (+1 study room)	116.48 m²	Type 2

Table 4.1 (continued): Apartment unit types (AUT) in first case study building.

	AUT	Number of Rooms	Area (m²)	Type
2nd residence floor North side	D1B2	3+1	229.05 m²	Type 3
Between 8th and 13th residence floors	D1B D2B	4+1	220.9 m²	Type 4
14th residence floor South side	D2C	4+1 (duplex)	329.9 m²	Type 5
14th residence floor North side	D1B3	1+1 (+1 living room)	191.3 m²	Type 6
15th residence floor North side	D1B4	2+1	191.4 m²	Type 7

In accordance with the distinguisment in Table 4.1 there are 7 apartment unit types in this case study building. The distribution of the units for the first seven floors are mostly Type 1 and Type 2. And starting from the 8th floor the most common unit is Type 4. The standard location of the apartment units in the floors are shown in the architectural plan view in Figure 4.4.

Figure 4.4 : Architectural zoning of the typical floors of first case study building.

The room types in architecutral plan is shown in Figure 4.5. As explained, mainly there are 1+1 types in the first 7 floors and 4+1 types in the upper 8 floors. Also, there are some differentiations. Figure 4.5 represents the most common layouts within the project.

Figure 4.5 : Architectural plans of the typical floors of first case study building.

4.1.1.3 Building facade thermo-physical and optical characteristics

As mentioned, the main focus of this thesis study is the facade and facade retrofits. Therefore, the information in this part is necessary only for facade. Because the varied parameter will be facade features. According to the investigations most common opaque facade components for luxury high-rise residential buildings are aluminum or ceramic curtain wall claddings. In this case study building, the opaque facade component is ceramic cladding. All thermo-physical data for construction materials of exterior wall component were gathered and thermal transmittance value (U-value) of the opaque facade component was calculated. Obtained data and the sources are shown in Table 4.2.

Table 4.2 : Thermo-physical properties of opaque external wall component.

Material	Thick ness (m)	Conductivity (W/m.K)	Density (kg/m³)	Specific Heat (J/kg.K)	Reference	U-value (W/m².K)
Ceramic	0.01	1.3	2300	840	BEP-TR,2010	
Air	0.16	R= 0.16 m².K/W Vertical>100 mm			TSE, 1999	
Black glass tissue	0.08	0.039	50	840	Url-11	
Waterproof membrane	0.001	0.19	2000	1000	BEP-TR, 2010	0.296
Aerated BIMS	0.2	0.28	450	1000	BEP-TR, 2010	
Air	0.1	R= 0.17 m².K/W Vertical, 51-100 mm			TSE, 1999	
Internal covering	0.02	0.21	700	1000	BEP-TR, 2010	

Thermo-physical and optical properties of transparent facade component was collected from the building management. The obtained data is shown in Table 4.3.

Table 4.3 : Thermo-physical and optical properties of the glazing and the frame.

Building Element	U-value (W/m².K)	SHGC	T_{vis}
Glazing	1.56	0.45	0.51
Frame	1.8	-	-

As a regulation in Turkey, U-value of the building facade components should meet the given values in TS 825 Heat Insulation Standard. The building was constructed between 2000-2006 and TS 825 1999 was in force at that time. Therefore, U-values of opaque and transparent facade components should be proper to the limit values in this standard. The comparison between U-values of the case study building facade and TS 825 1999 is shown in Table 4.4.

Table 4.4 : Comparison of U-values of case study building and TS 825 1999.

Building Component	Case Study Building U-value (W/m².K)	TS 825 1999 U-value (W/m².K) [TSE, 1999]
External Wall	0.296	0.6
Window	1.65	2.8

Related U-values in TS 825 are defined in accordance with the climatic conditions. The values in Table 4.4 are defined values for the climatic zone of Istanbul. As in Table 4.4, thermo-physical properties of the facade components are better than the values suggested in the standard. This is a very important parameter to direct the study to the advanced facade retrofits. Because the facade U-values are not in the limit and far better than the recommended values.

4.1.1.4 Boundary conditions and operational schedules

Boundary conditions for occupancy, household electrical appliances and lighting were designated by investigating several luxury high-rise residential building projects.

The average household member rate in Turkey is 3.8 according to Turkish Statistical Institute (TUIK). So, most common family consists of parents and 2 children. However, one of the findings of the investigations for occupancy is there is not any specific limit for household members of luxury high-rise residential buildings. Additionally, according to TUIK data second most common family type in Turkey is couple without children and this type of family usually prefers to live in luxury high-rise residential buildings.

Briefly, the number of the occupants for each apartment unit were determined in accordance with the room numbers since this is an existing case condition. Additionally, since the occupant profile of these buildings are high-income group a stayed-in or a daily housekeeper was defined for each apartment unit. In summary there are two, three and four-person families in this case study building. So, there are 3 different operation schedules for occupancy. The operational scenario for occupancy was defined according to the published researches by Ministry of Family and Social Policies in 2011 and 2013 [Republic of Turkey Ministry of Family and Social Policy, 2011; 2013]. Activity levels of the occupants were specified in accordance with ASHRAE 55 – Thermal Environmental Conditions for Human Occupancy standard [ANSI/ASHRAE, 2013]. User intensity diverse from 33 to 38 m²/person. Only in three of the apartment unit types this value is different; in D1B3 type 63 m²/person, in D2C type 54 m²/person and in D1B4 47 m²/person.

Operation schedule for 2-person family with a daytime housekeeper (housekeeper during weekdays between 08:00-17:00) is shown in Table 4.5; for 3-person family with a daytime housekeeper in Table 4.6; for 3-person family with a stay-in housekeeper in Table 4.7; and for 4-person family with a stay-in housekeeper in Table 4.8.

Table 4.5 : Occupancy operation schedule for 2-person family with a daytime housekeeper.

	Hours	Number of People	Activity
Weekdays	00:00-07:00	2	Sleeping
	07:00-08:00	2	Getting ready
	08:00-17:00	1	Housework
	17:00-23:00	2	Dinner, House activities
	23:00-24:00	2	Sleeping
Saturday	00:00-11:00	2	Sleeping, Reclining
	11:00-12:00	2	Breakfast, Getting ready
	12:00-18:00	0	-
	18:00-20:00	2	House activities
	20:00-23:00	0	-
	23:00-24:00	2	Sleeping, Reclining
Sunday	00:00-11:00	2	Sleeping, Reclining
	11:00-12:00	2	Breakfast, Getting ready
	12:00-15:00	0	-
	15:00-23:00	2	Dinner, House activities
	23:00-24:00	2	Sleeping, Reclining

Table 4.6 : Occupancy operation schedule for 3-person family with a daytime housekeeper.

	Hours	Number of People	Activity
Weekdays	00:00-07:00	3	Sleeping
	07:00-08:00	2	Getting ready
	08:00-17:00	1	Housework
	17:00-18:00	2	House activities
	18:00-23:00	3	Dinner, House activities
	23:00-24:00	3	Sleeping
Saturday	00:00-11:00	3	Sleeping, Reclining, Standing
	11:00-12:00	3	Breakfast, Getting ready
	12:00-18:00	1	House activities
	18:00-20:00	3	House activities
	20:00-23:00	2	Dinner, House activities
	23:00-24:00	3	Sleeping, Reclining
Sunday	00:00-11:00	3	Sleeping, Reclining, Standing
	11:00-12:00	3	Breakfast, Getting ready
	12:00-15:00	1	House activities
	15:00-23:00	3	Dinner, House activities
	23:00-24:00	3	Sleeping, Reclining

Table 4.7 : Occupancy operation schedule for 3-person family with a stay-in housekeeper.

	Hours	Number of People	Activity
Weekdays	00:00-07:00	4	Sleeping
	07:00-08:00	2	Getting ready
	08:00-17:00	1	Housework
	17:00-18:00	2	House activities
	18:00-23:00	4	Dinner, House activities
	23:00-24:00	4	Sleeping
Saturday	00:00-11:00	4	Sleeping, Reclining, Standing
	11:00-12:00	4	Breakfast, Getting ready
	12:00-18:00	2	Housework
	18:00-20:00	4	House activities
	20:00-23:00	3	Dinner, House activities
	23:00-24:00	4	Sleeping, Reclining
Sunday	00:00-11:00	4	Sleeping, Reclining, Standing
	11:00-12:00	4	Breakfast, Getting ready
	12:00-15:00	2	Housework, House activities
	15:00-23:00	4	Dinner, House activities
	23:00-24:00	4	Sleeping, Reclining

Table 4.8 : Occupancy operation schedule for 4-person family with a stay-in housekeeper.

	Hours	Number of People	Activity
Weekdays	00:00-07:00	5	Sleeping
	07:00-08:00	2	Getting ready
	08:00-17:00	1	Housework
	17:00-18:00	2	House activities
	18:00-23:00	5	Dinner, House activities
	23:00-24:00	5	Sleeping
Saturday	00:00-11:00	5	Sleeping, Reclining, Standing
	11:00-12:00	5	Breakfast, Getting ready
	12:00-18:00	3	Housework, House activities
	18:00-20:00	4	House activities
	20:00-23:00	2	Dinner, House activities

Table 4.8 (continued): Occupancy operation schedule for 4-person family with a stay-in housekeeper.

	Hours	Number of People	Activity
Sunday	23:00-24:00	5	Sleeping, Reclining
	00:00-11:00	5	Sleeping, Reclining, Standing
	11:00-12:00	5	Breakfast, Getting ready
	12:00-15:00	2	Housework, House activities
	15:00-23:00	5	Dinner, House activities
	23:00-24:00	5	Sleeping, Reclining

Average power values of household electrical equipment were designated by investigating the existing household electrical equipment in the market [Url-4; Url-5; Url-6]. Determined equipment powers and operating times per each apartment unit were defined in Table 4.9.

Table 4.9 : Household electrical equipment powers and operation schedules.

Household Electrical Equipment	Power (W)	Operating Time
Refrigerator	54.3	All day (24 h)
Oven	3100	6 hours / week
Electrical Stove	7200	Weekdays: 2 hours / day Saturday: 2 hours / day Sunday: 1.5 hours / day
Range Hood	290	Weekdays: 2 hours / day Saturday: 2 hours / day Sunday: 1.5 hours / day
Dishwasher	1399	4 hours / week
Washing Machine	718.2	4 hours / week
Tea Maker	1650	All week: 2 hours / day
Iron	2600	6 hours / week
Vacuum Cleaner	1450	4.5 hours / week
TV	128	Weekdays: 3 hours / day Weekends: 5 hours / day
Laptop	88	Weekdays: 3 hours / day Weekends: 5 hours / day

In order to define lighting power density, lighting projects of luxury high-rise residential buildings were investigated and it was revealed that there is not any limitation for lighting appliance or luminaire selection in this building type. The selection highly depends on the occupants. So, lighting projects are collected from electricity project group of Kanyon Residence and lighting power densities for each apartment unit were designated from the projects. They are shown in Table 4.10.

Table 4.10 : Lighting power densities of each apartment unit type.

Apartment Unit	Lighting Power (W)	Lighting Power Density (W/m^2)
Between 1st and 7th residence floors	D1, D2: 1100 D3, D4: 1100	10.18 9.44
2nd residence floor North side	D1B2: 2657	11.6

Table 4.10 (continued): Apartment unit types (AUT) in first case study building.

Apartment Unit	Lighting Power (W)	Lighting Power Density (W/m²)
Between 8th and 13th residence floors	D1B, D2B: 1850	8.4
14th residence floor South side (duplex)	D2C: 7250	21.97
14th residence floor North side	D1B3: 1900	9.9
15th residence floor North side	D1B4: 1850	9.7

4.1.1.5 Information data for heating and cooling system

Thermostat values for heating and cooling periods were defined in convenient to the data that were collected from Kanyon Residence mechanical engineering project group. So, heating set-point was designated as 22 °C and cooling set-point was designated as 24 °C. Accordingly, since the retrofits are through the façade, in order to see the influence of the proposed façade component on building energy performance, it is important to see the effects of the retrofit cases without any intervention from HVAC systems. Therefore, the thermostat values are the only necessary data for HVAC system. Because, in order to see the effects of facade mesasures, HVAC system was modelled as 100% efficient in ideal loads mode.

4.1.1.6 Other

As an additional internal comfort parameter, all windows have texture roller interior shading device according to the architectural projects. Thermal and optical characteristics of the chosen shading device are shown in Table 4.11. The data was collected from a well-known window treatments firm's software [Hunter Douglas, Energy and Light Tool].

Table 4.11 : Thermal and optical characteristics of the interior shading device.

Characteristics	Values
Solar Transmittance	0.349
Solar Reflectance	0.597
Visible Transmittance	0.35
Visible Reflectance	0.649
Thickness (m)	0.0002
Conductivity (W/m.K)	0.3

Working schedule of the shading device was decided in accordance with investigations. The operational schedule is basically during the heating period, shading devices are off between the hours 08:00 to 18:00 on weekdays and off between the hours 11:00 to 18:00 on weekends. During the cooling period, shading devices are off between the hours 15:00 to 18:00 for the whole week. This schedule highly depends on the general behaviors of the occupants as investigated. However, a generalization is crucial for the simulation tests. Therefore, the closest scenario to the most common real use was designated.

Additionally, there is daylight automation control in the living room of each apartment unit.

4.1.2 Primary energy demand calculation and result of first case study residential building

The calculation of yearly energy demand of the first case study building were done in convenient to the method of part 3.4 and through internationally known and scientifically proven before mentioned building energy performance simulation tools. Case study buildings were geometrically modelled by using DesignBuilder v4.2 and all detailed input data for building energy performance calculations were defined in EnergyPlus v8.2. Both simulation tools are under the license of US Department of Energy (DoE). Weather data was gathered from the database of EnergyPlus [Url-10].

As a result of the analysis yearly energy demand of the first case study building was designated and the results are distinguishedly shown in Table 4.12.

Table 4.12 : Yearly energy demand results of first case study building.

Yearly Energy Demand for Heating (kWh/m².y)	Yearly Energy Demand for Cooling (kWh/m².y)	Yearly Energy Demand for Lighting (kWh/m².y)	Total (kWh/m².y)
22.99	42.02	19.12	84.13

In order to calculate the yearly primary energy demand of the first case study building, the equations that was explained in the approach were used. Thus, for the calculation of yearly primary energy demand for cooling and lighting equation 3.1, for heating equation 3.2 and for the total equation 3.3 were used. The results are shown in Table 4.13.

Table 4.13 : Yearly primary energy demand results of first case study building.

Yearly Primary Energy Demand for Heating (kWh/m².y)	Yearly Primary Energy Demand for Cooling (kWh/m².y)	Yearly Primary Energy Demand for Lighting (kWh/m².y)	Total (kWh/m².y)
22.99	99.17	45.12	167.28

4.1.3 Explanation of the proposed advanced retrofit measure and verification simulations

The proposal is defining a new advanced component in order to reduce the yearly primary energy demand of the luxury high-rise residential buildings. The advanced retrofit measure was designated in accordance with the parameters in part 3.5:

- The building typology is luxury high-rise residential building. Providing energy saving during the heating period is more important for residential buildings. Therefore, the advanced retrofit should ensure increase in solar gains.

- The building locates in warm-humid climate. Therefore, providing energy performance improvement also in cooling period in addition to the heating period is necessary.

- The building locates in Istanbul, Levent district. There are lots of high-rise buildings at that area. One of them is very close to the case study building and has shading effect on it.

- The direction of this building is East façade. Therefore, maybe the advanced retrofit could not show its real efficiency (Further cases should be done with another case study building).

- Since the dealt building typology is luxury high-rise residential buildings the largest outdoor area of the buildings is their facades. Thus, proposing an advanced façade component would be logical in order to benefit from the most.

- The building façade existing components' thermo-physical and optical properties are better performed than the required levels in TS 825 standard. Therefore, the building façade is high-performed in its base condition. Therefore, standard façade retrofits would be meaningless. Advanced façade retrofits should be proposed.

- The occupant profile of luxury high-rise residential buildings is usually high income group. Therefore, they are open for increase in initial investment cost of an apartment unit. Thus, an advanced façade retrofit that is not cost-optimum suits to this building typology and occupant profile since it provides reduction in monthly energy costs.

Therefore, in the light of the explanations above, an advanced retrofit is a necessity in this building typology and it should reduces firstly the heating demand and then cooling demand. In order to increase solar gains selective surface use would be a suitable choice. Additionally, since the largest part of the building is its façade, this retrofit should be an advanced façade retrofit in order to benefit from it the most. Additionally, a façade component proposal that benefits from renewable energy will be the best combination in order to provide the requirements of the Directive and National Action Plan by increasing the renewable energy portion in buildings and improving the building energy performance. Finally, this advanced façade retrofit can increase the initial investment cost, since it reduces the energy costs it is more than welcome.

4.1.3.1 Definition of the construction details of the proposed new advanced façade component

Ceramic, aluminum or glazing curtain walls are most preferred building facade components for luxury high-rise residential buildings according to the research results through investigating several existing luxury high-rise residential building projects. The opaque facade component of the case study buildings in this thesis study is ceramic curtain wall cladding in the base condition. It is assumed that the proposed advanced facade component was applied as an opaque facade component that has glazing as outermost layer. Therefore, in the advanced retrofit cases the proposed facade component was applied on the designated facade surfaces instead of ceramic cladding.

The proposed component locates in front of concrete wall layer as shown in the architectural plan in Figure 4.6 instead of existing cladding. Basically, a selective surface layer locates on concrete wall and after 10 cm of air gap, glazing layer locates. Selective surface layer can be aluminum or copper based according to the market research, so the base material of the selective surface differs in between cases. Thermal conductivity values and initial costs of these two base materials are different. According to the data in BEP-TR: Opaque Material Library, thermal conductivity of aluminum is 160 W/m.K and copper is 392.6 W/m.K [BEP-TR, 2010]. Also, the unit price of a copper based selective surface layer is 39 TL/m² more expensive than aluminum based selective surface layer. Therefore, both layer types were investigated in the energy performance simulations. Another difference between the cases is concrete wall thickness. It changes as 20 cm or 40 cm depending on the case. The reason of this difference is to analyze the effect of mass wall thickness on the primary energy demand results.

In addition to the construction material layers, there are additional features to block overheating during cooling period. Façade vents applied to increase ventilation rate in the gap and shading devices applied to decrease the solar gains during cooling period.

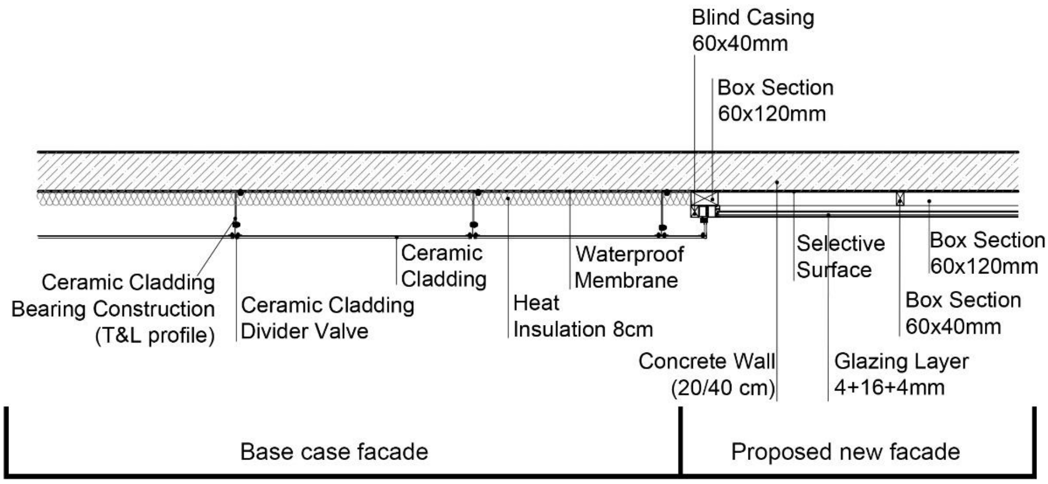


Figure 4.6 : Partial architectural plan of the base case and proposed component applied facade.

On the left side of the plan in Figure 4.6 there is the facade of the base case building and on the right side of the plan there is the plan of the proposed component applied facade part. In some cases of this thesis study, proposed facade component wasn't applied on all facade surfaces, but applied on the available opaque areas. Therefore, at some point the two facade component come next to each other. Basically the proposed facade component was applied on opaque facade areas.

As it can be clearly seen in the plan view, there is selective surface application on the right side instead of heat insulation. Also, the hole depth is narrower than the ceramic cladding application's. There is another type of beaming construction (box profiles) on the right side in order to carry the facade component. The outermost layer of the proposed component is a glazing layer instead of ceramic cladding.

Architectural vertical sections of the base case and proposed facade component applied facade parts are shown in Figure 4.7. The additional features for cooling period can be seen clearly in the sections. There are inlet and outlet vents for each floor together with shading device application.

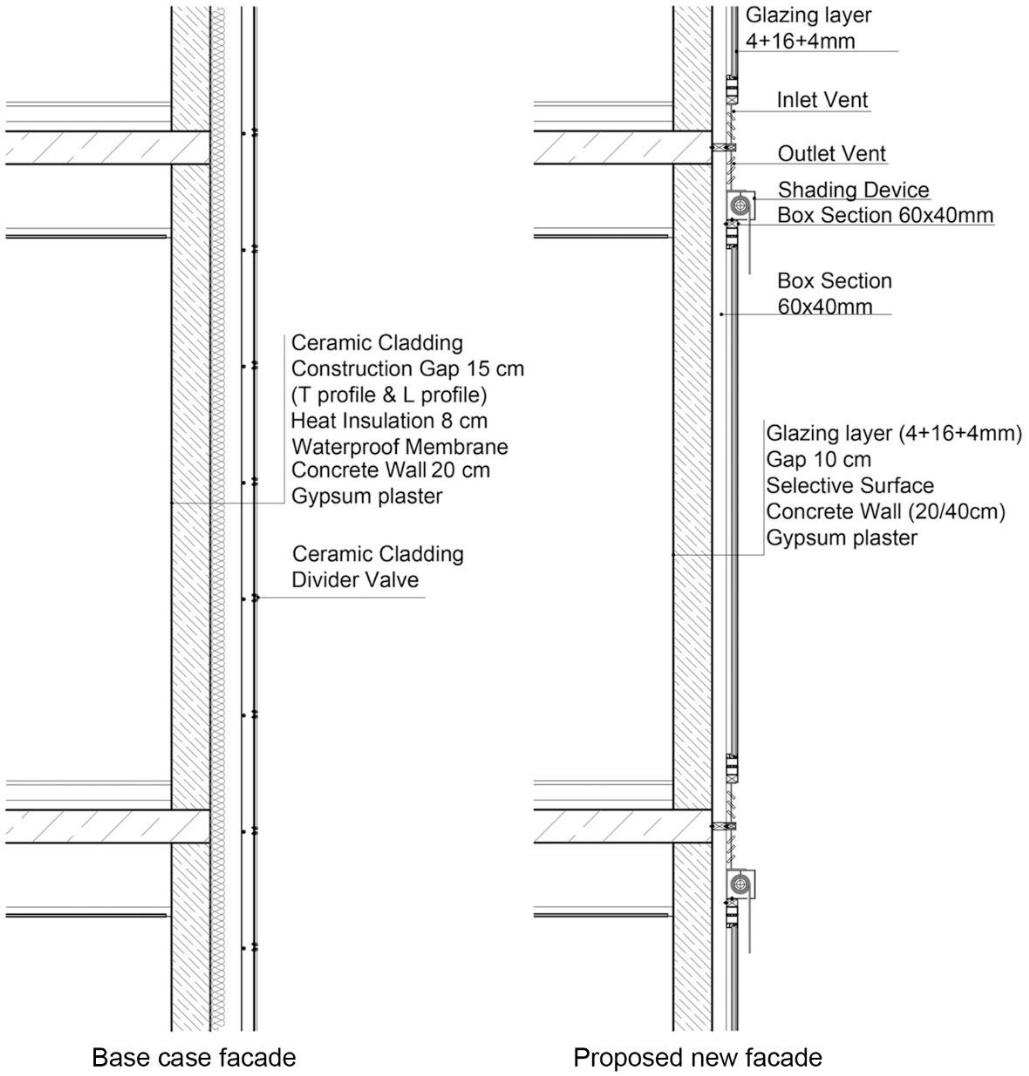


Figure 4.7 : Architectural vertical sections of base condition and proposed facade component applied facade areas.

Thermo-physical and optical properties of the glazing of the proposed façade component is shown in Table 4.14. These data were provided by a well-known national glazing brand [Url-12]. The glazing was chosen by considering solar heat gain amount in order to get maximum benefit from solar radiation on selective surface for heating period. Also, for both heating and cooling periods U-value was considered to be low.

Table 4.14 : Thermo-physical and optical propoerties of glazing and frame of proposed new facade.

	U-value (W/m².K)	SHGC (%)	T_{vis} (%)
Glazing	1.1	0.6	0.78
Frame	1.8	-	-

4.1.3.2 Process procedure of the proposed new advanced façade component

The working principle of the proposed component during the heating period directly depends on the characteristics of the selective surface and then glass. The selectivity is defined as the ratio of solar radiation/absorption to thermal infrared radiation/emission [Url-13]. Typical values for a selective surface is 0.90-0.95 solar absorption and 0.1-0.05 thermal emissivity. The properties of selective surface was decided in accordance with the gathered information from the manufacturer and solar absorption was accepted as 0.95, thermal emissivity was accepted as 0.05 within this thesis study.

During the heating period there is not any shading device to block the solar radiation falling on selective surface layer. Therefore, solar radiation falls on the selective surface layer and the layer absorbs around 95% of it and since glass is blind to long-wave radiation remaining amount also cannot escape outside from the air gap. Thus, the absorbed radiation enters to the residential zones through conduction and supports the heating process. Therefore, this system helps to reduce the energy expenses for heating.

As in Figure 4.7, there are shading devices on top and bottom of each floor’s facade area. Bearer profiles divide floors, therefore the system works for each floor separately. The working schedule of the exterior shading device was designated through several simulation tests. Different working schedules were tested to decide on/off periods as months of the year and as hours of the day. In order to designate the schedule various starting and ending times were tested and the most effective working schedule was defined as, the devices were on from 1st of April until 1st of November between the hours of 06.00 and 20.00. During the other times of the year, exterior shading devices are off and stay in the box on top of the fenestrations.

There are air inlet and outlet vents at the bottom and on top of each floor facade area as in Figure 4.7. The vents provide air circulation during cooling period, the path of circulation is shown in Figure 4.8. The working schedule of air inlet and outlet vents were designated with several simulation tests as shading devices. To this aim, different starting and ending days of the months and hours of the days were tested and the most effective working schedule for inlet and outlet vents was designated as, open from 1_{st} of May until 1_{st} of October for 24 hours. During the other times of the year, air inlet and outlet vents are closed in order to have the most benefit from solar radiation.

Exterior shading devices help on transition and cooling periods. The device helps alone during transition seasons since the vents are closed during that periods, however during summer period air circulation is an obligation. Exterior shading devices behave as obstacles for solar radiation not to increase the air gap temperature with negative effect on cooling energy saving during the day at transition season. They are off between the hours of 20.00 and 06.00, because during these hours site outdoor air temperature is lower than air gap temperature, therefore losing heat to outside is avaliable.

On summer period shading devices are not enough alone because of the high ratio of solar radiation can enter into to the air gap through the devices and heat the air of air gap. When air inlet and outlet vents are open during that period, according to updrafting of the warming air, air circulation occurs and cools the air inside of the gap. This circulation also helps to cool down the wall temperature on which has selective surface. After a while, air temperature in the gap becomes lower than internal zone mean air temperature, therefore zones of the building start to cool down by losing heat to the gap via walls. And walls continuously are cooled down by air circulation through vents. Additionally, since there is selective surface on the walls the temperature of the air gap without air circulation is higher than the temperature of a gap air where is no selective surface. Therefore, air circulation becomes faster in the cavity with selective surface and the system finally helps to cool down the air gap and wall temperature.

As a result of all those explanations, proposed component also provides reduction on yearly cooling energy demand. Therefore, the system helps to reduce the energy expenses for cooling.

In Figure 4.8 the path of air circulation during the cooling period can be seen.

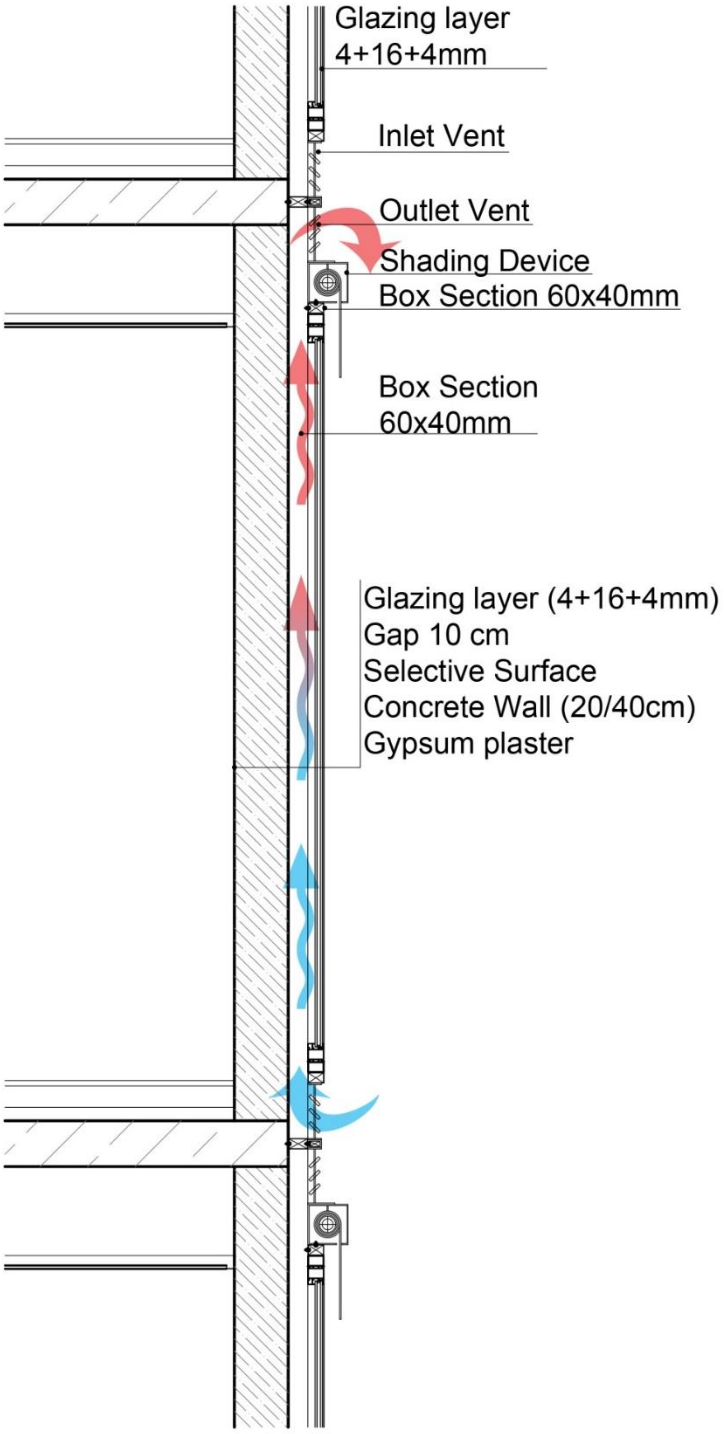


Figure 4.8 : Air circulation in architectural section.

As in the figure, during the cooling period cooler air enters inside to the air gap and updrafts by taking the heat from the wall surface with selective surface application and therefore the heat of the air increases and it leaves the air gap from the top vent. Since the bearer construction divide the floors as in the figure, this circulation happens in each floor level separately and this condition provides a higher air flow.

Additionally, the direction of the vents differentiates depending on being inlet or outlet vent. The reason of this differentiation is letting the air easily.

The figure mainly reflects the evening condition during the cooling period since the shading device is closed. However as shown partially, the device is closed as in the figure until the air inlet vent. If we look carefully, shading device rolls up at the bottom of outlet vent. Therefore the device does not blocks the air circulation with this design way of application. So basically, shading devices only close in front of the glazing layer.

The system gets benefit from natural ventilation in order to produce a direct renewable energy system without any mechanical aid.

The location of shading devices and inlet-outlet vents are shown also on architectural elevation in Figure 4.9. This figure shows the appereance of the facade during heating period when shading devices and vents are off. The elevation represents the partial application of the proposed facade component on first case study building.

The figure reflects the application of the proposed new facade component on an existing building facade. Therefore, there are areas without proposed facade component application. The reason of this situation is for the existing buildings it is not possible to apply a new component wherever it is effective but it is possible to apply it only on available surface areas (There are also analyzes for new buildings within this thesis study). In this figure, the new facade component was aimed to be applied in a continuous path without any intervention, therefore there were no application on bottom and top of the fenestration areas on right and left sides as in the figure (There are case studies in this thesis study for the application of the new facade component on parapet walls (bottom of the fenestration)). The component was applied on the related area instead of the existing ceramic cladding. As shown in Figure 4.6, the existing component and new facade component locates side by side.

As in Figure 4.9, the proposed new facade application seems as glazing facade or looks similar to a glazing curtain wall from outside which is very familiar to all of us for high-rise buildings. Therefore, air inlet and outlet vents are on top and bottom of each glazing part. In architectural design point of view, the proposed new facade component breaks the monotone aspect of the existing facade and adds a new sight.

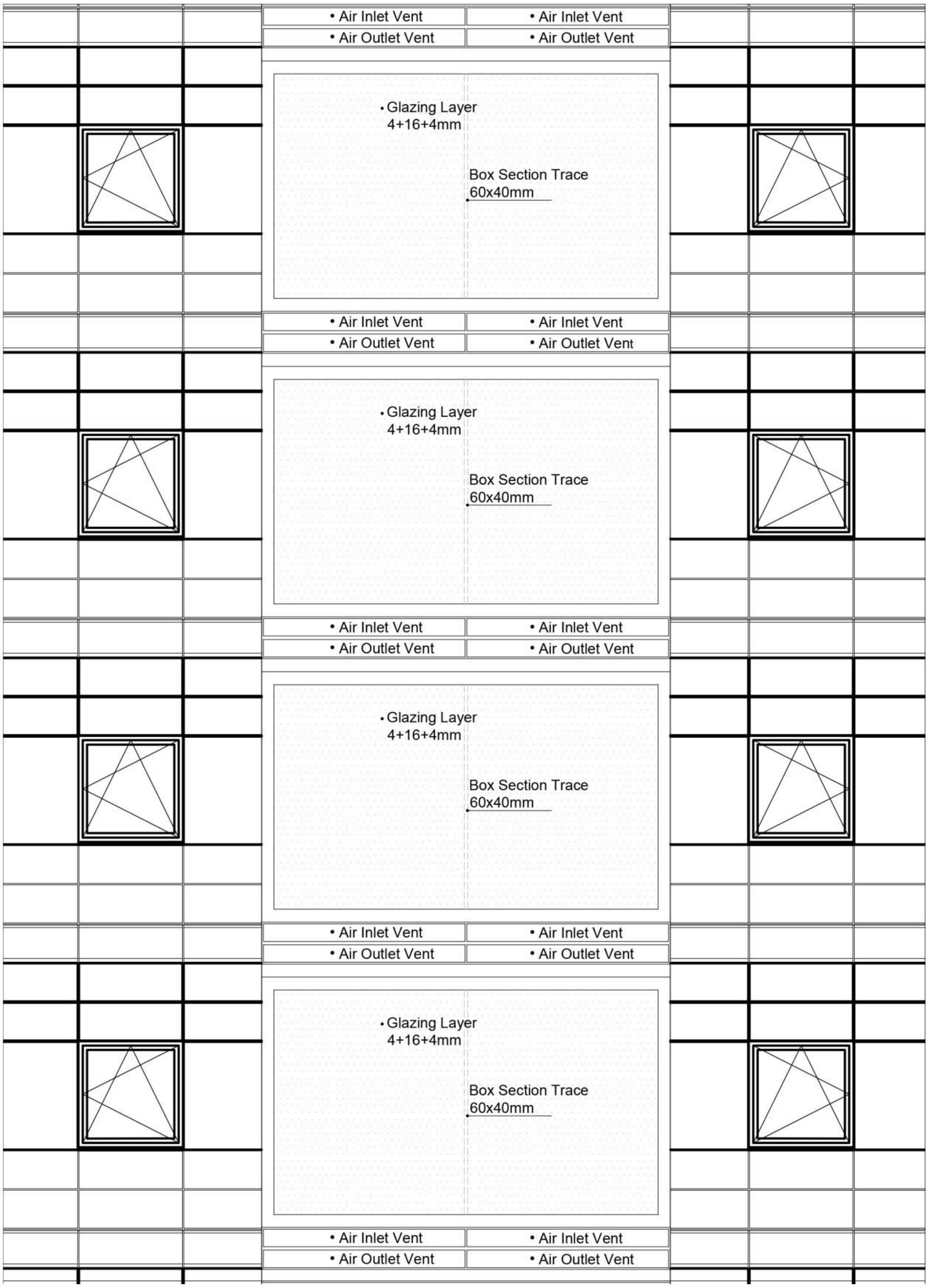


Figure 4.9 : Partial architectural elevation of the façade during the heating period.

The facade elevation during the cooling period is shown in Figure 4.10. Shading devices and vents are on during this period as a requirement of the climatic conditions. Therefore, the appeareance of the building during cooling period is different than the appereance in heating period.

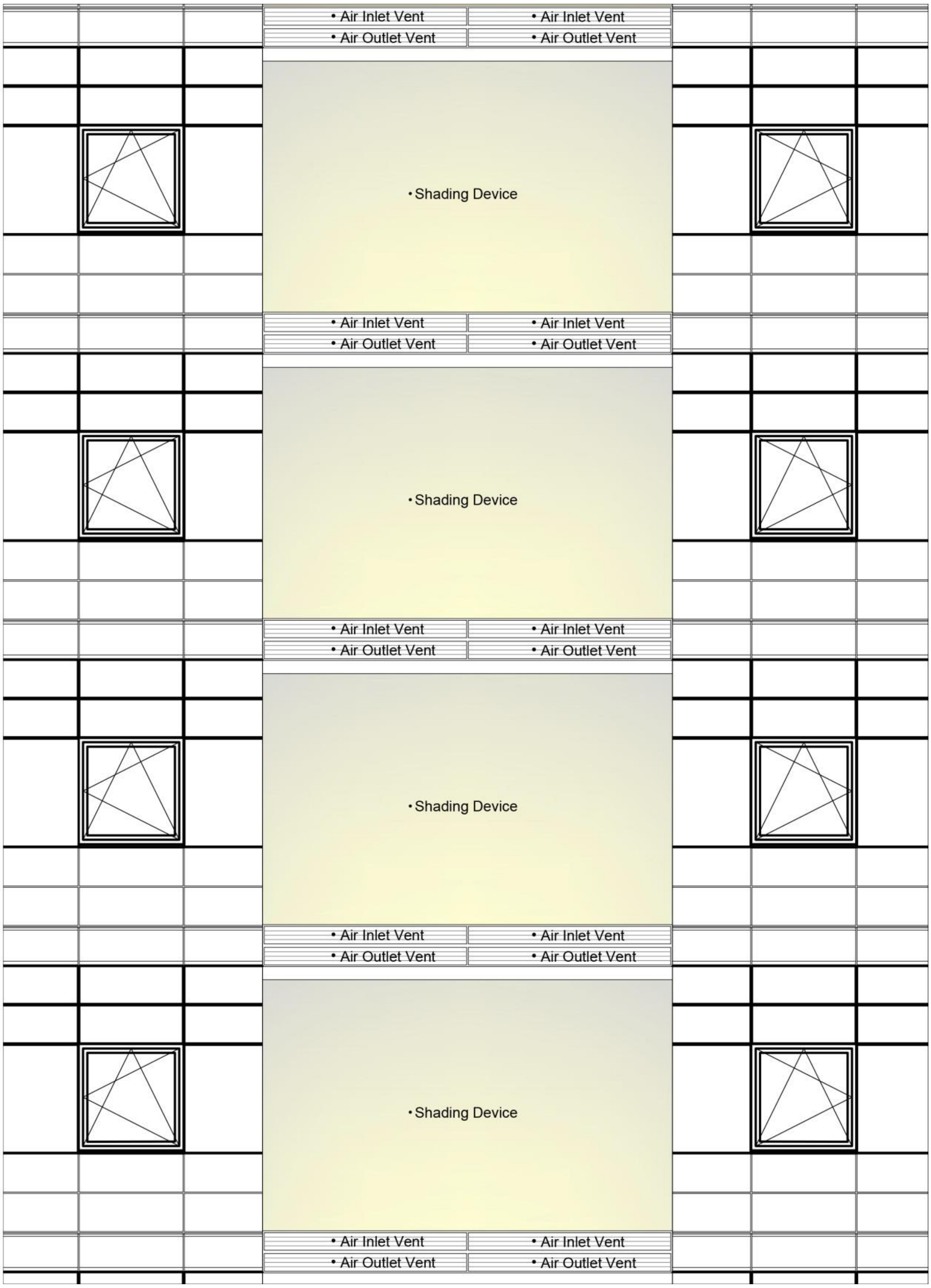


Figure 4.10 : Partial architectural elevation of the façade during the cooling period.

In architectural point of view, the model of shading devices could be used for design concerns. For example variations in colors or texture would be very effective on the attractiveness of the building facade. Therefore, the proposed new facade component also can be used for facade design aims. Inlet and outlet vents are open for 24 hours between from 1st of May until 1st of October and their design is as traditional vents. However, as explained the shading devices are off between the hours 20.00 and 06.00. So, between these hours glazing layer is the outermost layer again.

4.1.3.3 Defining the proposed new advanced façade component in building energy performance simulation tools

The proposed facade component is an advanced component and it should not be modeled as standard façade components. So, the components in the simulation tools were used in harmony. The method that were used to model the proposed component was discussed with the support groups of both simulation tools and verified by the supervisors of the tools [Url-14, Url-15].

Material layers of the proposed façade component were defined similar to defining other material layers in EnergyPlus. For inside surface convection TARP algorithm and for outside surface convection DOE-2 algorithm were selected. Conduction transfer function algorithm was selected as heat balance algorithm. In the simulation calculations, full interior and exterior solar distribution was considered [US DoE, 2015].

Shading devices were modelled in window material, shade object that is common for window shading device definition. Reflectance and emissivity properties are assumed to be the same on both sides of the shade. Shades are considered to be perfect diffusers (all transmitted and reflected radiation is hemispherically-diffuse) with transmittance and reflectance independent of angle of incidence [US DoE, 2015]. Thermo-physical and optical properties of shading device was provided from an internationally known window treatment firm's extension tool [Hunter Douglas, Energy and Light Tool].

Air circulation between bottom and top vents was modeled by wind and stack open area object in the simulation tool. For this object, the ventilation airflow rate is a function of wind speed and thermal stack effect, along with the area of the opening being modeled. The total ventilation rate calculated by this model is the quadrature sum of the wind and stack airflow components [US DoE, 2014].

4.1.3.4 Verification simulation tests of the proposed new façade component model

In order to demonstrate whether the proposed new façade component works efficiently as expected, verification tests were done through simulations. This part is not a test on the sensitivity of the software and represents tests on the new facade component. Thermal results of the proposed component in various modes were tested by construction, shading and ventilation modules of EnergyPlus. After modeling the whole component, verification simulation tests were done to validate if the proposed component model worked correctly and the obtained results were reasonable. For this part, first of all a box as a thermal zone was created in EnergyPlus. The box was 1m^2 and the facade characteristics are the same with the case study building. Then, the proposed component was applied on it. Modifications were done until the proposed component works efficiently and reduces the energy demand in comparison to the base case. Afterwards, the recent condition of the proposed component together with the designated operational schedules was applied on the case study building. The simulations were run for 21st of January, April, July and October and hourly mean air temperature (MAT) results were controlled for those days.

In terms of protecting the integrity of the thesis study, in this part in the graphs the case names take place with their later explained names. Because, in the following part the case names and their explanations are defined and in order to prevent any later confusion and to be understandable the case names used as in part 4.1.4. So, the base condition of the building was represented with "CA0" and the proposed facade component applied case was represented with "CA13". CA13 represents the application of proposed new facade component with aluminum based selective surface use on 20 cm thick mass wall. Simulations were run as there were no HVAC system (free-running mode) to see the pure effect of proposed new facade component on hourly MAT results. The results were compared with hourly MAT results of CA0 without HVAC system, in terms of ideal loads. Heating set-point temperature is 22 °C and cooling set-point temperature is 24 °C. Since there is no HVAC system, the analyzes also show how the temperature range is close to the set-point values only thanks the effect of proposed façade application. Verification analyzes results of CA0 and CA13 comparison and hourly zone and air gap MAT in different conditions for 21st of January is shown in Figure 4.11.

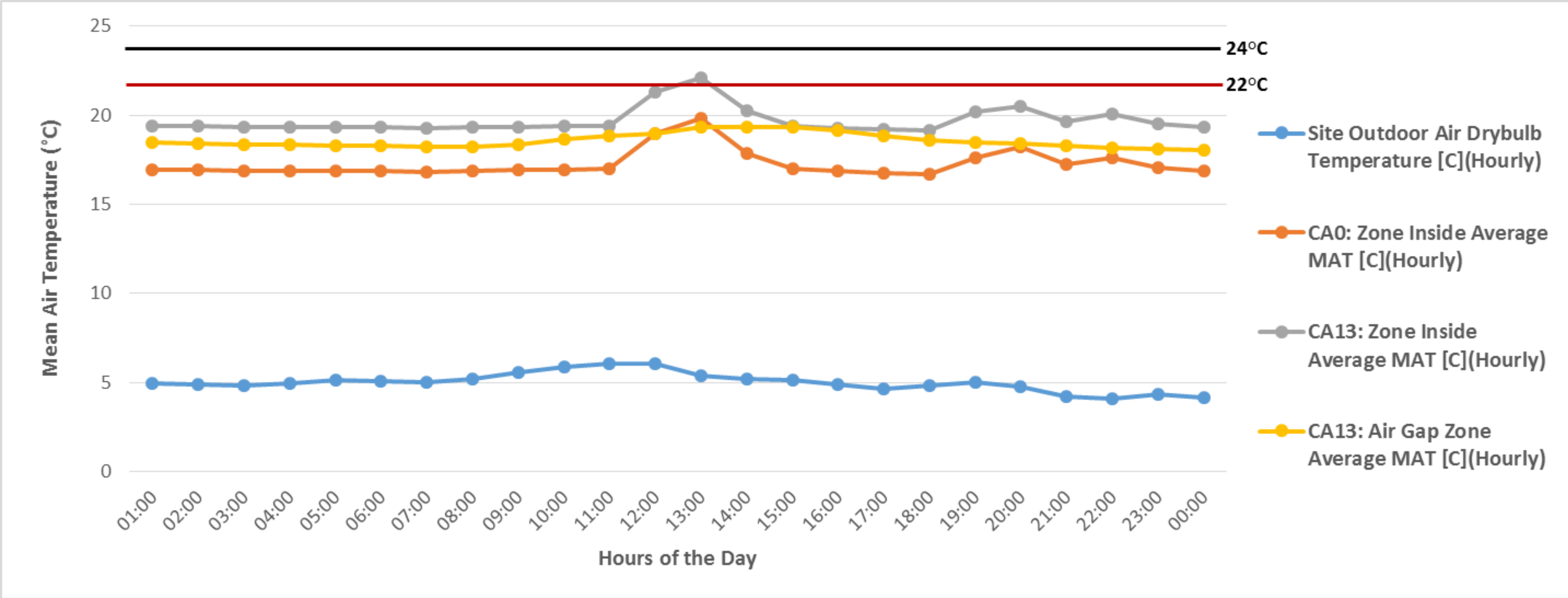


Figure 4.11 : Comparison between CA0 and CA13 for hourly MAT on 21st of January.

During 21st January shading devices and vents are not in use and the proposed new facade component is in heating period mode. Therefore, solar radiation directly transmits through the glazing to the selective surface covered wall. The zone mean air temperature is around 17 ºC in CA0 (color orange), while it is around 20 ºC in CA13 (color grey). Also, zone mean air temperature of air gap is around 19 ºC (color yellow). Heating set-point is 22 °C, therefore as expected from the proposed new facade component, the zone mean air temperature approaches to the set point value in CA13, hence using the proposed façade component reduces the heating demand. As explained in detail before the characteristic propoerites of selective surface and glass support the temperature increase in the inside zone mean air temperature. Selective surface absorbs around 95% of the radiation that enters through the glazing layer, additionally the glazing does not permit the remain amount of solar radiation transmit back to outside, therefore the remained amount rises the temperature of the air gap zone. Additionally, the radiation absorbed by selective surface rises the temperature of the mass wall and through this condition both the air gap temperature rises and also since the surface temperature of the mass wall rises the heat enters inside the residential zones. Also, since the air gap temperature is higher than the internal zone temperatures, the heat also transfers to the internal residential zones. So, with the benefits of selective surface and glass layer the zone mean air temperature of the air gap rises and provides heat to the residential zones. Therefore, air gap application helps to reduce the heating demand too together with selective surface and glazing layer applications. Thus, each building element that was used within the proposed new facade component was selected in order to benefit from the solar radiation at the possible highest level.

The difference between zone mean air temperature of residential zones in CA0 (17 °C) and CA13 (20 °C) is very high and directly shows how the proposed new facade component application effects the heating demand of the building.

There is a temperature peak in the hours between 11:00-14:00 in the graph. That is caused by housework, especially kitchen work originated internal heat gain in accordance with the occupancy and electric equipment schedules.

Verification analyses results of CA0 and CA13 comparison and hourly zone and air gap MAT in different conditions for 21st of April is shown in Figure 4.12.

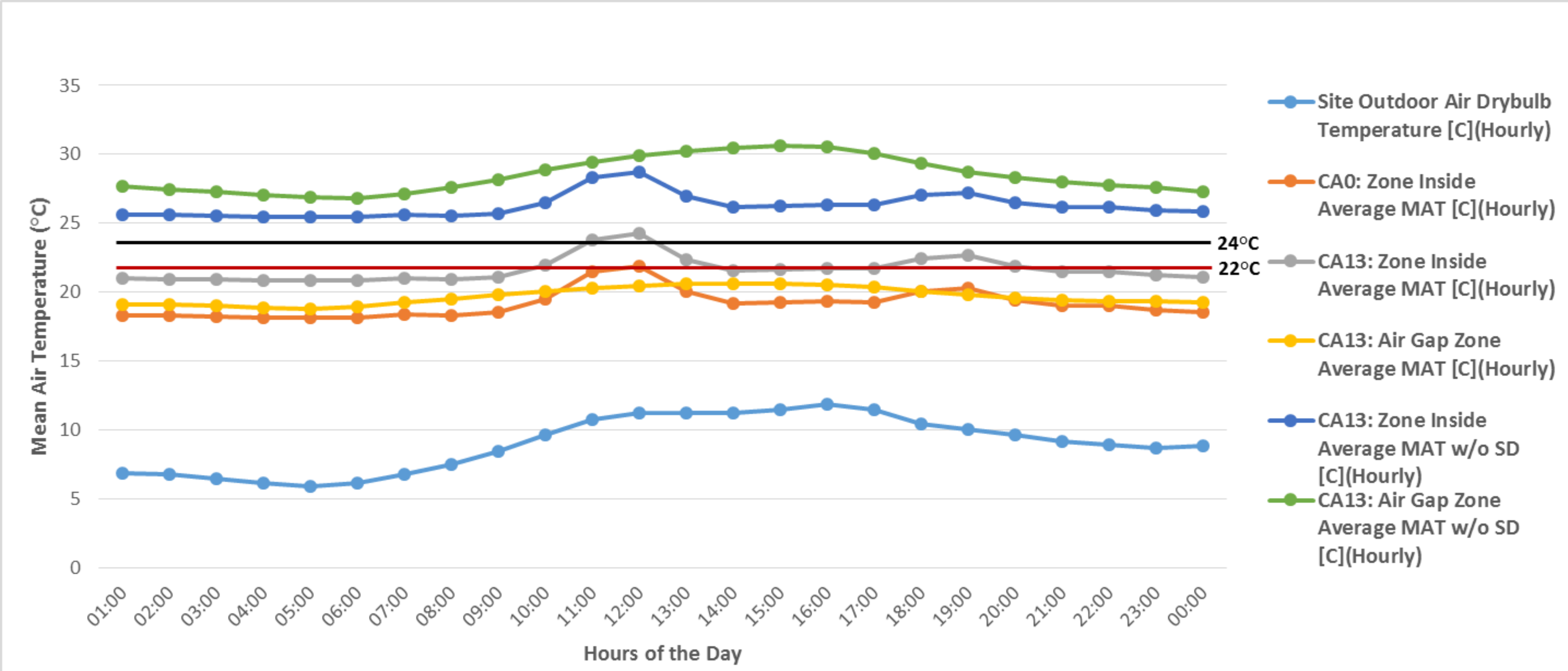


Figure 4.12 : Comparison between CA0 and CA13 for hourly MAT on 21st of April.

April is in the transition season. During the transition season, shading devices (SD) are on between the hours of 06.00 and 20.00 to decrease the solar loads. However, in accordance with the test results, during this period inlet and outlet vents are not in use.

Zone MAT is around 18 ºC in CA0 (color orange), while it is around 21-22 ºC in CA13 (color grey). Temperature values in CA13 are very close to the heating set-point temperature as shown with the red line in the graph. According to this result since the heating set-point temperature is 22 °C, there is an important difference between the set-point temperature and zone MAT of CA0. Therefore, there is a heating energy demand during this period in the base condition of the building. Whereas with the use of the proposed new facade component, there is almost no need to use the HVAC system during this period. Zone MAT catches the heating set-point temperature value. Therefore, as expected, using the proposed new façade component could reduce the heating demand during the related period.

In order to present the effect of shading device use on the proposed component, CA13 was simulated again while shading devices are off during April. When shading devices are in use, air gap MAT of the proposed new façade component is around 19 ºC (color yellow) and inside zone MAT is 21-22 ºC (color grey) in CA13. When shading devices are off on April, air gap MAT of proposed façade component becomes 29-30 ºC (color green) and zone MAT becomes around 25-26 ºC (color dark blue). Air gap, glazing and selective surface applications are all for benefitting from the solar radiation as possible. Therefore, without shading device application the proposed component will try to benefit from the solar radiation in order to support heating. However, during this period cooling is necessary so, that specialty of the system in terms of benefitting from solar radiation needs to be reduced by preventing. Besides, cooling set-point is 24 ºC as shown with the black line in the graph and inside zone MAT (dark blue line) together with air gap MAT (green line) are above that line. Therefore as predicted in convenience with the climatic conditions of this period, absence of shading device could cause cooling energy demand.

Verification analyzes results of CA0 and CA13 comparison and hourly zone and air gap MAT in different conditions for 21st of July is shown in Figure 4.13.

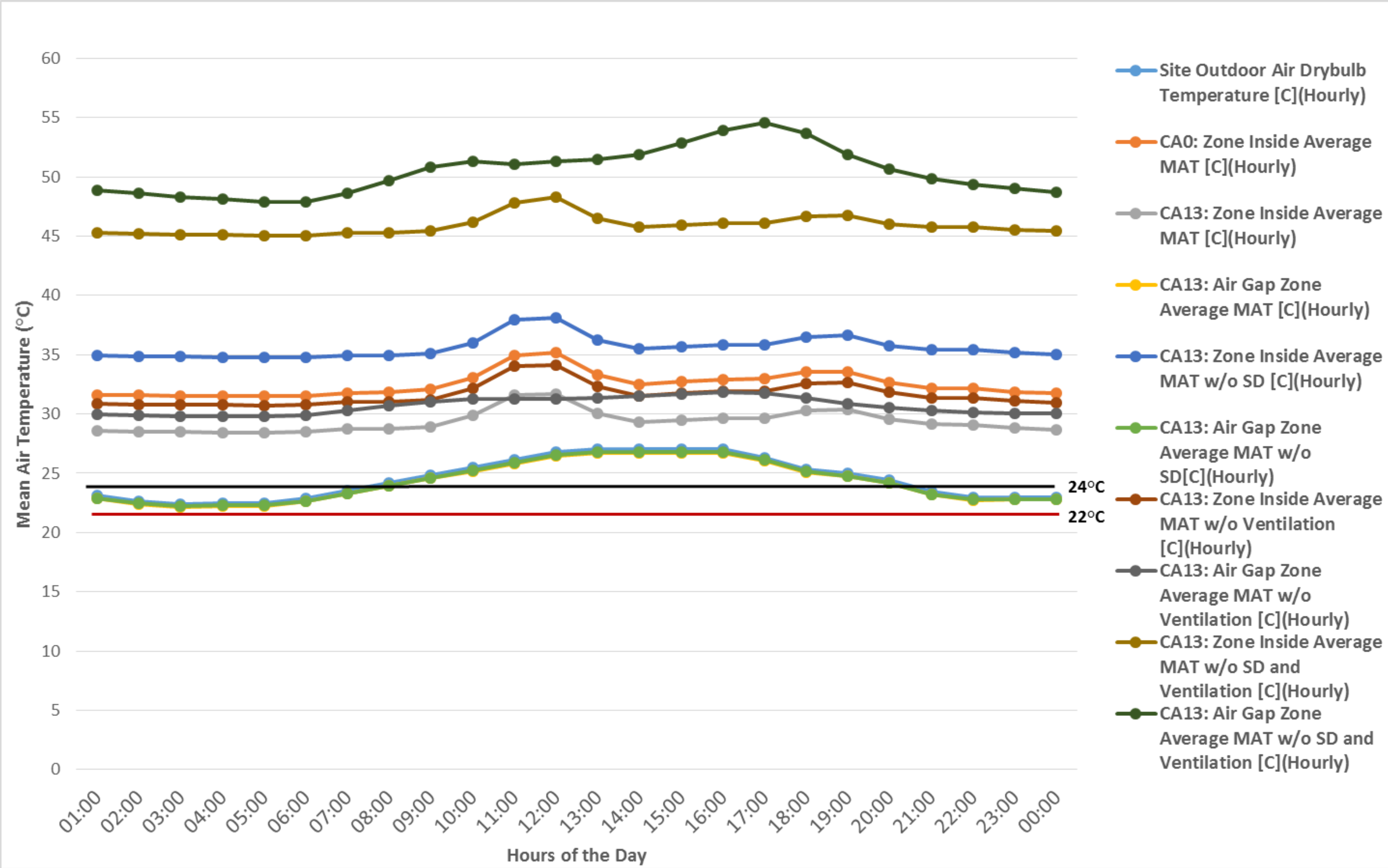


Figure 4.13 : Comparison between CA0 and CA13 for hourly MAT on 21st of July.

July is in the cooling period. During this period shading devices are on between the hours of 06.00 and 20.00 to decrease the solar gain and vents are open 24h for air circulation to increase the ventilation rate in the gap to cool down the inner façade surface. Zone MAT is around 32 ºC in CA0 (color orange), while it is around 29 ºC in CA13 (color grey). There is an important difference between the zone mean air temperature values of CA0 and CA13. Cooling set-point value is 24 ºC as shown with the black line. Thus, as expected using the proposed façade component approaches the zone MAT to the cooling set-point value, therefore using the component could reduce the cooling energy demand.

In order to show the impact of using shading device with the proposed new facade component during cooling period, CA13 was simulated as shading devices are off during July. When shading devices are in use, air gap MAT of proposed new façade component is around 24-25 ºC (color yellow, the line is imbricated with another) and zone MAT around 29 ºC in CA13 (color grey). When shading devices are off on July, air gap MAT of proposed façade component does not change (color green, imbricated with the yellow one), but zone MAT becomes around 35 ºC in CA13 (color dark blue). Vents are still open in this simulation test, thus it is obvious with this test results that vents are effective on air gap temperature. However, as predicted in convenience to the climatic conditions of this period, vents are not enough alone on decreasing the zone MAT and as indicated by this simulation test results using shading device reduces the inside zone MAT efficiently. Therefore, using shading device with the proposed component during this period has an important effect to decrease the cooling energy demand.

In order to see the effects of using vents in the proposed façade component during this period, CA13 was simulated while vents are closed but shading devices are in use during July. When vents are in use, air gap MAT of proposed new façade component is around 24-25 ºC (color yellow) and zone MAT is around 29 ºC in CA13 (color grey). When vents are closed on July, air gap MAT becomes 30 ºC (color dark grey) and zone MAT becomes around 33 ºC (color dark orange). Hence, according to the results, air circulation in the gap of the proposed façade component is very effective firstly on air gap temperature and then on zone MAT. Especially, during this period ventilation has a crucial importance. Placing vents has an important effect to decrease cooling energy demand.

To designate the effects of using shading devices and vents together on zone MAT, CA13 was simulated again as shading devices are off and vents are closed during July. When both are in use, air gap MAT of the proposed new façade component is around 24-25 ºC (color yellow) and zone MAT is around 29 ºC in CA13 (color grey). When shading devices are off and vents are closed on July, air gap MAT becomes 50 ºC (color dark green) and inside zone MAT becomes around 46-47 ºC (color dark yellow) as expected. The temperature differences of air gap and residential zones are very high. Therefore, according to the test results in accordance with the climatic requirements of this period, shading devices and vents have separate and important effects on decreasing zone MAT. Additionally, it is very important to use them together properly according to the simulation test results.

As explained before, each element of the proposed new facade component is connected to the other for functioning. So, in this case of July, inlet and outlet vents are for air circulation within the air gap and for cooling the wall surface together with the air gap and shading devices are for supporting to block the solar radiation to enter inside (air gap). This working process is very important to prevent solar radiation to fall on selective surface. Because if this condition happens, air gap and wall surface temperatures will become significantly high. Presence of selective surface speeds up air circulation by increasing the temperature. Finally, through temperature reduction on wall surface and in air gap, inner zones cool down by losing heat through conduction.

The operation schedules of shading devices and inlet-outlet vents were fixed through this kind of verification test simulations in the background of this study as explained in part 4.1.3.2. In addition to the explanations, with this verification simulations the validation of the designated operation schedules were tested. According to the results of July analysis, the schedules work efficiently to reduce the yearly cooling energy demand.

Verification analyzes results of CA0 and CA13 comparison and hourly zone and air gap MAT in different conditions for 21st of October is shown in Figure 4.14. October is also an example for transition period, however the results could differ from April since the previous season was summer, while in April the previous season was winter. Therefore, firstly the results of transition periods should be evaluated separately, then for the general aspects the results could be generalized.

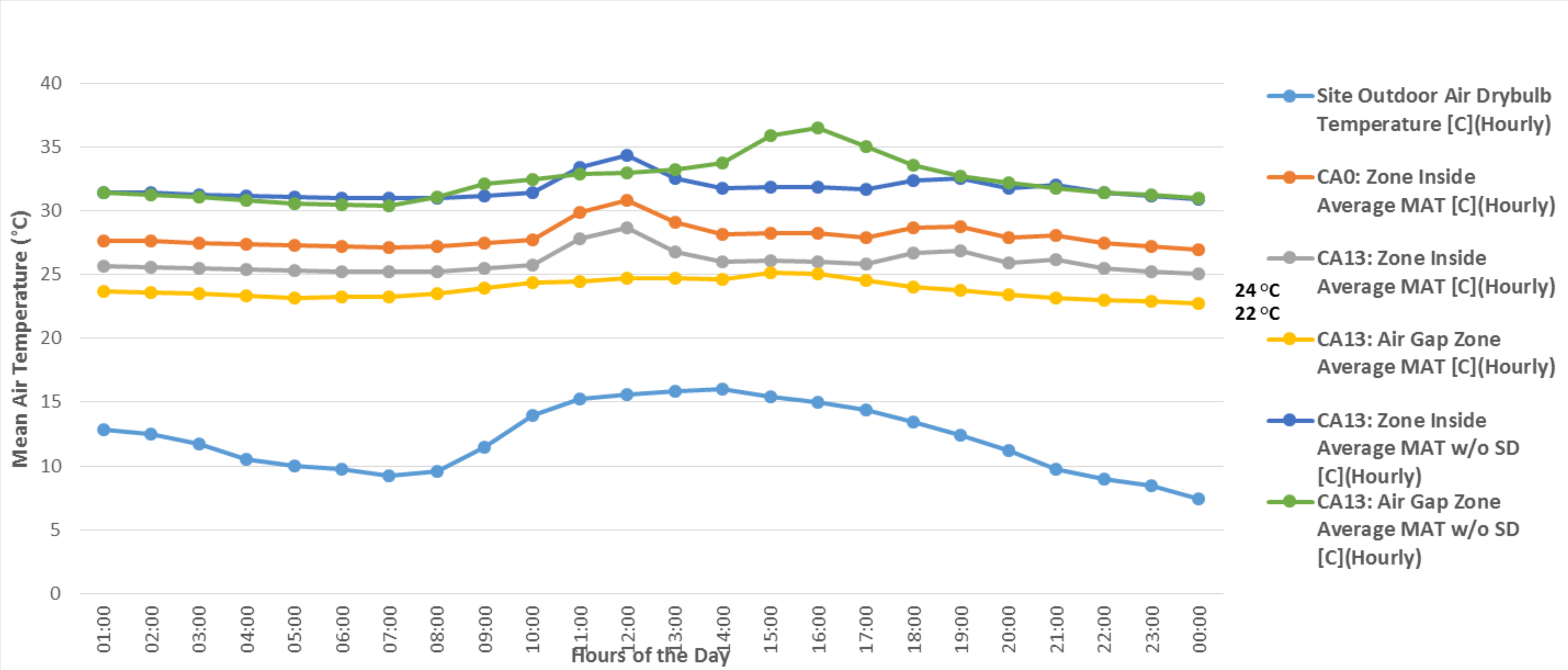


Figure 4.14 : Comparison between CA0 and CA13 for hourly MAT on 21st of October.

Since October is in the transition season, shading devices are on between the hours of 06.00 and 20.00, vents are closed. Zone mean air temperature is around 28-29 ºC (color orange) in CA0, while it is around 25-26 ºC in CA13 (color grey). Also, air gap mean air temperature is around 24-25 ºC (color yellow). Cooling set-point temperature is 24 ºC as shown with the black line. As expected with the use of proposed façade component, hourly temperature results in CA13 are closer to the cooling set-point than CA0. Therefore, applying the proposed component reduces cooling energy demand effectively.

In order to see the effect of using shading device on October, CA13 has been simulated again as shading devices are off during this period. When shading devices are off on October, air gap temperature of the proposed façade component becomes 31-33 ºC (color green) and zone mean air temperature becomes around 31-32 ºC (color dark blue). As predicted in accordance with the climatic requirements of this period, absence of shading device causes increase in cooling energy demand in comparison to the presence of the proposed new facade component. Therefore, using shading device during this period have an important effect on decreasing the cooling energy demand. The ratio of the shading device's effect on cooling energy demand also depends on the time of the year as it can be seen in the April and October results. In October, the temperature of the zones are higher than April, however according to the related tests at this temperature values, there is no need for vents during this period and only shading devices are enough.

This research phase helped to understand whether the parts of the proposed new façade component reacted in accordance with the requiremets of the climatic conditions. Additionally, this section is to see if the simulation model is reactive in accordance with the effects of proposed new façade component.

4.1.4 Explanation of the façade retrofit cases for the first case study building

Retrofit measures can be standard and advanced as explained in part 3.6. There are standard and advanced facade retrofit measures for the first case study building. Standard retrofits are in order to show the explained ineffectiveness briefly on luxury high-rise residential buildings. Standard and advanced facade retrofit cases that were investigated for the first case study are shown in Table 4.15. The C mark indicates the cases, the A mark indicates that the case belongs to the first case study building and the number next to the mark shows the case number.

CA0 represents the base condition of the case study building. Cases from CA1 to CA9 are standard façade retrofit cases that are very effective on standard residential buildings as explained. CA1 shows adding heat insulation layer to the existing building façade. From CA2 to CA9, the cases show various glazing type applications instead of the existing glazing for the whole building facade.

Cases from CA10 to CA50 are advanced façade improvement scenarios with proposed new façade component that has selective surface and air vent applications to increase solar gain and façade surface ventilation through the air gap.

Table 4.15 : Façade retrofit case explanations for the first case study building.

Case Name	Explanations
CA0	Base condition of the case study building
CA1	2 cm extra heat insulation to the exterior walls
CA2	New Glazing; U:1.3W/m².K SHGC:0.54 Tvis:0.77 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA3	New Glazing; U:1.3W/m².K SHGC:0.43 Tvis:0.69 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA4	New Glazing; U:0.9W/m².K SHGC:0.48 Tvis:0.69 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA5	New Glazing; U:0.7W/m².K SHGC:0.48 Tvis:0.69 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA6	New Glazing; U:1.6W/m².K SHGC:0.44 Tvis:0.71 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA7	New Glazing; U:0.9W/m².K SHGC:0.37 Tvis:0.61 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA8	New Glazing; U:0.9W/m².K SHGC:0.29 Tvis:0.43 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA9	New Glazing; U:1.4W/m².K SHGC:0.34 Tvis:0.49 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CA10	Proposed new façade component (PNFC) application on available East, North and West exterior opaque walls; Mass wall thickness 20 cm; Aluminium based selective surface used
CA11	PNFC application on East, North and West exterior opaque walls; Transparency ratio of West facade is lower than C0; Mass wall thickness 20 cm; Aluminium based selective surface used
CA12	PNFC application on East and West exterior opaque walls; Transparency ratios of East and West facades are lower than C0; Mass wall thickness 20 cm; Aluminium based selective surface
CA13	PNFC application on East, West and North exterior opaque walls; transparency ratios of East and West facades are lower than C0; Mass wall thickness 20 cm; Aluminium based selective surface used
CA14	PNFC application on East and West parapet walls, Mass wall thickness 20 cm, Aluminium based selective surface used
CA15	PNFC application on East parapet walls; Mass wall thickness 20 cm; Aluminium based selective surface used; The building was turned 90° and East facade turned to South facade
CA16	C15 without surrounding high-rise building with shading effect

Table 4.15 (continued): Facade retrofit case explanations for the first case study building.

Case Name	Explanations
CA17	PNFC application on East exterior opaque wall; Transparency ratio of East facade is lower than C0; Mass wall thickness 20 cm, Aluminium based selective surface used; The building was turned 90° and East façade turned to South facade
CA18	CA17 without surrounding high-rise building with shading effect
CA19	CA11 with copper based selective surface instead of aluminum
CA20	CA12 with copper based selective surface instead of aluminum
CA21	CA13 with copper based selective surface instead of aluminum
CA22	CA14 with copper based selective surface instead of aluminum
CA23	CA15 with copper based selective surface instead of aluminum
CA24	CA16 with copper based selective surface instead of aluminum
CA25	CA17 with copper based selective surface instead of aluminum
CA26	CA18 with copper based selective surface instead of aluminum
CA27	CA11 with mass wall thickness of 40 cm instead of 20 cm
CA28	CA12 with mass wall thickness of 40 cm instead of 20 cm
CA29	CA13 with mass wall thickness of 40 cm instead of 20 cm
CA30	CA14 with mass wall thickness of 40 cm instead of 20 cm
CA31	CA15 with mass wall thickness of 40 cm instead of 20 cm
CA32	CA16 with mass wall thickness of 40 cm instead of 20 cm
CA33	CA17 with mass wall thickness of 40 cm instead of 20 cm
CA34	CA18 with mass wall thickness of 40 cm instead of 20 cm
CA35	CA11 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA36	CA12 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA37	CA13 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA38	CA14 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA39	CA15 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA40	CA16 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA41	CA17 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA42	CA18 with copper based selective surface instead of aluminum and with mass wall thickness of 40 cm instead of 20 cm
CA43	CA11 with black paint application instead of selective surface
CA44	CA12 with black paint application instead of selective surface
CA45	CA13 with black paint application instead of selective surface
CA46	CA14 with black paint application instead of selective surface
CA47	CA15 with black paint application instead of selective surface
CA48	CA16 with black paint application instead of selective surface
CA49	CA17 with black paint application instead of selective surface
CA50	CA18 with black paint application instead of selective surface

As explained while introducing the case study building, South façade of the building is adjacent to another building block. Therefore, there is not any application on South façade in the cases. The façade views of the cases are shown in Table 4.16. The images of all cases were generated by DesignBuilder v4.2. The figures in the table are simulation model views therefore look different than architectural elevation drawings. There is no application on South facade however in some cases as explained in Table 4.15, the main facade of the building (East facade) was turned to South in order to benefit more from solar radiation and analyze the effect of this condition.

Table 4.16 : Façade elevations of advanced retrofit cases for first case study building.

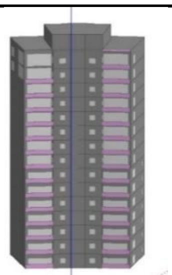
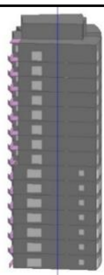
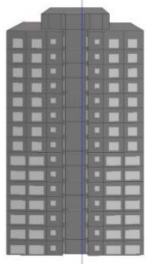
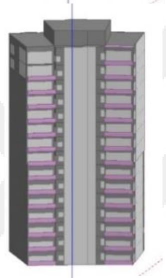
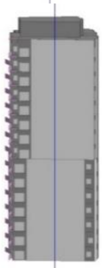
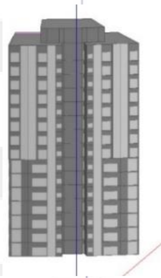
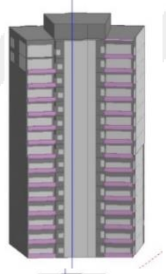
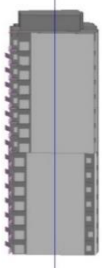
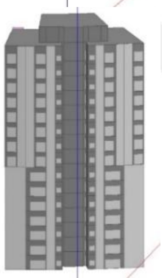
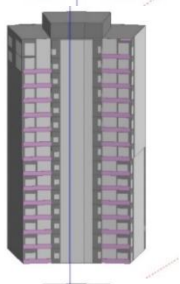
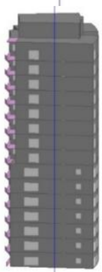
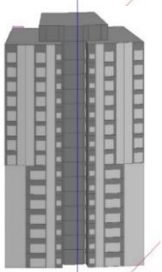
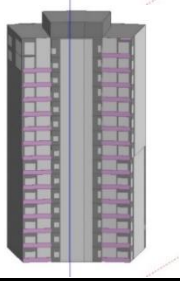
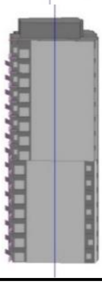
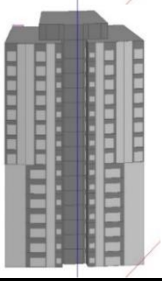
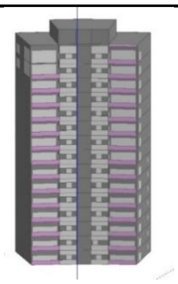
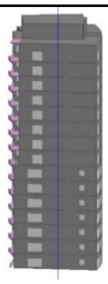
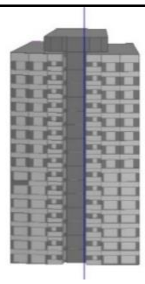
Case Name	East Facade	North Facade	West Facade	South Façade
CA0				-
CA10				
CA11, CA19, CA27, CA35, CA43				-
CA12, CA20, CA28, CA36, CA44				-
CA13, CA21, CA29, CA37, CA45				-

Table 4.16 (continued): Facade elevations of advanced retrofit cases for first case study building.

Case Name	East Facade	North Facade	West Facade	South Façade
CA14, CA22, CA30, CA38, CA46				-
CA15, CA23, CA31, CA39, CA47 & CA16, CA24, CA32, CA40, CA48	-	-	-	
CA17, CA25, CA33, CA41, CA49 & CA18, CA26, CA34, CA42, CA50	-	-	-	

In CA10 the proposed facade component was applied on the available opaque facade areas (exterior walls without window on it) on East, North and West facade directions. In the cases CA11, CA19, CA27, CA35, CA43 the proposed facade component was applied on the available opaque facade areas on East and North facade directions; and on West facade direction through reducing the transparency ratio of this facade area. In the cases CA12, CA20, CA28, CA36, CA44 the proposed facade component was applied on the available opaque facade areas on East facade direction and also on West facade direction through reducing the transparency ratio of this facade area. In the cases CA13, CA21, CA29, CA37, CA45 the proposed facade component was applied on the available opaque facade areas on North facade direction; and also on East and West facade directions through reducing the transparency ratios of these facade areas. The reduction on transparency ratio was done by considering appropriate lighting levels and providing sufficient window areas for each room. In the results part of this case study building it will be seen that there is no effect of this reduction in yearly lighting energy demand.

In the cases CA14, CA22, CA30, CA38, CA46 the proposed façade component was applied on exterior parapet walls of East and West façade directions. In the cases CA15, CA23, CA31, CA39, CA47 for a specific analysis the proposed façade component was applied only on exterior parapet walls of East façade direction and in the simulation model, the case study building was turned 90° as East façade will be South façade. Very similarly in the cases CA16, CA24, CA32, CA40, CA48 the same application was done but additionally surrounding high-rise building (as shown in Figure 3.1) was assumed to be not exist, therefore shading effect was omitted. In the cases CA17, CA25, CA33, CA41, CA49 CA45 the proposed facade component was applied on East facade direction through reducing the transparency ratio of this facade area. Then, the case study building was turned 90° as East façade will be South façade. Very similarly in the cases CA18, CA26, CA34, CA42, CA50 the same application was done but additionally surrounding high-rise building (as shown in Figure 4.1) was assumed to be not exist, therefore shading effect was omitted.

After determining the retrofit cases passing to calculate the yearly energy demand of each is possible.

4.1.5 Calculation and results of primary energy demand of first case study retrofit cases

First of all, all retrofit cases was modelled and input data was entered in simulation tools. Then, yearly energy demand of each retrofit case for heating, cooling and lighting was calculated through the simulations. Afterwards, the energy demand results per category (heating, cooling, lighting) were converted to primary energy demand through the application of the equations 3.1, 3.2 and 3.3 in part 3.4. In order to do this calculation, a formula was formed in Microsoft Excel. Because, there are lots of cases and calculating the primary energy demand of each manually would resulted with mistakes and unreliable conclusions. Therefore, tables were prepared and the provided formula was applied to each case in Microsoft Excel. Then, primary energy demand in each category for each case was calculated.

Separately heating, cooling and lighting primary energy demands and the calculated total primary energy demand of each case was compared with calculated primary energy demand results of case study building (base case, CA0). Comparative results of the façade retrofits are shown in Figure 4.15.

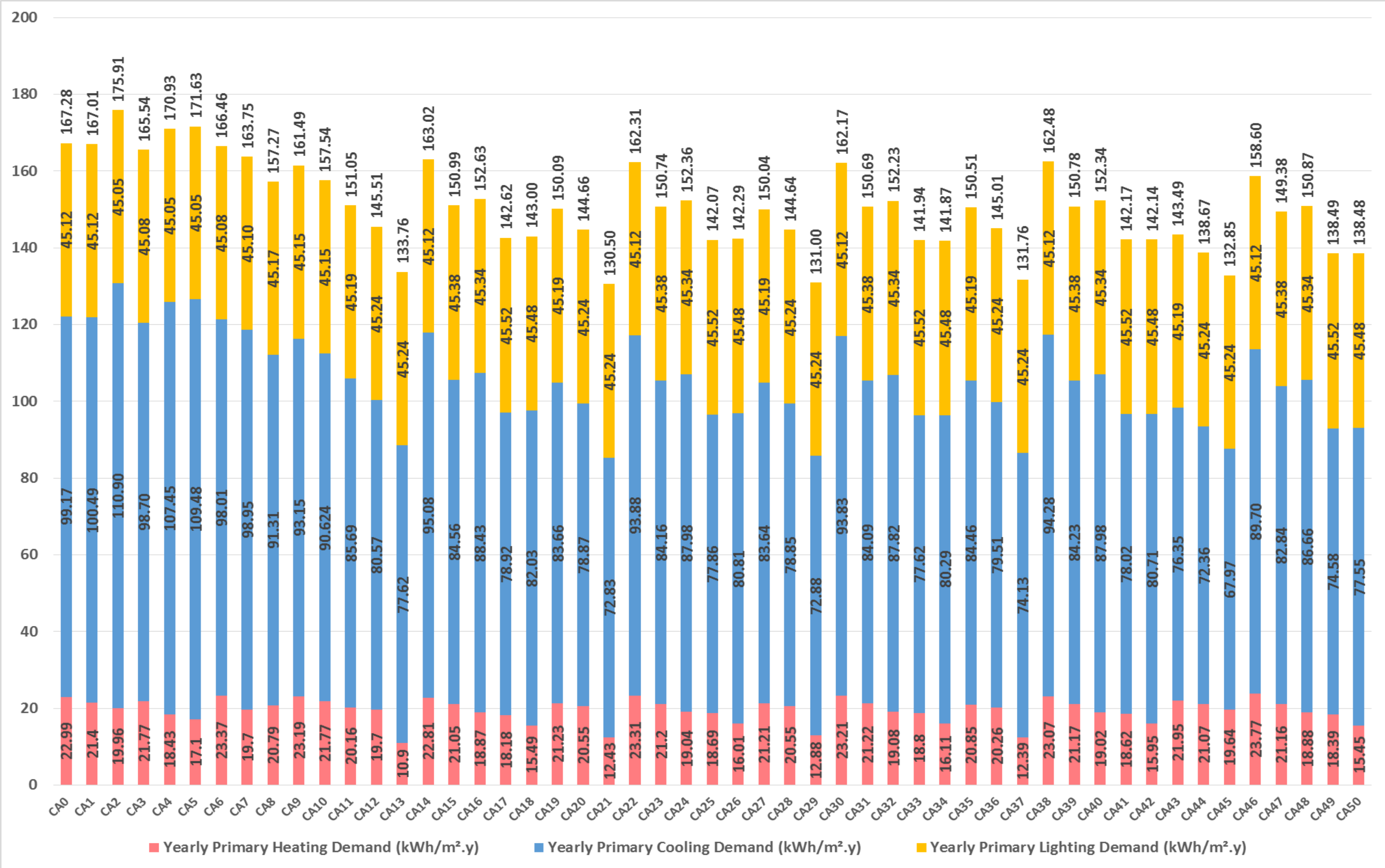


Figure 4.15 : Yearly primary energy demand results of the retrofit cases of first case study building for heating, cooling, and lighting.

According to the results, primary energy demand of CA0 is 167.28 kWh/m²y. The benefits of standard retrofits are very few, even some of the cases as CA2, CA4 and CA5 were resulted with more primary energy demand than CA0. CA1 is the case of adding 2 cm extra heat insulation to the external walls and it was resulted as 167.01 kWh/m²y. This result shows that there is a neglectable reduction in yearly primary energy demand through extra heat insulation. In the other standard retrofit measures, the glazing applications with higher solar heat gain coefficient value were reduced the yearly primary energy demand more than the other suggested glazings but not sufficient enough.

Further investigations with proposed new façade component were done in order to see whether advanced façade retrofit are more effective. According to the results in Figure 4.15; CA14, CA22, CA30, CA38 and CA46 although more effective than the standard retrofit cases were resulted not very effective as the other advanced cases. In those cases proposed new facade component was applied on East and West parapet walls with variation in mass wall thickness and selective surface base. In all of them the application surface area of the proposed component is limited since parapet walls are short surfaces on building facade. In order to get more benefit from the proposed component it is very important to expand its application area. The reason that CA46 was resulted better than other similar cases is there is black paint application on the mass wall instead of selective surface. CA10 was resulted with low reduction in yearly primary energy demand than the other advanced measures. Because in CA10, the proposed component was applied only on the existed opaque walls, however there were not enough opaque wall surface to apply the component. Moreover, as explained before, the transparency ratio was reduced in the other cases to have more opaque facade surfaces in order to apply the component.

The other cases have similar primary energy demand reduction amounts in comparison to CA0, except CA13, CA21, CA29, CA37, and CA45. These cases are the best resulted cases. The proposed component was applied on East, West and North exterior opaque walls (transparency ratios of East and West facades are lower than CA0). The only difference between these cases are mass wall thickness and selective surface base, also there is black paint application instead of selective surface in CA45. Primary energy demand based improvement ratio of each retrofit case are shown in Figure 4.16.

Figure 4.16 : Yearly primary energy performance improvement ratio of the cases in comparison to CA0.

Figure 4.15 clearly shows the effects of the cases on yearly primary energy demand. As in Figure 4.16 CA2, CA4, and CA5 are on the negative side of the improvement ratio graph. Also, the primary energy performance improvement ratio of CA1 is ~0.16% which is neglectable. Additionally, the other standard retrofit measures have similar improvement ratios, the highest ratio is ~6%, which is very low. The reason of these results is case study building façade has better thermal transmittance coefficients than TS825 1999 requirements both for external wall and window. Even more efficient than standard building components. That is one of the characteristics of luxury high-rise residential buildings, to use high efficient building components. Therefore, increasing the facade heat insulation thickness or suggesting efficient window appliances would be ineffective as in this case study. CA14, CA22, CA30, CA38, and CA46 have very low primary energy performance improvement ratios as explained before.

Another important point in the results is the effect of South facade application. For example in CA12 the application areas are East and West facades and primary energy performance improvement ratio is 13% while in CA17 the application area is only South facade the improvement ratio is 14.7%. Similarly, in CA20 the application areas are East and West facades and the improvement ratio is 13.5%, while in CA25 the application area is only South facade the improvement ratio is 15%. So, South facade application alone is better performed than two other facade direction applications together. This result should be considered for the further case studies. When the cases were investigated one by one, the best resulted case is CA21 with 22%. There is proposed new facade component application on East, West and North facade directions, mass wall thickness is 20 cm and selective surface is copper based in CA21.

In order to show the reduction in yearly heating and cooling energy demands in more detail, hourly heating/cooling energy demands of CA0, CA13 and CA21 through the year were analyzed and the relationship between energy demand and outdoor dry-bulb temperature was investigated in the same graph. The graph of CA0 and CA13 comparison is shown in Figure 4.17 and the graph of CA0 and CA21 comparison is shown in Figure 4.18. Hourly energy demand and outdoor dry-bulb temperature was shown in the graphs. The graphs investigate the behaviour of the proposed facade component thorugh yearly energy demand and not primary energy demand.

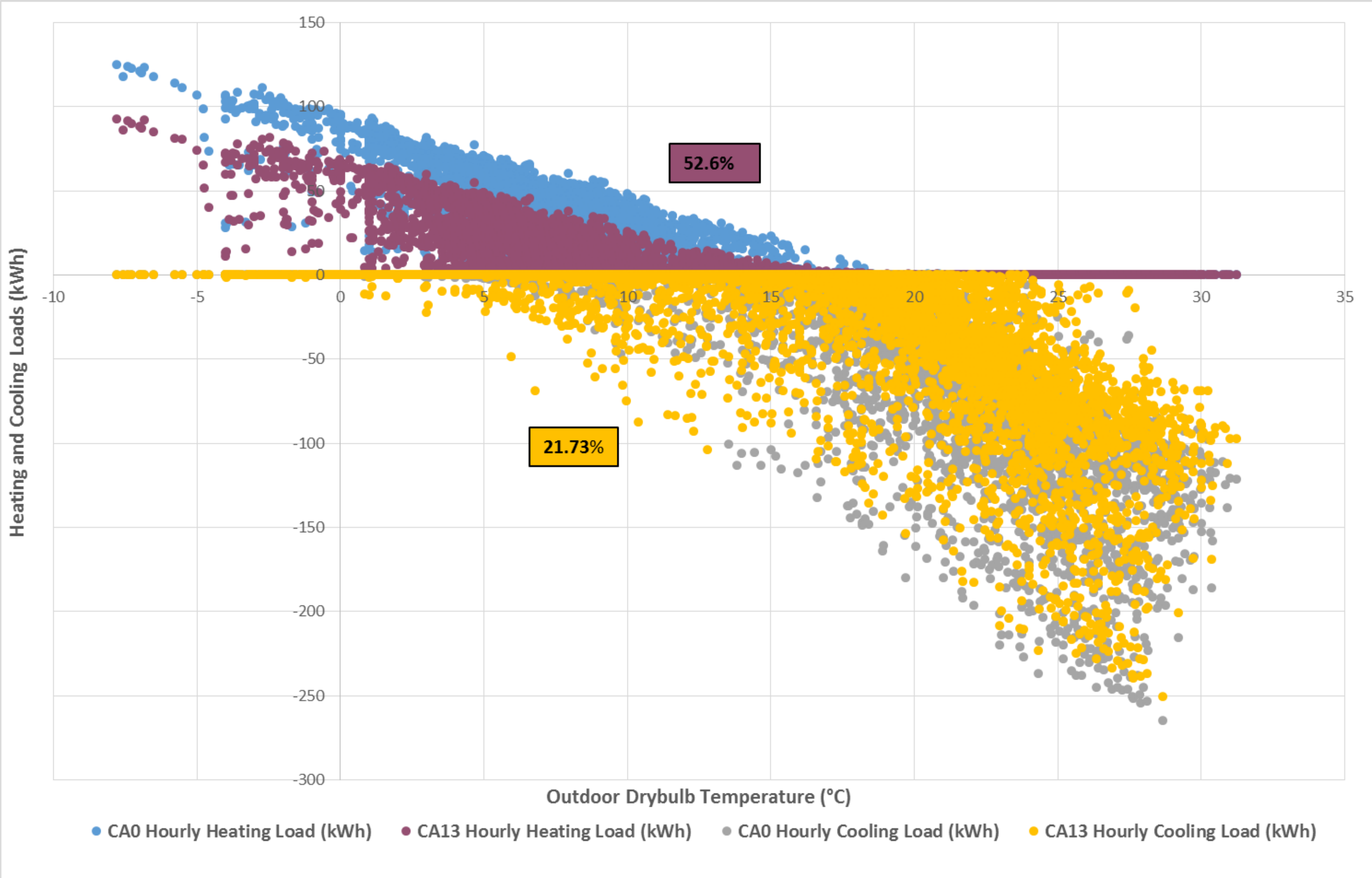


Figure 4.17 : Hourly heating/cooling energy demand vs. outdoor dry-bulb temperature through the year for CA0 and CA13.

According to the graph in Figure 4.17, blue colored dots are hourly heating energy demand of CA0 changing in accordance with outdoor dry-bulb temperature through the year and the purple dots show the same parameter for CA13. Purple dots are mostly below the blue dots, even when the outdoor dry-bulb temperature is below 0 °C still the purple dots are below the blue dots. This condition shows that the during the heating period, heating demand of CA13 is less than CA0. So, this analyze reveals that the heating energy demand was reduced for the whole year with proposed new façade component application in comparison to the base case. The reduction ratio in yearly heating demand for the whole year is shown in the purple box and 52.6% in CA13 in respect to CA0. This is a very important amount and it shows the effect of using proposed new façade component in heating period on heating demand in a hourly base through the year.

For the cooling period grey dots show hourly cooling energy demand of CA0 changing in accordance with outdoor dry-bulb temperature through the year and the yellow dots show the same parameter for CA13. Yellow dots are mostly above the grey dots, therefore as predicted the cooling energy demand is reduced for the whole year by proposed new façade component application. The reduction ratio in cooling demand for the whole year is shown in yellow box and 21.73% in CA13 in respect to CA0. This reduction amount is high enough for considering to use the proposed component during the cooling period.

Therefore, for both periods using proposed new facade component is very effective. This graph is very important since it makes the effect of the component visible. The difference can be easily seen without any calculation. Despite being effective during the cooling period, the proposed new facade component is more effective during the heating period. This situation was explained also in primary energy demand result comparisons. The difference during the heating period is sharper. Reducing half of the yearly energy demand is a very high ratio. Certainly, the cooling reduction performance of the component is also very high with its passive working process without any special characteristic element connection. Both results directly show the load reduction amount on HVAC system and this will direct the building management to select mechanical system components with smaller capacity.

The same comparison is shown in Figure 4.18 between CA0 and CA21 as mentioned before.

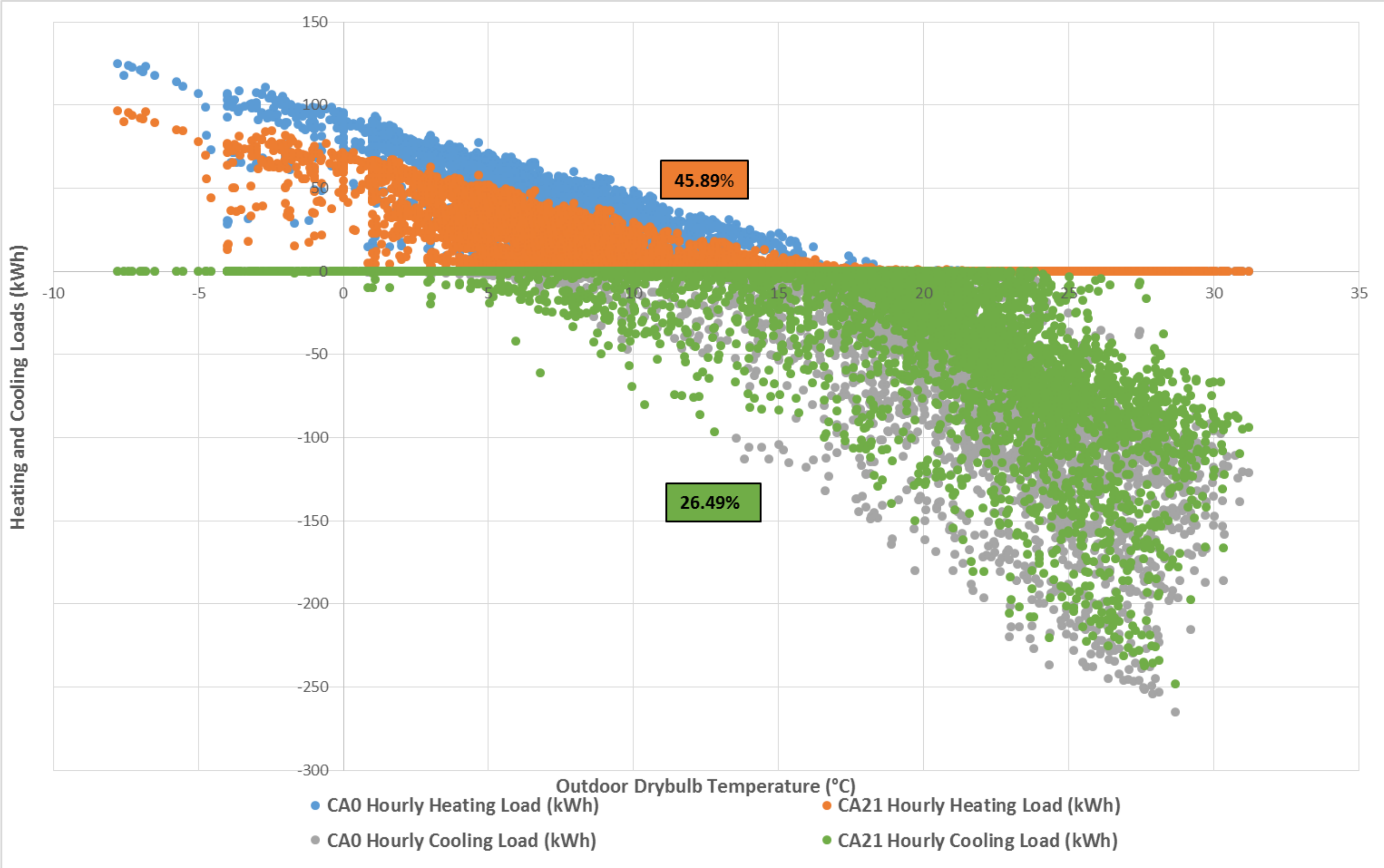


Figure 4.18 : Hourly heating/cooling energy demand vs. outdoor dry-bulb temperature through the year for CA0 and CA21.

In consistent with the graph in Figure 4.18 blue colored dots are hourly heating demand of CA0 changing in accordance with outdoor dry-bulb temperature through the year and the orange dots show the same parameter for CA21. Orange dots are mostly below the blue dots, even when the outdoor dry-bulb temperature is below 0 °C still the orange dots are below the blue dots. This analyze reveals that the heating demand is reduced for the whole year with new façade component application in comparison to the base case. The reduction ratio in heating demand for the whole year is 45.89% in CA21 in respect to CA0. For the cooling period grey dots show hourly cooling demand of CA0 changing in accordance with outdoor dry-bulb temperature through the year and the green dots show the same parameter for CA21. Green dots are above the grey dots, therefore the cooling demand is reduced for the whole year by new façade component use. The reduction ratio in cooling demand for the whole year is 26.49% in CA21 in respect to CA0.

Heating and cooling demand reduction ratios are very high for both cases. However, the performance of CA13 is better in heating period and the performance of CA21 is better in cooling period. The difference between two cases is the selective surface base material. It is aluminum based in CA13 and copper based in CA21. As shown in Figure 4.16, the primary energy performance improvement ratio of CA13 is 20% while it is 22% for CA21 in total. (In Figure 4.17 and 4.18 minus values don't mean any minus results. In order to prevent mixing of the heating and cooling load results, cooling loads were shown on the minus part of the graphs). Again the results direct to select mechanical systems with smaller capacity for this building.

4.1.6 Calculation of global costs for base case and retrofit cases of first case study building and primary energy demand – global cost comparison

4.1.6.1 Calculation of global costs of the base case and retrofit cases

In the global cost calculations as for the construction costs only the costs of facade elements were calculated since the only effective building component on building energy performance is facade in this study. Also, the aim of the research is to investigate the effects of the facade components on building yearly primary energy demand.

Initial investment costs, replacement costs, running costs, energy costs and residual value were considered within the scope of this thesis study.

Lifespan of the building elements were collected from national data and these data were mainly gathered from the related companies for each building element kind. The cost of the building façade was calculated for each proposed façade component case to compare the standard and advanced retrofits. In order to calculate initial investment costs of each building element that are effective on energy performance improvement, costs were gathered from the market in Turkey. These include material, transportation, labor and scaffolding costs together.

If gathering the costs of building elements part is examined in a bit detailed, firstly only the costs of the varied building elements were collected in convenience with the Directive 2010/31/EU. The varied elements between the cases are facade materials and facade materials are directly effective on building energy performance between the cases, therefore cost calculations were done only for facade elements. First of all the area of each varied facade element was calculated through the architectural drawings (The material details for the proposed new facade component were explained in part 4.1.3.1 and for the base case explained in the definitions of the case study buildings). These elements for the base case is glazing, frame, sub-frame, gypsum plaster, concrete wall (for some cases), heat insulation, waterproof membrane, ceramic wall cladding (this is a construction with bearer profiles). For the standard facade retrofits there are heat insulation additions and glazing changings in the cases, therefore costs of heat insulation and the varied glazings were collected. For the advanced facade retrofits the price of the component that was explained in part 4.1.3.1 were collected. The elements of the proposed component are selective surface, bearer profiles for glazing layer, sub-frame, frame, glazing, exterior shading device, and vent application.

After designating the building elements which the costs would be calculated for, unit prices were collected from the market for each and possible prices were compared with the construction and installation unit prices of 2015 published by Turkish Ministry of Environment and Urbanization [Republic of Turkey Ministry of Environment and Urbanization, 2015].

Glazing costs were gathered from a well-known Turkish glazing brand [Url-16]. First the unit price of the base case's glazing was provided. Then, as it was shown in the definition of case studies there are several glazing types were used in the standard facade retrofits and their unit prices were gathered. And finally, the unit price of the glazing that was used in the proposed component was provided. After the unit prices, lifespan of the glazing material data was provided by the brand and the calculation process for glazing elements became ready.

For the frames and sub-frames the company that the case study building management (Kanyon Residence management) was in contact provided the prices and lifespan of the materials [Url-17].

For ceramic wall cladding the unit price for the whole component was gathered from a construction firm [Url-18]. This component contains ceramic exterior wall plates together with bearer profiles, anchor elements and clips.

Heat insulation and waterproofing membrane prices were collected from sectoral brands.

For the proposed facade component the price of selective surface layer was collected in two options as with aluminum based and with copper based. The prices were gathered from international companies together with a national manufacturer.

The prices of bearer profiles and vent applications were gathered from the construction firm that provided the unit price of ceramic wall cladding [Url-18].

The unit price of exterior shading device together with its lifespan were provided by a known shading device company [Url-19].

Gathering the unit prices is a long period for the thesis study.

The calculations were done for 30 years and the equations in part 2.1.2.4 were used. Calculation procedure was applied for each case study. In order to calculate global cost for each case, a calculation sheet that was prepared in accordance with the mentioned equations was prepared and in harmony with the used sheet in TUBITAK 1001 project. The example sheet locates in Appendix A.

As a brief explanation of what the sheet does: in order to calculate initial investment cost after collecting whole prices, total prices of the varied materials were calculated for each case including the base cases. For the replacement costs, the prices of the elements that should be changed in 30 years were added to the total prices according to lifespans of the materials. Energy costs were calculated for each case including the base cases through calculating yearly heating, cooling and lighting energy demands and multiplying them by using the equation 2.6 and as explained in part 3.8.2.1.

Finally, residual value is determined for cases seperately. Then, for each case the extra costs were calculated in respect to the base cases. Basically, extra costs were used as each case study's global cost.

4.1.6.2 Primary energy demand - global cost comparison

In this part, in Figure 4.19, global cost calculation results of all cases are shown. The global cost of the base case is 351.13 TL/m^2. Most of the standard retrofits locate directly on CA0 which means they only increase the global cost, but do not have a considerable effect on primary energy demand. The cases that increase the yearly primary energy demand could be seen clearly in the graph on the upper-right side of CA0. Luxury high-rise residential buildings are well constructed buildings and as explained in the description of the case study, building facade thermo-physical properties are mostly better than the guidance in national standards. Therefore, there is no need to improve the building façade with standard improvement measures. Since the building façade is high-performed, changing the façade components for improving energy efficiency would result with higher costs. For example, global cost of CA1 is 382.6 TL/m^2. That is the case of adding heat insulation to the building facade. Therefore, improving U-value is not always improves the building energy performance. This case directly locates on top of CA0. However, advanced retrofits are mostly locate on the left side of the graph which means they reduce the primary energy demand effectively. So, there is an important difference between standard and advanced retrofits even they are not cost effective. Regarding global cost, according to the results most of the advanced cases are not cost-optimum as expected. Only the cases where proposed component faces South and no surrounding for shading effect were resulted as cost-optimum; such as CA15, CA16, CA23, CA24, CA31, CA39, CA47, and CA48. The primary energy performance improvement ratio of these case studies is around ~9-10%. This improvement ratio could be considerable according to the energy demand level of the building. Additionally, CA8 and CA9 were resulted as cost-optimum, however their primary energy performance improvement ratio are 5.98% and 3.46% respectively and those percentages are not enough to consider these cases in the scope of primary energy performance improvement studies. In accordance with the results, since the application of the proposed facade component reduces the loads on HVAC system, it reduces the installation cost for HVAC systems.

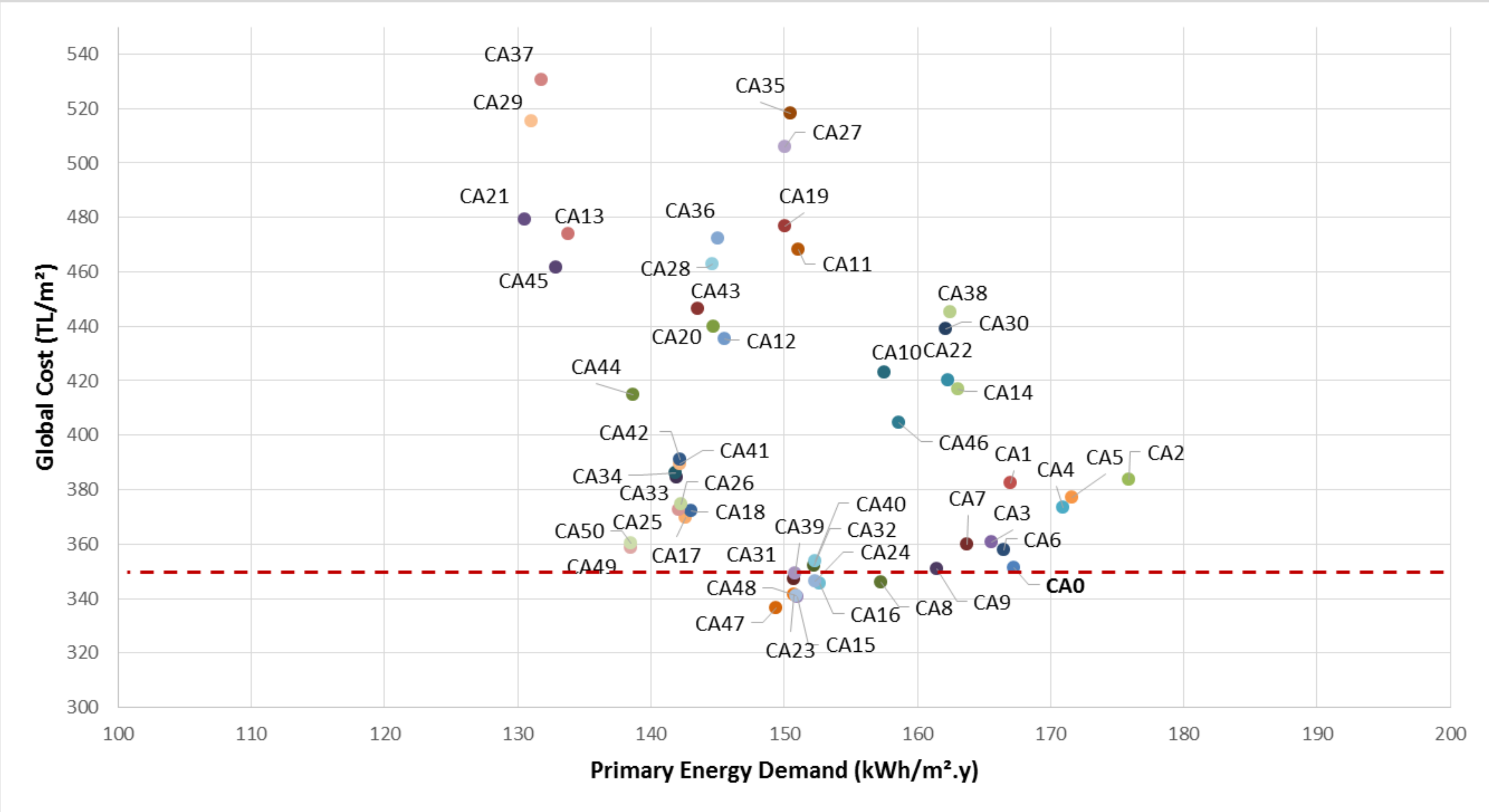


Figure 4.19 : Global cost and yearly primary energy demand comparison.

The main problem of the occupants/owners of this building typology is the monthly energy expenses. Therefore, it is crucial to reduce the energy expenses than the initial investment cost. The occupants/owners are from high-income group. Therefore, they have the ability to pay higher costs at first place as long as the monthly energy expenses are reduced. Thus, the first aim in here to reduce the yearly primary energy demand and so energy costs. So, cases with high primary energy demand reduction are more than welcome even if they are not cost-optimum. The aspect is different in this study than a study with investigation of standard retrofits.

4.1.7 Investigation of thermal comfort condition of the first case study building and advanced retrofits

At this point it is important to evaluate also the thermal comfort level of the apartment units when proposed new façade component applied on the building façade. Hence, hourly operative temperatures of CA0, CA13 and CA21 were analyzed for the whole year and the evaluations was done in accordance with EN 15251. During the analyzes it is assumed that there is no HVAC installation in the building (free-running mode), therefore the pure effect of façade components could be focused. The comfort level expectations are in accordance with the categorization in EN 15251, Category II: Normal level of expectation and should be used for new buildings and renovations. Heating and cooling operative temperature set-points were fixed in the analyzes according to comfort category II of EN 15251: for heating is 20 °C and for cooling is 26 °C. This operative temperature values are for residential buildings living spaces [BSI, 2008].

The graph is shown in Figure 4.20 was divided in three parts. The parts in sides represent heating period and the part in the middle represents cooling period. The red line shows limit operative temperature for heating (20 °C) and the blue line shows limit operative temperature for cooling (26 °C). Uncomfortable hours (UH) for C0, CA13 and CA21 were calculated according to these limit values and shown on the graph in the boxes. For heating period, hours with operative temperature below 20 °C; for cooling period, hours with operative temperature above 26 °C were counted as uncomfortable. Heating period was divided in two parts, therefore UH were indicated in separate boxes under the related period, then the total UH for heating period through the year is shown in the red box. UH for cooling period of CA0, CA13 and CA21 were shown in the blue box.

According to Figure 4.20, operative temperature variations of CA0 through the heating period is mostly under the limit value (20 °C), while in CA13 and CA21 the operative temperature values are mostly above the limit value. That means the number of uncomfortable hours are less in CA13 and CA21 in comparison to CA0. For the cooling period, operative temperature variations of CA0 is mostly above the limit value (26 °C) and the tendency is the same in CA13 and CA21, but not as much as CA0. So, the number of uncomfortable hours in CA13 and CA21 are less than the number in CA0.

As in Figure 4.20, UH of CA13 and CA21 are less than CA0's. UH total for the whole year for CA0 is 6865 hours, for CA13 is 4526 hours and for CA21 is 4471 hours. During the heating periods UH of CA13 and CA21 are almost half of the UH of C0. UH of cooling period for the cases is closer than the difference in heating period, however UH of CA13 and CA21 are still less than CA0.

Uncomfortable hours for all case scenarios were calculated separately too, in order to compare with CA0 and to see if the proposed façade component application reduces the uncomfortable hours. The comparison of UH between the cases is shown in Figure 4.21. According to figure, all case studies have less UH than CA0 both for heating and cooling periods. During the heating period all case studies have less UH than CA0, some of them have UH almost half of CA0 has. Cases with proposed new facade component application on East, West and North exterior opaque walls (CA13, CA21, CA29, CA37) except CA45 with black paint application and cases with proposed new facade component application on East exterior opaque wall that faces South after turning the building 90° and without surroundings (CA18, CA42, CA50) were resulted with the least UH during the heating period. As explained before cases are parallel, only mass wall thickness and selective surface base varies in each eight cases and in the last eight cases there is black paint application instead of selective surface. Basically cases with aluminium based selective surface application on mass wall of 20 cm (from CA11 to CA18) has the least UH during heating period and cases with black paint application on mass wall thickness of 20 cm instead of selective surface (from CA43 to CA50) has the most UH during heating period.

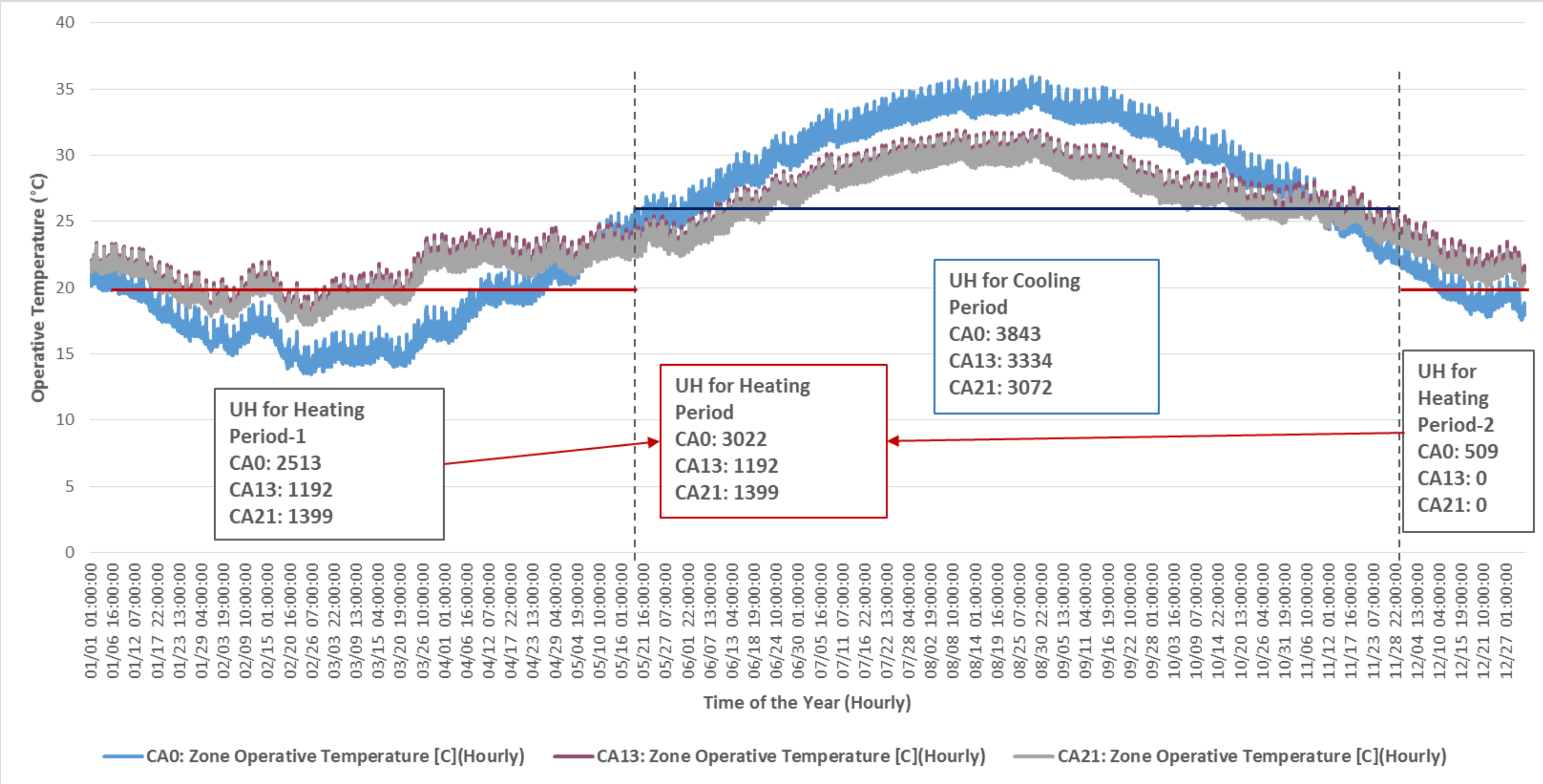


Figure 4.20 : Hourly operative temperature comparison of CA0, CA13, and CA21.

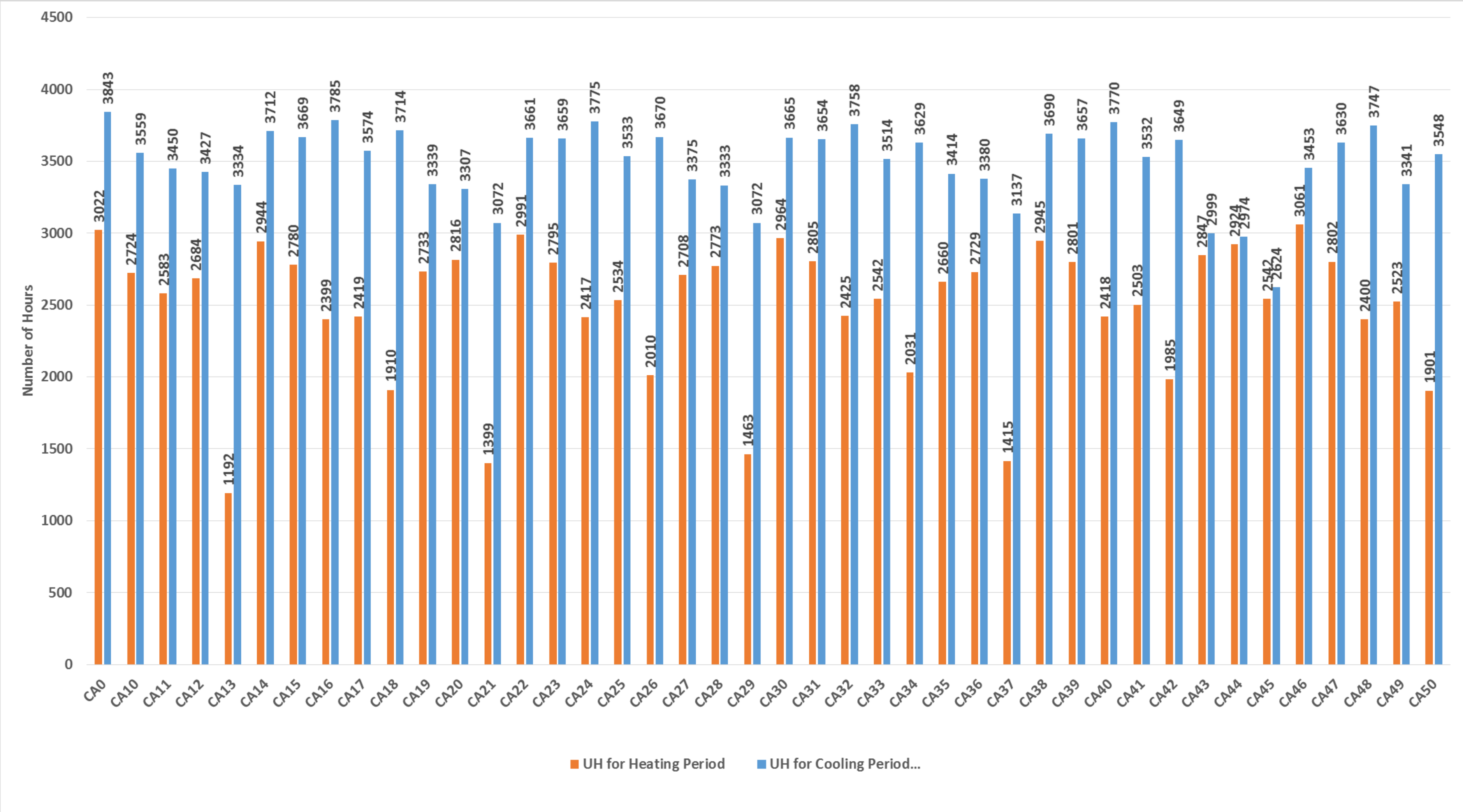


Figure 4.21 : Uncomfortable hours (UH) of CA0 and anvanced retorifts for heating and cooling periods.

In Figure 4.21, between aluminum and copper based selective surface applications, cases with aluminum based selective surface (from CA11 to CA18) has lower UH than cases with copper based selective surface application (from CA19 to CA26) while mass wall thickness is 20 cm. Cases with copper based selective surface (from CA35 to CA42) has lower UH than cases with aluminum based selective surface (from CA27 to CA34) while mass wall thickness is 40 cm. For the cooling period cases with black paint application on mass wall of 20 cm instead of selective surface (from CA43 to CA50) has the least UH while cases with aluminium based selective surface application on mass wall of 20 cm (from CA11 to CA18) has the most UH. During the cooling period between aluminum based and copper based selective surface applications, cases with copper based selective surface (from CA19 to CA26) have lower UH than cases with aluminium based selective surface (from CA11 to CA18) while mass wall thickness is 20 cm. Cases with aluminum based selective surface (from CA27 to CA34) has lower UH than cases with copper based selective surface (from CA35 to CA42) while mass wall thickness is 40 cm. Therefore, mass wall thickness effects the behavior of selective surface layer and the effect reverses in accordance with the period.

In order to analyze the improvement ratio in the scope of thermal comfort the pie charts in Figure 4.22, Figure 4.23 and Figure 4.24 were generated.

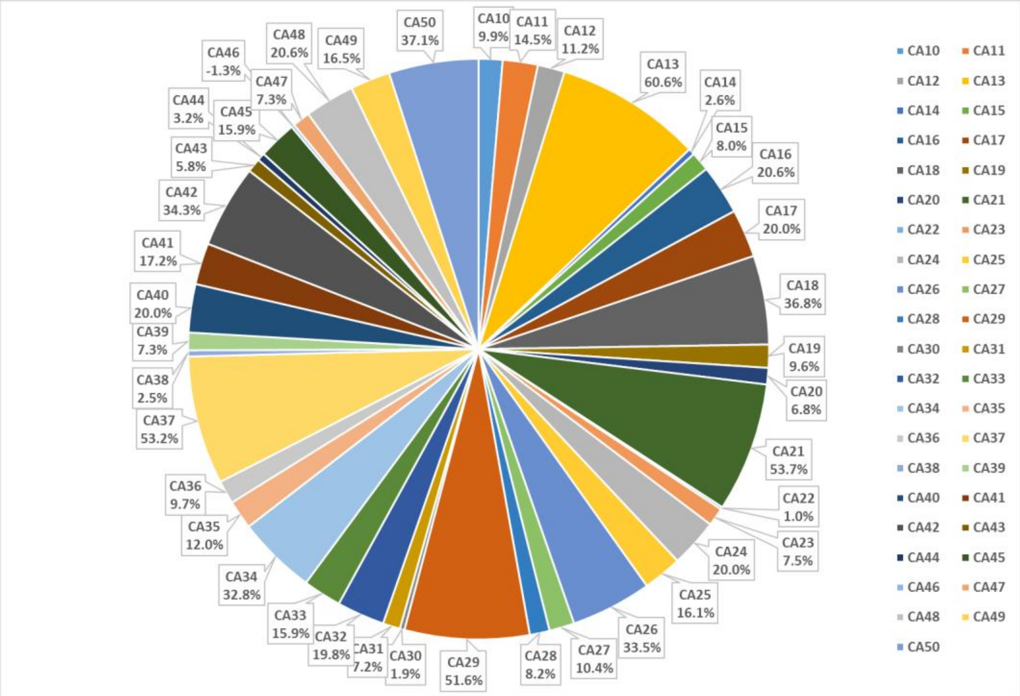


Figure 4.22 : Reduction ratio of UH in respect to CA0 for heating period.

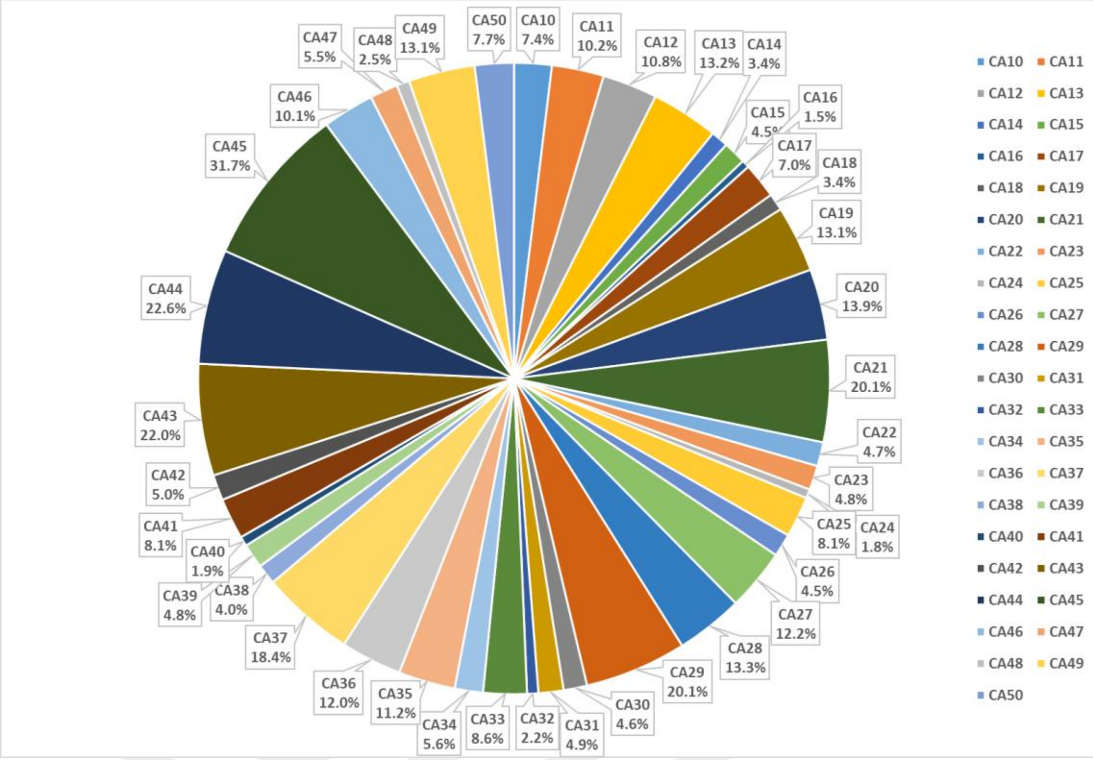


Figure 4.23 : Reduction ratio of UH in respect to CA0 for cooling period.

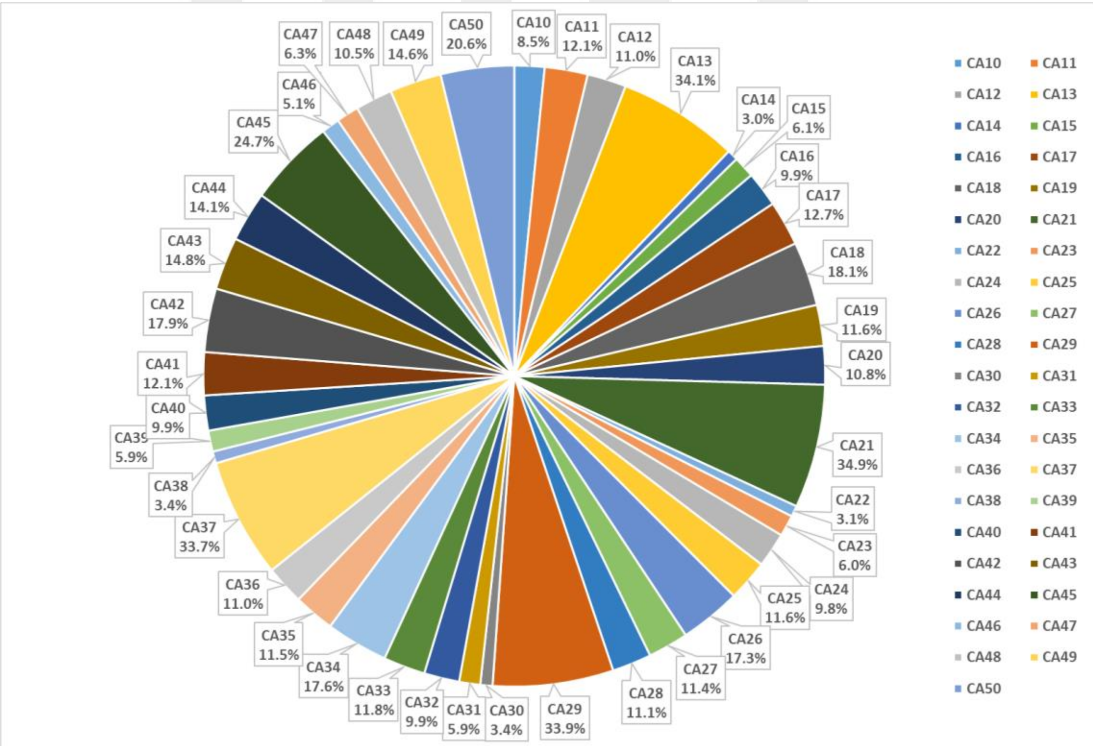


Figure 4.24 : Reduction ratio of UH in respect to CA0 for 1-year total.

According to Figure 4.22 most of the cases have a high UH reduction ratio during heating period in respect to CA0. CA13 has the highest reduction ratio with 60.6%. There is proposed new facade component application on East, West and North facade directions with aluminum based selective surface application on 20 cm mass wall. C21 has the second highest UH reduction ratio with 53.7% and C21 is a similar case to CA13, the only difference is selective surface is copper based instead of aluminum. C37 has the third highest UH reduction ratio with 53.2% and it is a similar case to CA21, the only difference is mass wall thickness is 40 cm instead of 20 cm.

In consistent with Figure 4.23, CA45 has the highest UH reduction ratio during cooling period with 31.7%. There is proposed new facade component application on East, West and North facade directions with black paint application on 20 cm mass wall. CA44 has the second highest UH reduction ratio with 22.6% and the only difference between CA45 is on North facade direction there is not any proposed component application. CA43 has the third highest UH reduction ratio with 22% and the only difference between CA45 is proposed new facade application on East facade is less. The behavior of proposed new facade component application is better in heating period in the scope of reducing uncomfortable hours.

According to Figure 4.24, cases with the highest UH reduction ratio both for heating and cooling periods in total are respectively CA21 (34.9%), CA13 (34.1%), CA29 (33.9%), CA37 (33.7%), and CA45 (24.7%). The common feature of these cases is there is proposed new facade component application on East, West and North exterior opaque walls and transparency ratios of East and West facades are lower than CA0. Therefore, as in primary energy performance results, the performance of the proposed component increases also in the scope of thermal comfort as the application area expands. Additionally, most of the cases, even the cases with a very few primary energy performance improvement ratio, have a reduction in uncomfortable hours. Hence, the improvement in indoor thermal comfort by applying proposed façade component is significant.

4.1.8 Analization of the results for the first case study building

The results show that the standard façade retrofits does not have any improvement effect on building energy performance of luxury high-rise residential buildings. Advanced facade retrofit cases are very effective on building energy performance especially when applied to wide surface areas. In this case study building, since the building is existing, the façade design is not directly convenient for the application of the proposed façade component. Therefore, modifications were done in window-to-wall ratio of the building preventing an increase in lighting energy demand. Black paint application within the component is effective in the scope of reducing primary energy demand, however in terms of thermal comfort other application styles are better performed in total. Also, in terms of energy performance improvement the results of the cases are close and almost all of them are very effective. Therefore selecting the cases as CA13 and CA21 will be better choices. In addition, the cases are not cost-optimum, however the main target is to find out the effective application method of the proposed façade component in terms of energy efficiency.

4.2 Application of the Suggested Approach on Second Case Study Building

4.2.1 Definition of second case study residential building

This part contains the necessary data about the second case study building. This data is required to define the second reference building for this study and also crucial for the investigations.

4.2.1.1 Climatic condition of the second case study building

This case study building assumed to be located in Istanbul as the first case study building. Therefore, the climatic conditions of the two case study building is the same. This method provides to compare the pure effects of retrofit cases.

4.2.1.2 Location, direction and geometry of the second case study building

This case study building is a virtual luxury high-rise residential building that was generated in convenient to passive design parameters. Therefore, the effects of the parameters were investigated together with the facade retrofit cases.

The necessity of this part is there were not enough application areas on building opaque facade parts of the first case study building since the facade design was done without considering any advanced system application. Also, the main facade was facing East, however South facade is very important for solar gains, also the primary energy performance results supported this condition. Additionally, there were high surrounding buildings that blocks the solar gains in the first case study building, however especially the new residential building projects take place in less crowded areas. So, for all those reasons a new building was generated both to see the effects of passive parameters and the pure effect of proposed facade component when the architectural design is more convenient for the application of new proposed facade component without any intervention when the all conditions were fitted**.**

Architectural plan of the newly designed building is shown in Figure 4.25. Main living areas locates in South part of the building. Transparency ratio of the South is the highest among all other directions. This layout design of the rooms is beneficial especially for heating period and also for lighting.

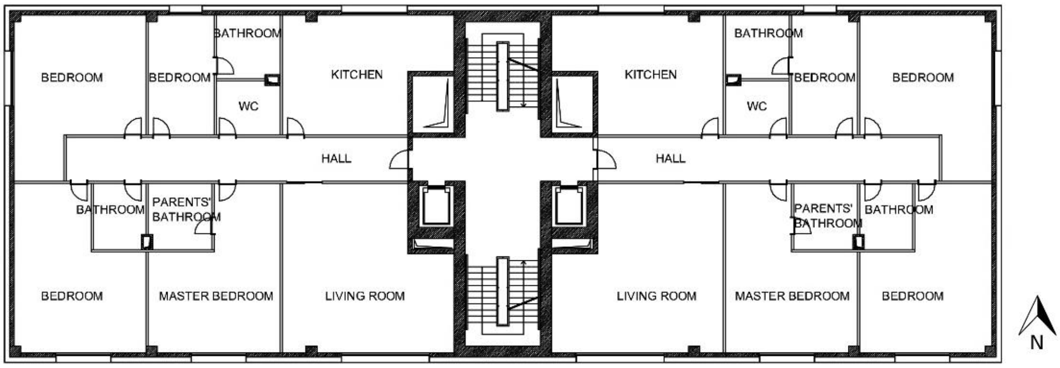


Figure 4.25 : Architectural plan of the second case study building.

There are 15 residential floors as in the first case study building and the floor component of the first floor was modelled as adabatic as in the first case study building in order to be able to compare them.

The building has two apartment units in each floor. Therefore, apartment units have three facade directions and so could be able to benefit in the scope of solar radiation from three different directions. This is a very important parameter to gain most benefit from the facades and facade applications. Therefore, all apartment units have facades on South direction. For residential buildings, benefitting form South facade is crucial for heating period.

There are 4 bedrooms in each apartment unit. In the first case study building, there are 4 bedrooms in the upper 8 floor, in the first 7 floor there are single bedrooms. Both of them are suitable for luxury high-rise residential buildings, since there is not any limitation.

South facade elevation of the newly designed (virtual) building is shown in Figure 4.26. The transparency ratio of the South facade is 33%.

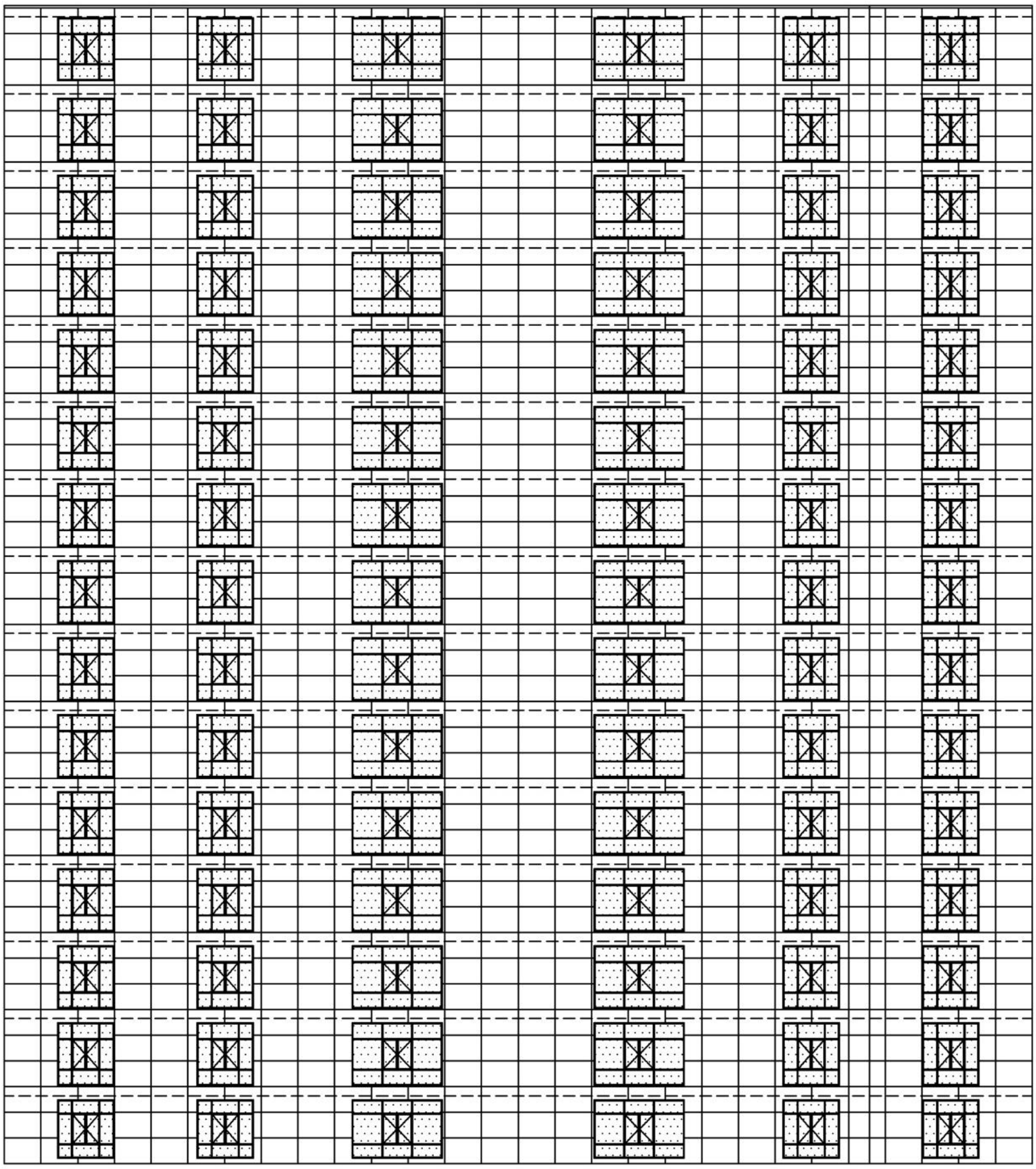


Figure 4.26 : Architectural elevation of South façade.

4.2.1.3 Building façade thermo-physical and optical characteristics

In order to demonstrate the pure effect of appropriate designing in the scope of passive parameters; the building envelope components were kept same with the first case study building. Therefore, this building has a ceramic cladding on opaque parts of the facade and it has the same glazing with the first case study building.

Thus, it has same U-values with the first case study building for all building envelope components and the envelope thermo-physical properties are on a higher level than the requirements in TS 825. So, this building is a high-performed building too as in the first one.

4.2.1.4 Boundary conditions

For the occupancy, the most common family type in Turkey according to TUIK data was selected which is couple with 2 children and since the occupant group is high income group there is one extra room for a housekeeper [TUIK, 2011]. The occupancy have the same operational schedule with the first case study building as in Table 4.8

Internal gains from household electrical appliances is the same with the first case study building and the data is as in Table 4.9. The operational schedule is the same too.

Internal gains from lighting were also kept same with the first case study building by taking one of the apartment units with a similar area with the apartment unit areas in second case study building and same lighting appliances with first case study building were used. The average lighting density is 7 W/m^2 for the residential zones. Additionally, there is daylight automation control in this building as in the first one.

4.2.1.5 Information data for heating and cooling systems

Thermostat values for heating and cooling periods were defined in accordance with the first case study building. Therefore, heating set-point was designated as 22 °C and cooling set-point was designated as 24 °C.

Accordingly, HVAC system was modelled as Ideal Loads as in the first case study building and the operational schedules are the same.

4.2.1.6 Other

The building has the same internal shading device and same operational schedule for the device with the first case study building.

4.2.2 Primary energy demand calculation and result of second case study residential building

The calculation of yearly energy demand of the second case study were done through the same simulation tools.

As a result of the analysis the yearly energy demand results of the second case study building is distinguishedly shown in Table 4.17.

Table 4.17 : Yearly energy demand results of second case study building.

Yearly Energy Demand for Heating (kWh/m².y)	Yearly Energy Demand for Cooling (kWh/m².y)	Yearly Energy Demand for Lighting (kWh/m².y)	Total (kWh/m².y)
25.61	22.18	8.03	55.82

Then, yearly primary energy demand of second case study building was calculated through the equations 3.1, 3.2 and 3.3. It is shown in Table 4.18.

Table 4.18 : Yearly primary energy demand results of second case study building.

Yearly Primary Energy Demand for Heating (kWh/m².y)	Yearly Primary Energy Demand for Cooling (kWh/m².y)	Yearly Primary Energy Demand for Lighting (kWh/m².y)	Total (kWh/m².y)
25.61	52.34	18.95	96.91

4.2.3 Explanation of the proposed advanced retrofit measure

The proposed advanced component is the unique part of this thesis study. The main aim of the study is to investigate the effects of it. Therefore, the same component was used in the second case study building.

There are two differences from the first case study building within the parameters that provide to determine the advanced facade component type. The building locates in a less crowded area, so there is no surroundings to cause shading and the main direction of this building is South. All the answers for the other parameters that were explained in part 3.5 as building typology, climatic conditions, building part that has the largest outdoor area, building envelope thermo-physical and optical properties for the existing condition and occupant profile are the same. In this case study building, the possible location of the proposed new facade component was thought in the design stage and window locations were decided in accordance with the proposed component. Therefore, facade appearance of the building is well designed and not as in the first case study building. Also, there is no need to change window-to-wall ratio on any facade direction. Proposed wall component can also be applied on existing buildings, however for a good architectural view it is better to consider using the proposed component on the design stage.

Verification simulations are not necessary in this case study building, since the same advanced component is used and it is verified before. South facade elevation with proposed new facade component application is shown in Figure 4.27.

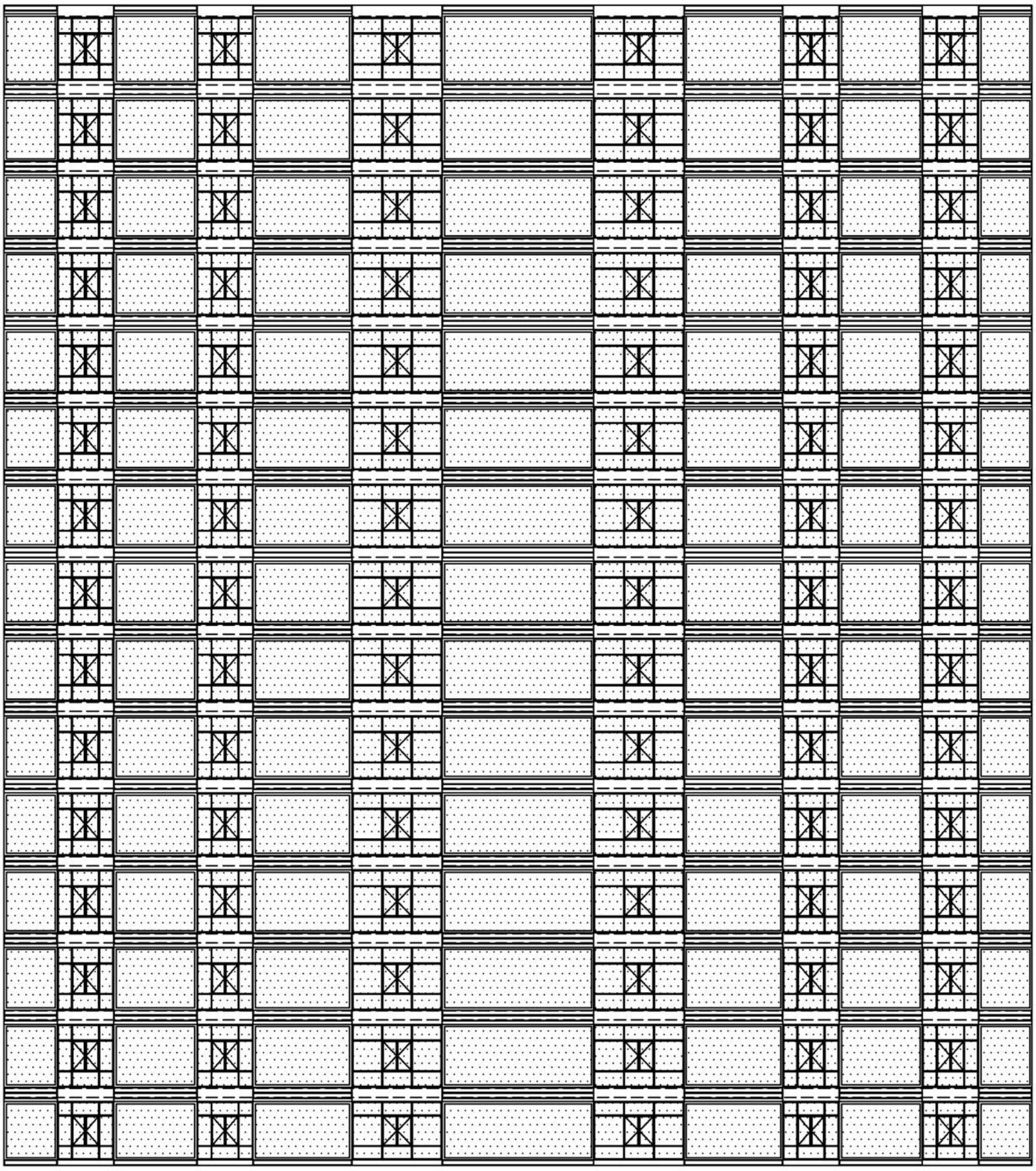


Figure 4.27 : Architectural elevation of South façade of the second case study building with proposed façade component.

There are wide window areas for each room. The possible location of the proposed component was thought in the design stage and window areas were decided accordingly. The proposed component locates between window fixtures as in Figure 4.27. There is an enough opaque facade area for proposed component application. As a design concern, glazing area alignment of the proposed component and windows are at the same level on the bottom and top of each floor. This kind of specific and metric design characteristics can be applied only if using the proposed component is considered at the design stage.

4.2.4 Explanation of the façade retrofit cases for the second case study building

There are standard and advanced facade retrofit cases as explained in part 3.6. The investigated cases for the second case study building are shown in Table 4.19. The C mark indicates the cases, the B mark indicates that the case belongs to the second case study building and the number next to the mark shows the case number.

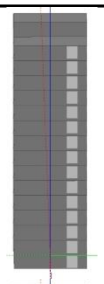
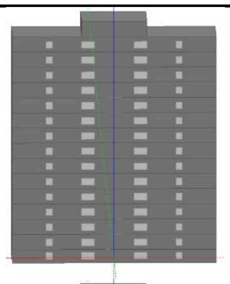
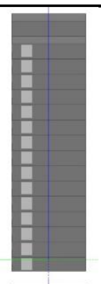
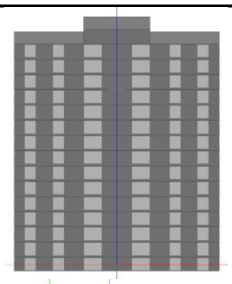
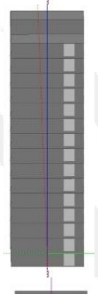
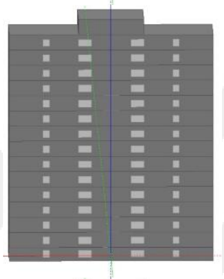
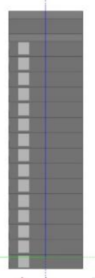
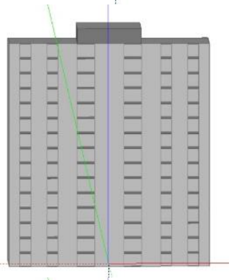
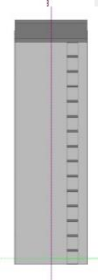
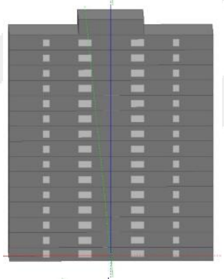
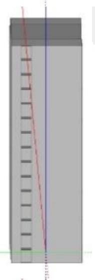
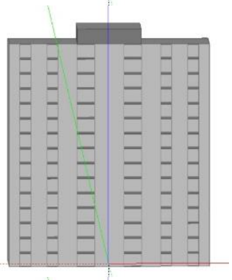
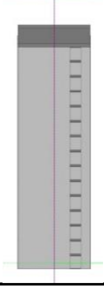
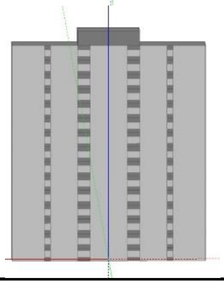
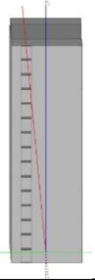
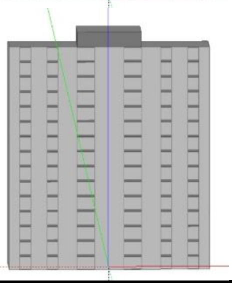
CB0 represents the base condition of the case study building. Cases from CB1 to CB4 are standard façade retrofits that are very effective on standard residential buildings. CB1 shows adding heat insulation layer to the base case building façade. From CB2 to CB4, cases show various glazing type applications instead of the base case glazing to the whole building facade. Cases from CB5 to CB16 are advanced façade improvement cases with proposed new façade component application.

Table 4.19 : Façade retrofit case explanations for the second case study building.

Case Name	Explanations
CB0	Base condition of the second case study building
CB1	2 cm extra heat insulation to the exterior walls
CB2	New Glazing; U:1.4W/m².K SHGC:0.34 Tvis:0.49 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CB3	New Glazing; U:1.3W/m².K SHGC:0.54 Tvis:0.77 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CB4	New Glazing; U:0.9W/m².K SHGC:0.37 Tvis:0.61 (Main U:1.56W/m².K SHGC:0.45 Tvis:0.51)
CB5	Proposed new façade component (PNFC) application on available South exterior opaque walls; Mass wall thickness 20 cm; Aluminium based selective surface used
CB6	PNFC application on available South, East and West exterior opaque walls; Mass wall thickness 20 cm; Aluminium based selective surface used
CB7	PNFC application on available South, East, West and North exterior opaque walls; Mass wall thickness 20 cm; Aluminium based selective surface used
CB8	PNFC application on available South exterior opaque walls; Mass wall thickness 20 cm; Copper based selective surface used
CB9	PNFC application on available South, East and West exterior opaque walls; Mass wall thickness 20 cm; Copper based selective surface used
CB10	PNFC application on available South, East, West and North exterior opaque walls; Mass wall thickness 20 cm; Copper based selective surface used
CB11	PNFC application on available South exterior opaque walls; Mass wall thickness 40 cm; Aluminium based selective surface used
CB12	PNFC application on available South, East and West exterior opaque walls; Mass wall thickness 40 cm; Aluminium based selective surface used
CB13	PNFC application on available South, East, West and North exterior opaque walls; Mass wall thickness 40 cm; Aluminium based selective surface used
CB14	PNFC application on available South exterior opaque walls; Mass wall thickness 40 cm; Copper based selective surface used
CB15	PNFC application on available South, East and West exterior opaque walls; Mass wall thickness 40 cm; Copper based selective surface used
CB16	PNFC application on available South, East, West and North exterior opaque walls; Mass wall thickness 40 cm; Copper based selective surface used

The façade views of the cases are shown in Table 4.20. The images of all cases were generated by DesignBuilder v4.2.

Table 4.20 : Façade elevations of advanced retrofit cases for second case study building.

Case Name	East Facade	North Facade	West Facade	South Façade
CB0				
CB5, CB8, CB11, CB14				
CB6, CB9, CB12, CB15				
CB7, CB10, CB13, CB16				

CB0 indicates the base case and as it can be seen in Table 4.20, South facade has the highest transparency ratio and North facade has an optimal transparency ratio for heating period requirements. The proposed facade component locates on the same exterior wall parts in CB5, CB8, CB11, and CB14 and only on South facade. Similarly in CB6, CB9, CB12, and CB15 the proposed facade component locates on the same exterior wall parts and on South, East and West facades. In CB7, CB10, CB13, and CB16 the proposed component locates on the same exterior wall parts and on South, East, West and North facades. The variations between the cases that have the proposed facade component on the same areas are selective surface base and mass wall thickness.

4.2.5 Calculation and results of primary energy demand of second case study retrofit cases

Heating, cooling and lighting energy demands were assessed with EnergyPlus and the calculated total primary energy demand of each scenario was compared to the case study building (CB0). Primary energy demand results of façade retrofits are shown in Figure 4.28. According to the results, primary energy demand of CB0 is 96.91 kWh/m²y. The benefit of standard retrofits are very few, even CB3 was resulted with more primary energy demand than CB0. CB1 is the case of adding 2cm extra heat insulation to the external walls and it was resulted as 95.95 kWh/m²y. The primary energy demand reduction amount of this case is very similar to CA1 in the first case study. As in CA1 there is a neglectable reduction in yearly primary energy demand through extra heat insulation. In the other standard retrofit measures, the glazing replications were resulted with neglectable primary energy demand reduction amounts too.

Further investigations with proposed new façade component were done. According to the results in Figure 4.28; all cases with proposed new facade component were resulted effective on reducing the yearly primary energy demand. So, in the advanced facade retrofit cases there are considerably effective reduction amounts in yearly primary energy demand in respect to CB0. Especially CB7, CB10, CB13 and CB16 were resulted with very low yearly primary energy demands in respect to CB0. These cases are where the proposed facade component was applied on all facade directions. The differences between those cases are there is aluminum based selective surface application in CB7 and CB13 while there is copper based selective surface application in CB10 and CB16. Additionally, the mass wall thickness is 20 cm in CB7 and CB10 while it is 40 cm in CB13 and CB16. So, in order to gain benefit from the proposed wall application, the most important parameter is applying it on as many surfaces as possible. Even the North direction is effective as working as a buffer-zone. An addition to effective use of the proposed component is South facade application. According to the results, cases with only South facade application have sharp reduction in yearly primary energy demands.

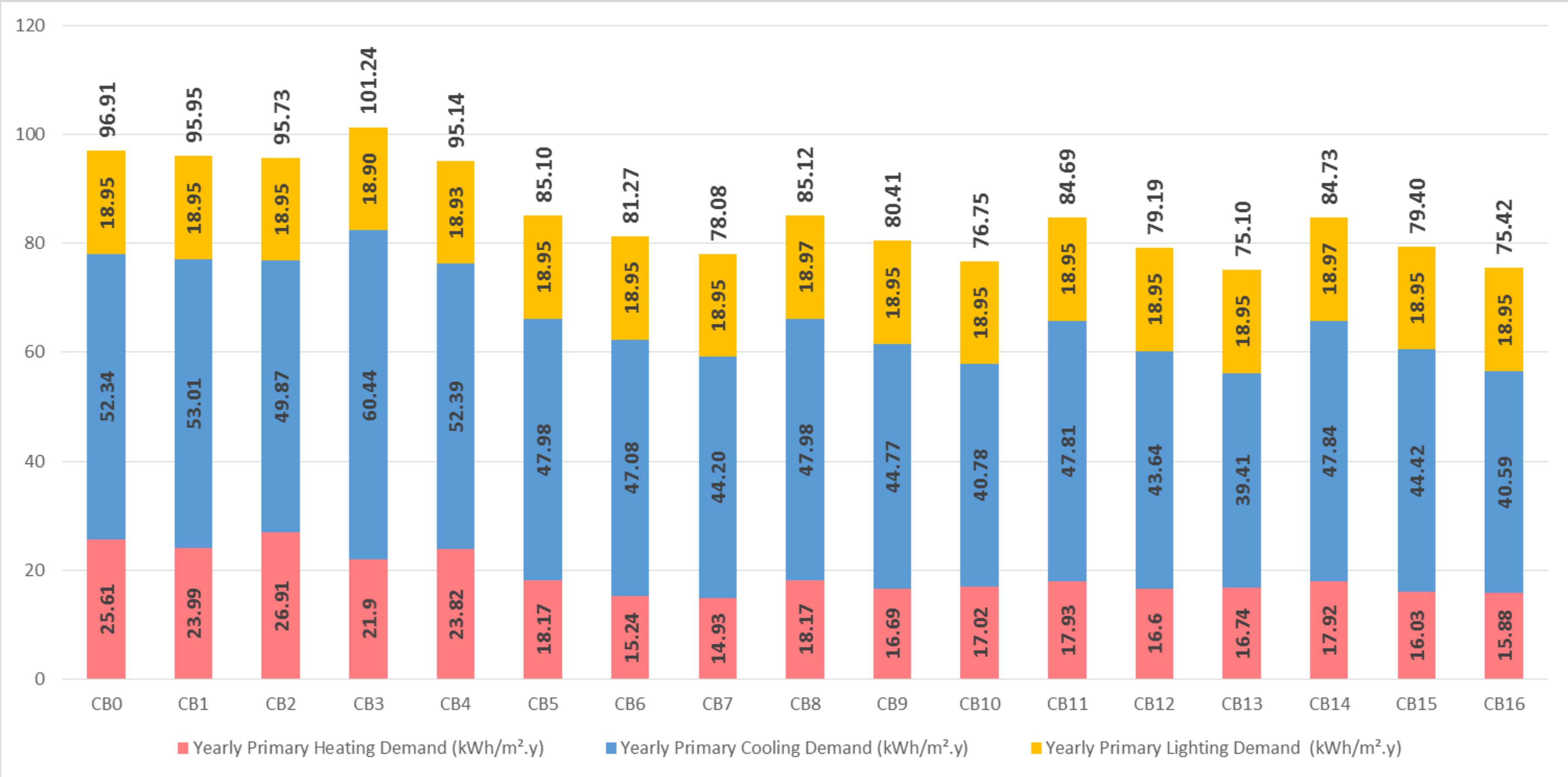


Figure 4.28 : Yearly primary energy demand results of the cases of second case study building for heating, cooling, and lighting.

Primary energy demand based improvement ratio of each case are shown in Figure 4.29 in order to discuss the effects of the standard and advanced retrofit cases on second case study building. The graph verifies that standard retrofits have neglectable effects on yearly primary energy demand improvement of the second case study building. The existing façade construction's thermo-physical properties of the second case study building is same with the first case study building. The façade is high performed in the scope of thermo-physical properties, therefore standard retrofits that increase the façade thermo-physical performance are not necessary to apply in this case study as in the first case study building. Also, im CB3 since the application of this case increases the yearly primary energy demand the case has a negative improvement ratio.

Results of the cases that have the proposed new facade component only on the South side are very similar and primary energy performance improvement results of those cases are respectively CB5; 12.18%, CB8; 12.16%, CB11; 12.6%, CB14; 12.56%. This ratios are very close to each other. The only difference between CB5 and CB8 is selective surface is aluminum based in CB5 and in CB8 it is copper based. So, the base material of selective surface is not effective in this case study building where all characteristic features of the building is convenient to passive building design. Additionally, the only difference between CB11 and CB14 is the mass wall thickness that the selective surface was applied on and according to the results this parameter also doesn't effective on primary energy performance ratio.

For the other cases that have proposed façade component on more façade surfaces there are variations in the results. For example the mass wall thickness is 20 cm in CB6, CB7, CB9, and CB10 while the thickness is 40 cm in CB12, CB13, CB15, CB16. Primary energy performance improvement ratio of the cases with 40 cm mass wall is higher than the cases with 20 cm mass wall thickness. The improvement ratios of the cases with 20 cm mass thickness are respectively CB6 16.13%, CB7 19.42%, CB9 17.02%, CB10 20.8%; the improvement ratios of the cases with 40 cm mass wall thickness are respectively CB12 18.28%, CB13 22.5%, CB15 18.07%, CB16 22.17%. Between the parallel cases that has the proposed new facade component application on same facade areas there is similar improvement ratio difference.

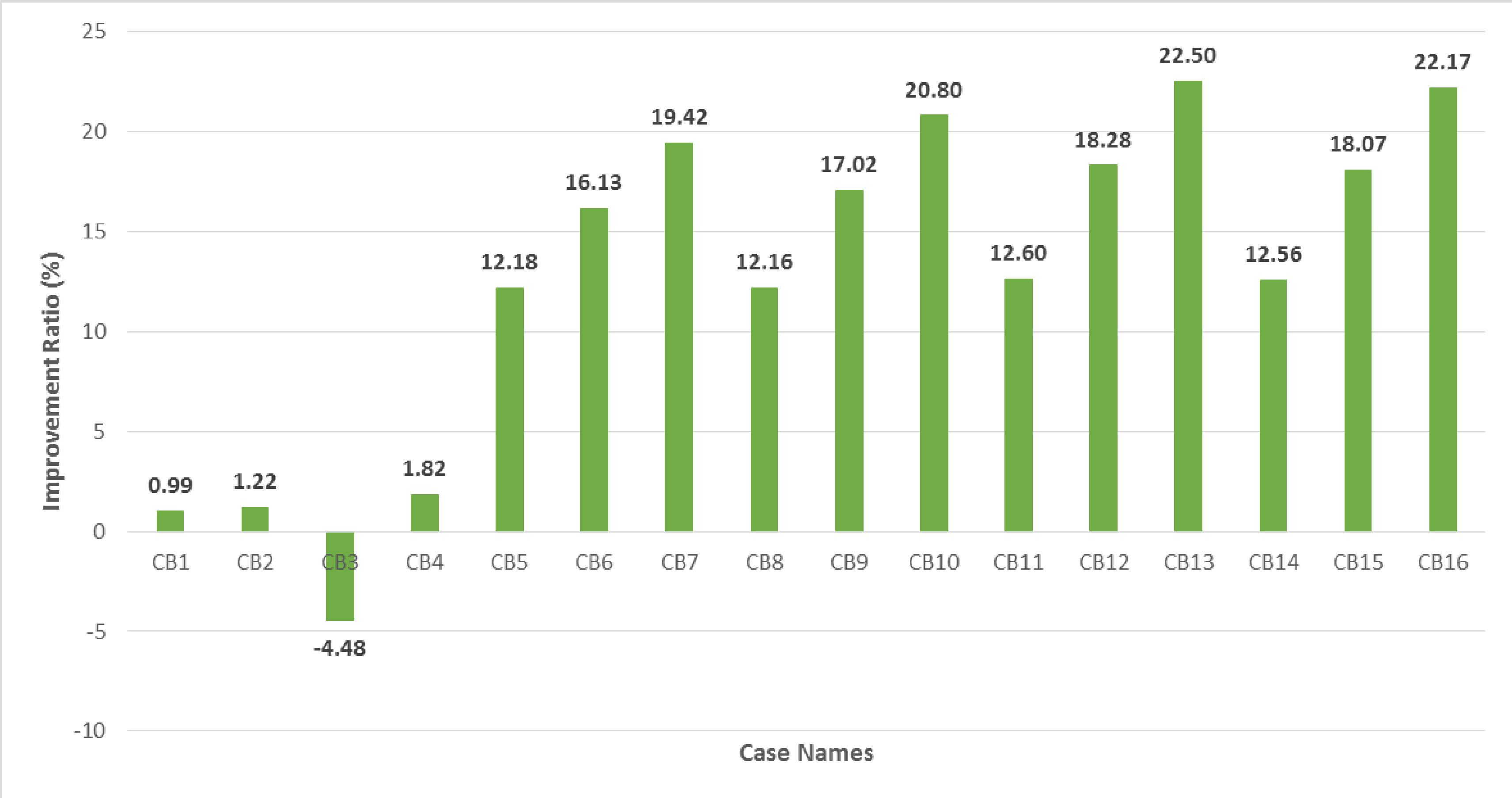


Figure 4.29 : Yearly primary energy performance improvement ratio of the cases in comparison to CB0.

The other varied parameter is selective surface base. There is aluminum based selective surface on 20 cm mass wall in CB6 and CB7 while there is copper based selective surface on 20 cm mass wall in CB9 and CB10. Primary energy performance improvement ratio of CB6 is 16.13% while in CB9 17.02% and the ratio is 19.42% in CB7 while it is 20.8% in CB10. So, using copper based selective surface is more energy efficient on 20 cm of mass wall. On the other hand, there is aluminum based selective surface on 40 cm mass wall in CB12 and CB13 while there is copper based selective surface on 40 cm mass wall in CB15 and CB16. Primary energy performance improvement ratio of CB12 is 18.28% while in CB15 18.07% and it is 22.5% in CB13 while 22.17% in CB16. So, on a 40 cm of mass wall using aluminum based selective surface is more energy efficient. This tendency of the selective surface and mass wall thickness relation was the same in first case study building results.

In order to investigate the effect of proposed new façade component on yearly energy demand, hourly heating and cooling loads of CB0 and CB7 were compared and the graph is shown in Figure 4.30. In the figure since the loads were investigated the focus is on energy demand before the conversion for primary energy demand.

In consistent with the graph in Figure 4.30, blue colored dots are hourly heating demand of CB0 changing in accordance with outdoor dry-bulb temperature through the year and the orange dots are showing the same parameter for CB7. Orange dots are mostly below the blue dots, even when the outdoor dry-bulb temperature is below 0 °C still the orange dots are below the blue dots. This analyze reveals that the heating demand is reduced for the whole year with proposed new façade component application in comparison to the base case also in this second case study building. The reduction ratio in heating demand for the whole year is 41.7% in CB7 in respect to CB0. For the cooling period grey dots show hourly cooling demand of CB0 changing in accordance with outdoor dry-bulb temperature through the year and the yellow dots show the same parameter for CB7. Yellow dots are above the grey dots, therefore the cooling demand is reduced for the whole year by new façade component use. The reduction ratio in cooling demand for the whole year is 15.55% in CB7 in respect to CB0. Heating and cooling demand reduction ratios are very high for both periods. This graph shows that the proposed new facade component is also effective on a case study that is in convenience with passive design strategies.

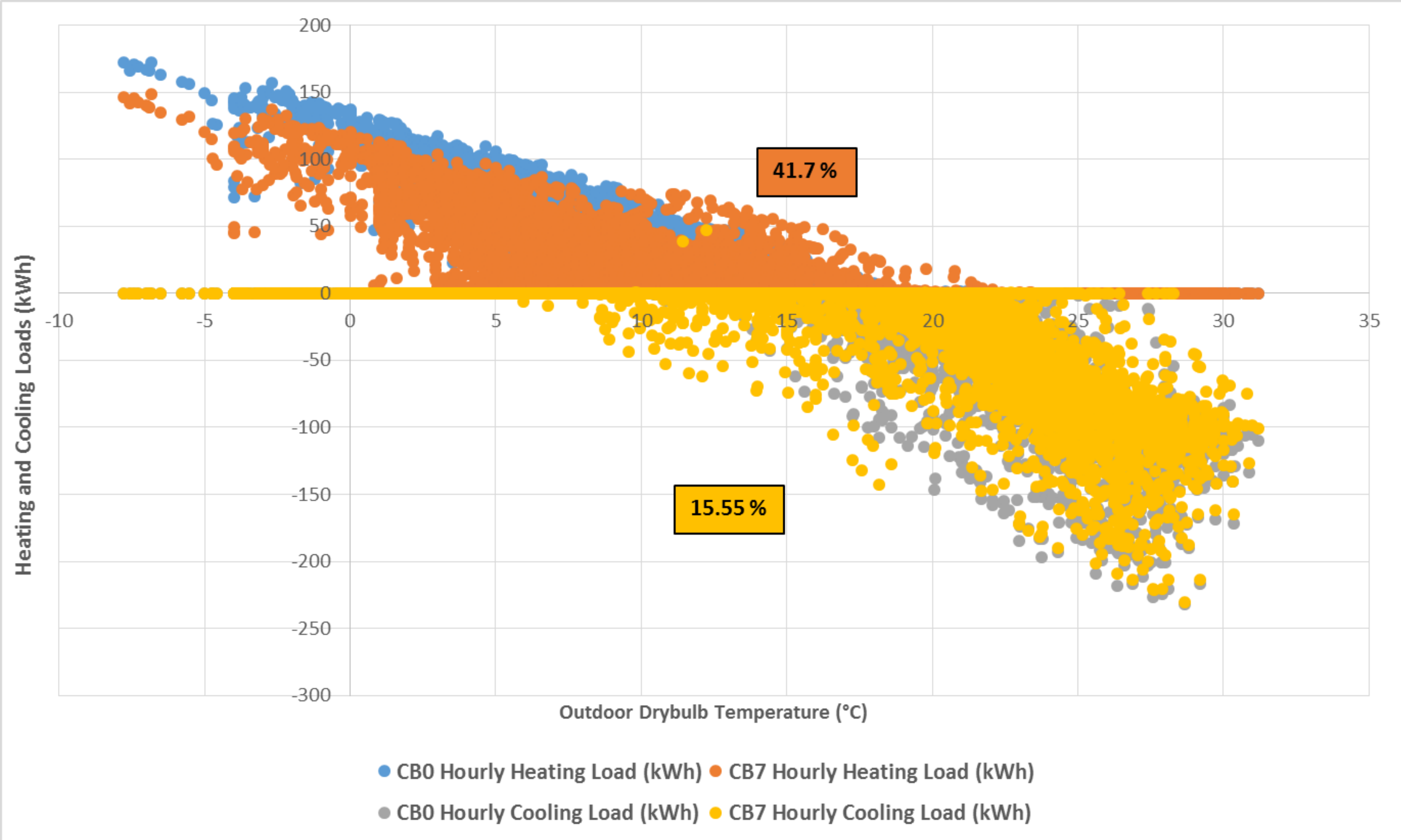


Figure 4.30 : Hourly heating/cooling energy demand vs. outdoor dry-bulb temperature through the year for CB0 and CB7.

4.2.6 Calculation of global costs for base case and retrofit cases of second case study building and primary energy demand – global cost comparison

In this part of the study, global cost calculation results and the comparison with primary energy demand of advanced facade retrofit cases are shown in Figure 4.31. Since the effect of standard facade retrofits are neglectable in the scope of primary energy performance improvement, they were not considered starting from this point of the study.

For the cost calculations, only the application areas were changed. The building elements are totally the same with the first case study building. Same calculation sheet was used (Appendix A).

Regarding global cost, according to the results none of the case scenarios is cost-optimum as expected. Only the cases where proposed facade component was applied only on South facade were resulted close to the cost of the case study building. The main issue in luxury high-rise residential buildings is reducing the monthly dues. The occupant profile is high-income group, so they can afford the apartment unit prices and this group is ready to pay a high budget for an apartment unit in a luxury high-rise residential building for its comfort and extra features, in addition to the reliable construction techniques. However, after a high payment, the occupant group expects an affordable amount of monthly dues. So, it is very important reducing the energy expenses even if the reducing method will increase the apartment unit costs.

Since the main aim of the study is reducing the monthly dues the first target is reducing the primary energy demand. However, between the cases there could be preferations according to the primary energy demand reduction and global cost relation. For example, according to the primary energy performance results in Figure 4.31 prefering mass wall thickness as 40 cm provides a higher improvement ratio. For example, the location of the proposed new façade component is same in CB7 and CB13. The only difference is there is 20 cm mass wall in CB7 and 40cm mass wall in CB13. Primary energy performance imrpovement ratio of CB7 is 19.42% while it is 22.5% in CB13. However, in the graph in Figure 4.30, global cost of CB13 locates on a higher point than CB7 and there is an important difference between the two cases. Therefore, CB7 could be preffered.

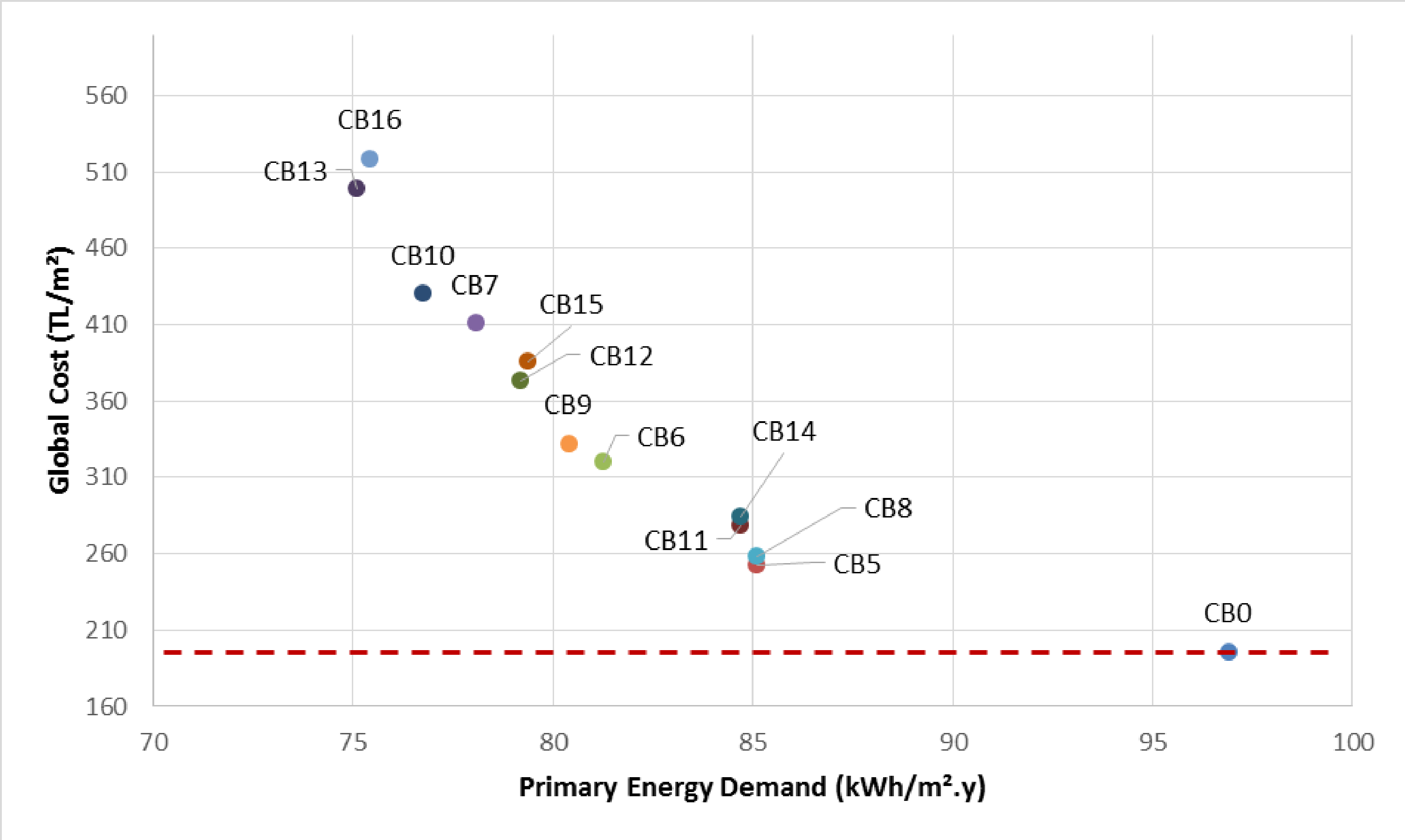


Figure 4.31 : Global cost and yearly primary energy demand comparison of second case study building.

In consistent with the graph, basically global cost increases parallel to the increase of the application area. So the cases that have the proposed new facade component only on South facade direction are at the underside of the graph, cases that have the proposed component of South, East and West facades are in the middle of the graph and cases that have the component on all facade directions are at the top of the graph.

According to the primary energy performance results, application of the proposed component reduces the yearly primary energy demand of the building, therefore reduces the loads on HVAC system. This condition provides reduction in installation costs of the HVAC systems. Therefore, even the global cost is high, installation costs of the HVAC systems will be lower.

4.2.7 Investigation of thermal comfort condition of the second case study building and advanced retrofits

As in the first case study building, in order to decide the most appropriate cases for reaching EU's 2020 and Turkey's 2023 targets thermal comfort was evaluated. So, uncomfortable hours of each advanced retrofit case was designated in free-running mode. Comfort level and requirements are the same. UH for heating and cooling periods are shown in Figure 4.32.

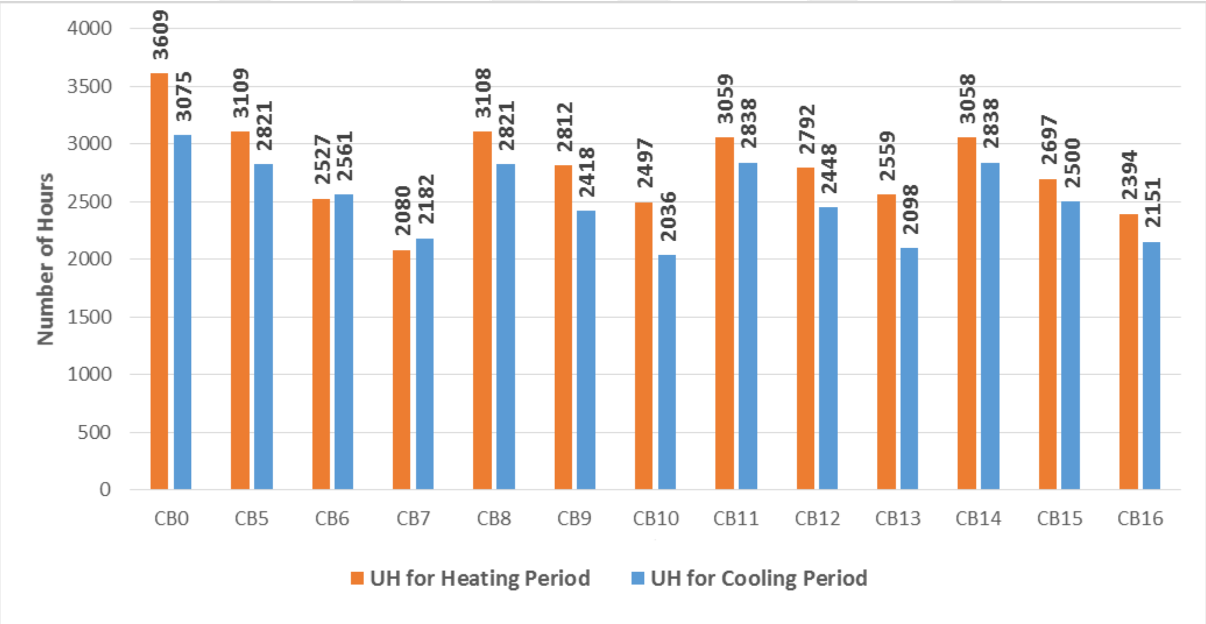


Figure 4.32 : Uncomfortable hours (UH) of CB0 and advanced retrofits for heating and cooling periods.

There are similar cases in the scope of selective surface base material and mass wall thickness. Cases CB5-CB6-CB7 have aluminum based selective surface on 20 cm mass wall, cases CB8-CB9-CB10 have copper based selective surface on 20 cm mass wall, cases CB11-

CB12-CB13 have aluminum based selective surface on 40 cm mass wall, and cases CB14-CB15-CB16 have copper based selective surface on 40 cm mass wall. In each case group, the first case represents only South façade application, the second case represents South, East and West façades application, and third case represents South, East, West and North façades application of the proposed component. Therefore, the comparison between the cases became easily within these groups. According to the graph in Figure 4.32, UH for heating and cooling periods of all advanced retrofit cases are lower than CB0's. In some cases such as; CB7, CB10, CB13 and CB16 there are severe reductions in UH. So in the cases where the proposed component was applied on all façade surfaces the UH reduction is the most. For the heating period, the most UH reduction is in CB7. For the cooling period, the most UH reduction is in CB10.

In order to investigate one of the case behavior in detail, hourly operative temperatures of CB0 and CB7 were compared for a year and how UH differentiates was shown in Figure 4.33. The graph in the figure was divided in three parts as in the first case study. The parts in sides represent heating period and the part in the middle represents cooling period. The red line shows limit operative temperature for heating (20 °C) and the blue line shows limit operative temperature for cooling (26 °C) in accordance with EN 15251 [BSI, 2008]. UH for CB0 and CB7 were calculated according to these limit values and shown on the graph in the boxes.

Heating period was divided in two parts, therefore UH were indicated in separate boxes under the related period, then the total UH for heating period through the year is shown in the red box in the middle. UH for cooling period of CB0 and CB7 were shown in the blue box. According to Figure 4.33, operative temperature variations of CB0 during the heating period is mostly under the limit value (20 °C), while in CB7 the values are more above the limit value than CB0. During the heating periods UH of CB7 are almost half of the UH of CB0. For the first period of UH for heating is 2868 hours in CB0 while 1647 hours in CB7. For the second part of the heating period UH of CB0 is 741 hours while 433 hours in CB7. In total, through the year UH for heating period is 3609 hours in CB0 while 2080 hours in CB7. For the cooling period, operative temperature variations of CB0 is above the limit value (26 °C). The tendency of CB7 is very similar to the heating period and more below the limit value than CB0. UH total for the whole year in CB0 is 3075 hours and in CB7 is 2182 hours. UH through the year in CB0 is 6684 hours and in CB7 is 4262 hours. Total UH is reduced in CB7 in a very important amount. This condition is shown in the graph with hourly operative temperature fluctuation through the year for both CB0 and CB7.

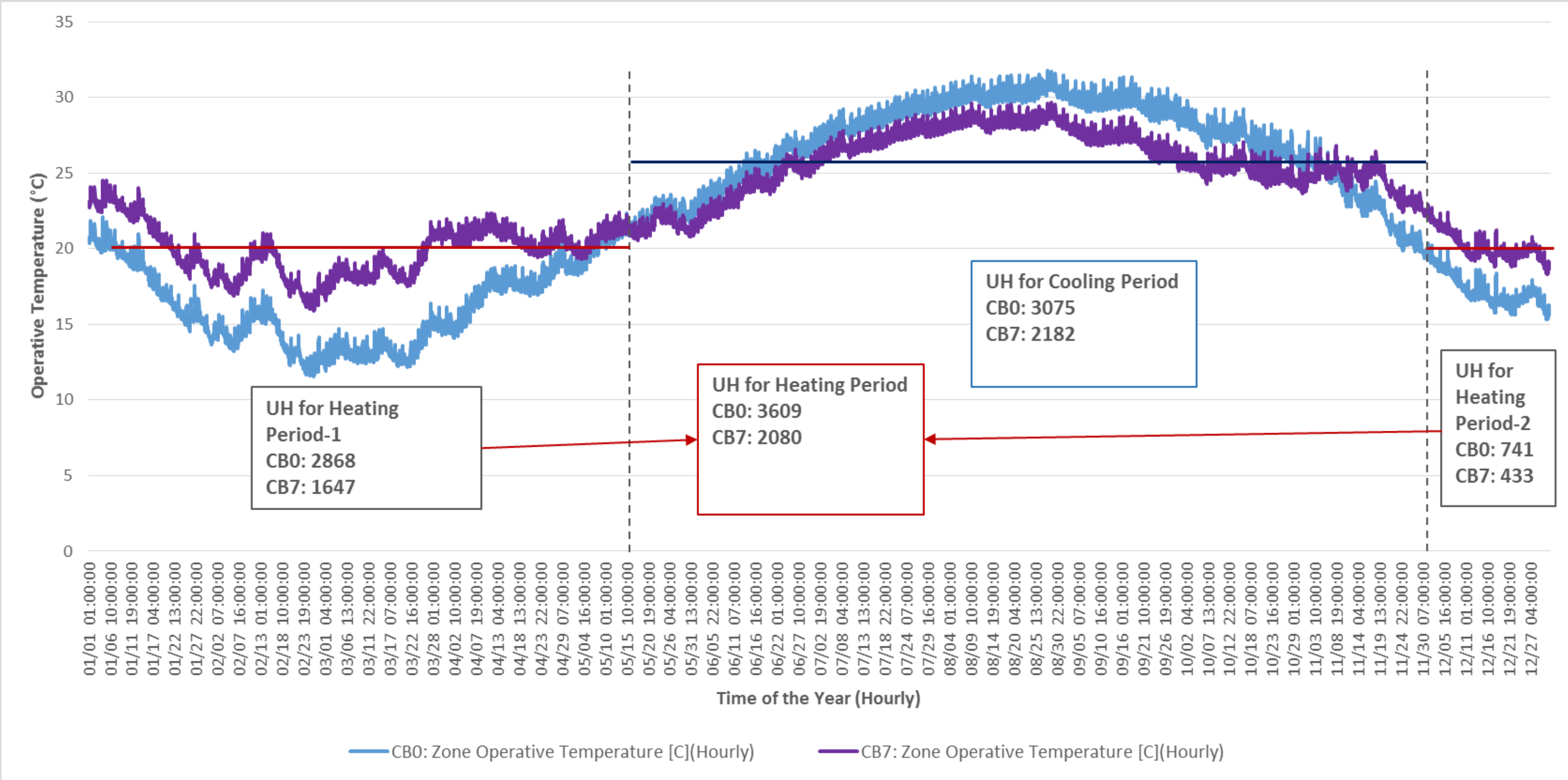


Figure 4.33 : Hourly operative temperature comparison of CB0 and CB7.

In order to investigate UH reduction ratio for heating period in respect to CB0 separately, the graph in Figure 4.34 was generated.

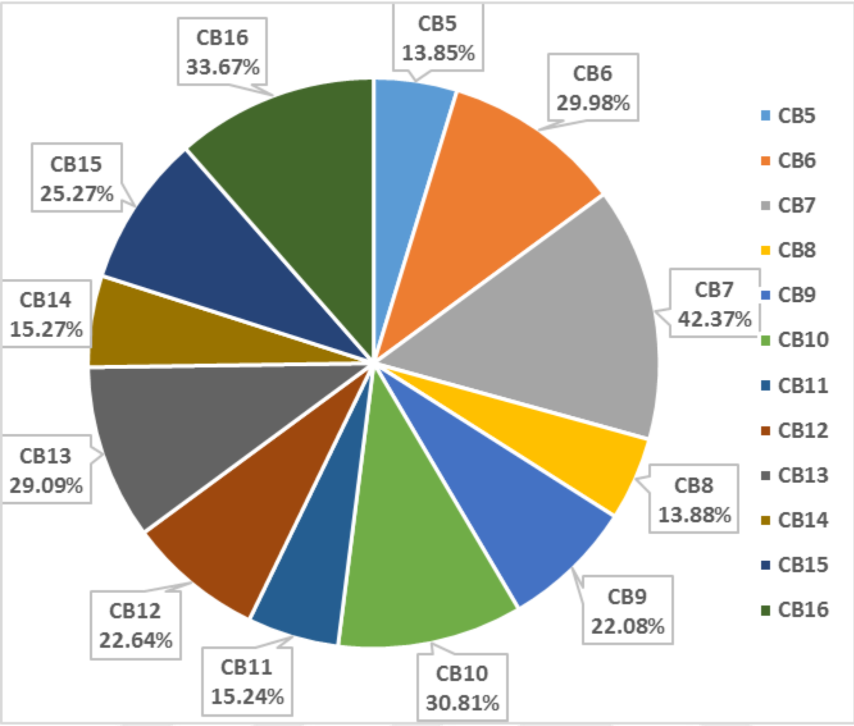


Figure 4.34 : Reduction ratio of UH in respect to CB0 for heating period.

The highest UH reduction ratio in respect to CB0 is in CB7, 42.37%. In CB7, there is proposed new façade component application on all façade directions and the selective surface is aluminimum based and applied on 20 cm mass wall. This tendency is very similar to the UH results of first case study building. Other highest reduction ratios are respectively CB16 (33.67%), CB10 (30.81%), CB6 (29.98%), and CB13 (29.09%). In CB16 there is proposed new façade component application on all façade directions and the selective surface within the the component is copper based on 40 cm mass wall. In CB10, the application area is same with CB7 and CB16, differently selective surface is copper based on 20 cm mass wall. In CB6 the application areas are South, East and West facades, but the construction properties of the proposed component is same with CB7. Lastly, in CB13, there is proposed component application on all façade directions and the selective surface is aluminum based on 40 cm mass wall. Accordingly, cases with aluminimum based selective surface application on 20 cm mass wall were performed better in the scope of UH reduction for heating period in comparison to the other cases. The tendency of this result is same with the result of the first case study building. Basically, proposed façade component application is very effective to reduce uncomfortable hours during heating period.

UH reduction ratio for cooling period in comparison to CB0 is shown in Figure 4.35. According to the graph, the case with the highest UH reduction in cooling period is in CB10 (33.79%). Other cases with the highest UH reduction ratio during cooling period are respectively CB13 (31.77%), CB16 (30.05%), CB7 (29.04%). According to the graph, cases with copper based selective surface application on 20 cm mass wall were performed better in the scope of UH reduction during cooling period in comparison to the other cases.

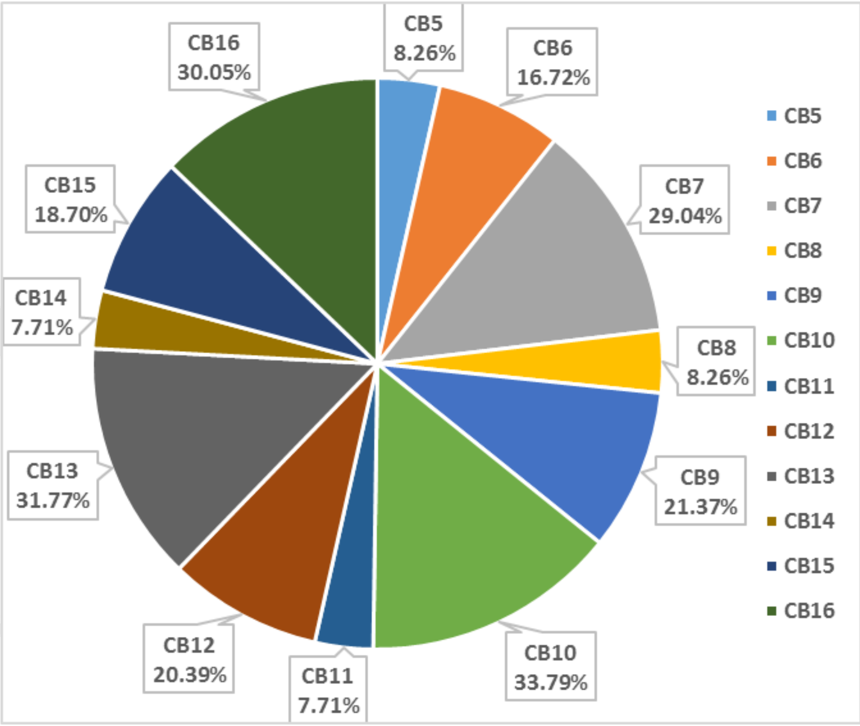


Figure 4.35 : Reduction ratio of UH in respect to CB0 for cooling period.

In order to examine the behavior of the cases in the scope of UH during the whole year the graph in Figure 4.36 was generated. According to the graph, the highest UH reduction ratio for the whole year (during heating and cooling periods together) is in CB7 (36.24%). The highest UH reduction during heating period was also in CB7 (42.37%) and its UH reduction ratio during the cooling period was also very high (29.04%).

Second case with the highest UH reduction ratio is in CB10 (32.18%). The highest UH reduction ratio during cooling period was also in CB10 (33.79%). Other cases with high UH reduction ratio for the whole year are respectively CB16 (32%) and CB13 (30.33%). Therefore, applying the proposed new façade component on all façade directions and using selective surface as aluminium based on 20 cm mass wall was resulted with the best performance in the scope of thermal comfort (CB7). In total, application of proposed new façade component is beneficial to reduce uncomfortable hours.

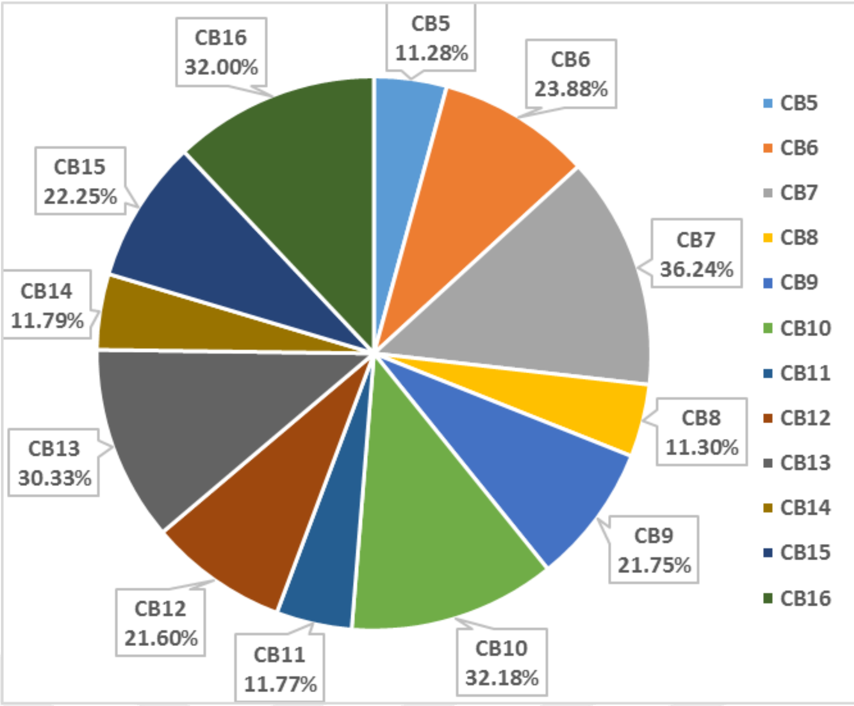


Figure 4.36 : Reduction ratio of UH in respect to CB0 for 1-year total.

4.2.8 Analization of the results for the second case study building

This case study building is in convenience with the passive design parameters, such as; façade direction, plan scheme (layout), window-to-wall ratio in accordance with the direction. Luxury high-rise residential buildings locate both in the city center and suburbial sites. In the center usually locates alone preventing any surrounding shading effect. This building is also an example of this condition.

In the first case study building, the location, direction, layout, window-to-wall ratio, surrounding parameters were complex. The second case study building is important to reveal the effect of these parameters.

Additionally, the tendency of the results are very similar to the first case study building but in this case without any modification on façade window-to-wall ratio. That is because application of the proposed component were considered in the early design stage.

4.3 Application of the Suggested Approach on Third Case Study Building

4.3.1 Definition of third case study residential building

This part contains the necessary data about the third case study building. This data is required to define the third reference building for this study and also crucial for the investigations.

4.3.1.1 Climatic condition of the third case study building

This case study building assumed to be located in Istanbul as the first and second case study buildings. Therefore, the climatic conditions of this case study building is the same with the others. This method provides to compare the pure effects of retrofit cases.

4.3.1.2 Location, direction and geometry of the third case study building

The third case study building has same layout with the second case study building. Only in this third part, there are 35 floors in the building block instead of 15 floors. This part was studied in order to test if the proposed building component is effective on reducing the yearly primary energy demand of taller buildings since the floor number of luxury high-rise residential buildings is variable.

4.3.1.3 Building façade thermo-physical and optical characteristics

In order to demonstrate the pure effect of appropriate designing in the scope of passive parameters and building height; the building envelope components were kept same with the first and second case study buildings. Therefore, this building has a ceramic cladding on opaque parts of the facade and it has the same glazing with the first and second case study buildings. It has same U-values with the other case study buildings for all building envelope components.

4.3.1.4 Boundary conditions

For the occupancy, since the room number is the same with the second case study building, the same occupancy type, couple with 2 children and a housekeeper was selected. The occupancy have the same operational schedule with the first case study building as in Table 4.8.

Internal gains from household electrical appliances is the same with the first and second case study buildings and the data is as in Table 4.9.

Internal gains from lighting were also kept same with the second case study building.

4.3.1.5 Information data for heating and cooling systems

Thermostat values for heating and cooling periods were defined in accordance with the first case study building. Therefore, heating set-point was designated as 22 °C and cooling set-point was designated as 24 °C. Accordingly, HVAC system was modelled as Ideal Loads as in the first and second case study buildings.

4.3.1.6 Other

The building has the same internal shading devices and operational schedule with the other case study buildings.

4.3.2 Primary energy demand calculation and result of third case study residential building

The calculation of yearly energy demand of the third case study were done through the same simulation tools.

As a result of the analysis the yearly energy demand results of the third case study building is distinguishedly shown in Table 4.21.

Table 4.21 : Yearly energy demand results of third case study building.

Yearly Energy Demand for Heating ($kWh/m^2.y$)	Yearly Energy Demand for Cooling ($kWh/m^2.y$)	Yearly Energy Demand for Lighting ($kWh/m^2.y$)	Total ($kWh/m^2.y$)
25.41	21.47	8.11	55

Then, yearly primary energy demand of third case study building was calculated through the equations 3.1, 3.2 and 3.3 as in the other case study buildings. Calculated results per category and total are shown in Table 4.22.

Table 4.22 : Yearly primary energy demand results of third case study building.

Yearly Primary Energy Demand for Heating ($kWh/m^2.y$)	Yearly Primary Energy Demand for Cooling ($kWh/m^2.y$)	Yearly Primary Energy Demand for Lighting ($kWh/m^2.y$)	Total ($kWh/m^2.y$)
25.61	50.69	19.16	95.27

4.3.3 Explanation of the proposed advanced retrofit measure

Proposed new facade component was applied on this building with more storeys. This case study building is also convenient for the proposed component to be applied in terms of the parameters explained in part 3.5 as building typology, climatic conditions, building part that has the largest outdoor area, building envelope thermo-physical and optical properties for the existing condition and occupant profile are the same with the other case study buildings. Also, building location and direction parameters are the same with second case study building.

The application method of the proposed component in terms of construction is the same with the other case study buildings. It was assumed to be applied on the concrete walls of the building facade instead of ceramic cladding. The application of the component was considered in the early design stage as in the second case study building, therefore there is enough application area for the component. The facade elevation with/without application of the proposed new facade component is the same with the second case study building, only there are more storeys in this one.

Since verification simulations were concluded before for this proposed new component, there is no need to do anymore tests.

4.3.4 Explanation of the façade retrofit cases for the third case study building

Since in previous two case study buildings it was proven that the standard retrofit measures are not effective on building energy performance, in this case study building only the propose advanced facade retrofit is considered. As explained in part 3.6, if standard retrofits are ineffective advanced retrofits should be considered.

As this part is a kind of verification test part for the taller buildings, CB5, CB6 and CB7 of the second case study building were applied on this case study building since CB7 was resulted as the optimal case both in the scope of primary energy demand and uncomfortable hours reduction, then the tendency of the results were compared to second case study building.

The case names were changed for the accordance to the new case study building. C indicates case, the C in the middle indicates that this case belongs to the third case study building and the number next to it indicates the case number. Retrofit cases that are investigated for the third case study building were explained in Table 4.23.

Table 4.23 : Facade retrofit case explanations for the third case study building.

Case Name	Explanations
CC0	Base condition of the second case study building
CC1	Proposed new façade component (PNFC) application on available South exterior opaque walls; Mass wall thickness 20 cm; Aluminium based selective surface used
CC2	PNFC application on available South, East and West exterior opaque walls; Mass wall thickness 20 cm; Aluminium based selective surface used
CC3	PNFC application on available South, East, West and North exterior opaque walls; Mass wall thickness 20 cm; Aluminium based selective surface used

The façade views of the cases are shown in Table 4.24. The images of all cases were generated by DesignBuilder v4.2. As it can be seen in the table the elevation of the case study building is same with the second case study building, only there are more storeys in this one. This is important to consider since nowadays, the building floor number is increasing. Especially for luxury high-rise residential buildings, the occupant number that prefers to live in this building typology increases, however as in the explanation of the luxury high-rise residential buildings the land prices are high, so in order to provide more apartment units increasing the floor numbers became the solution.

Table 4.24 : Facade elevations of advanced retrofit cases for third case study building.

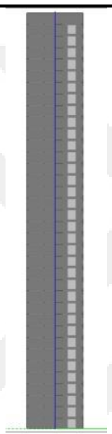
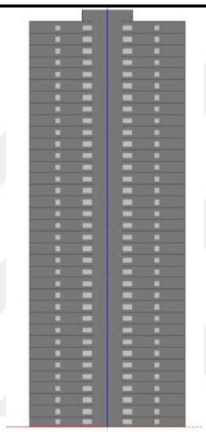
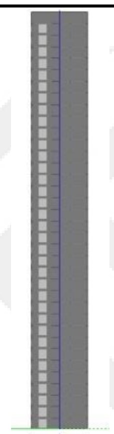
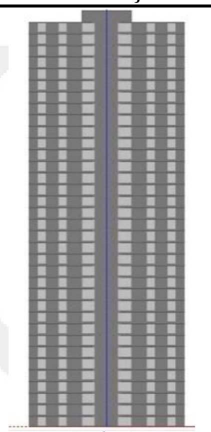
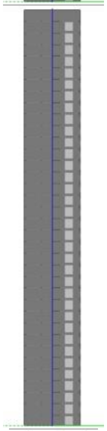
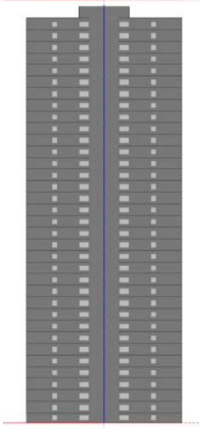
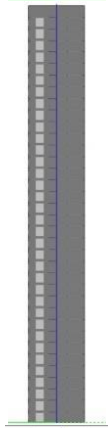
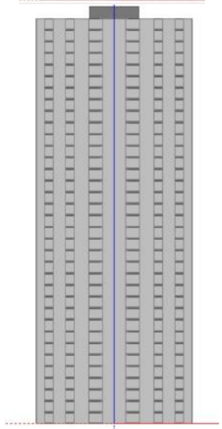
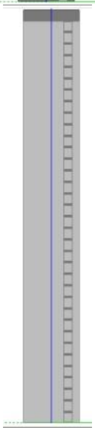
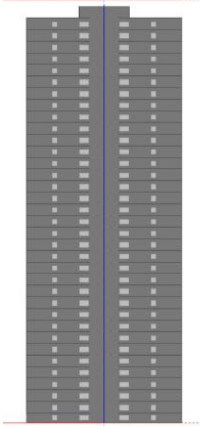
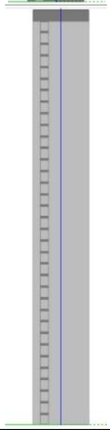
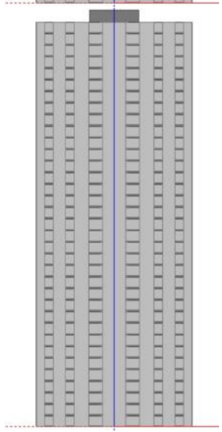
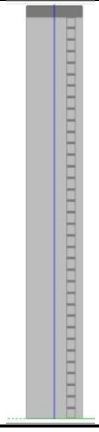
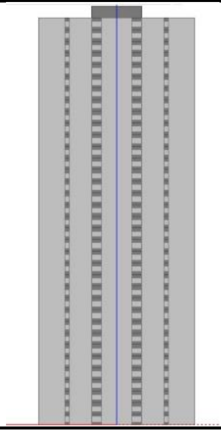
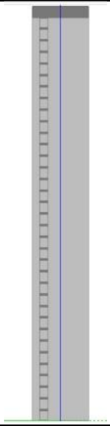
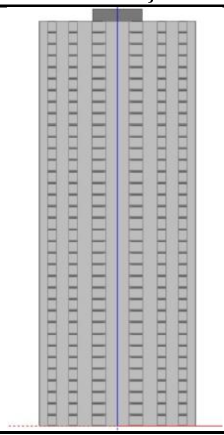
Case Name	East Facade	North Facade	West Facade	South Façade
CC0				
CC1				
CC2				

Table 4.24 (continued): Facade elevations of advanced retrofit cases for third case study building.

Case Name	East Facade	North Facade	West Facade	South Façade
CC3				

CC0 indicates the base case and as it can be seen in Table 4.24, South facade has the highest transparency ratio and North facade has an optimal transparency ratio for heating loads as in the second case study building. The proposed new facade component locates only on the South exterior wall parts in CC1. In CC2 the proposed component locates on South, East and West exterior opaque facade parts and in CC3 the component locates on all facade directions. In all of them, the selective surface is aluminum based and applied on 20 cm mass wall.

4.3.5 Calculation and results of primary energy demand of third case study retrofit cases

Heating, cooling and lighting energy demands were assessed by EnergyPlus and the calculated total primary energy demand of each scenario was compared with the base case (CC0). Primary energy demand results of façade retrofits are shown in Figure 4.37.

During the calculations, in order to reveal the effect of proposed new facade component, HVAC system was modelled as Ideal Loads as explained in part 3.6. Briefly, this type of definition provides a model for an ideal HVAC system by supplying cooling or heating air to zones in sufficient quantity to meet the load of each zone or up to each zone’s limit.

According to the graph in Figure 4.37, all cases have impacts on reducing the yearly primary energy demand. The heating demand reduction in CC2 and CC3 is very similar, however yearly cooling demand reduction of CC3 is higher than CC2’s. Therefore, in between three cases, best resulted case is CC3 in the scope of yearly primary energy demand reduction in comparison to CC0.

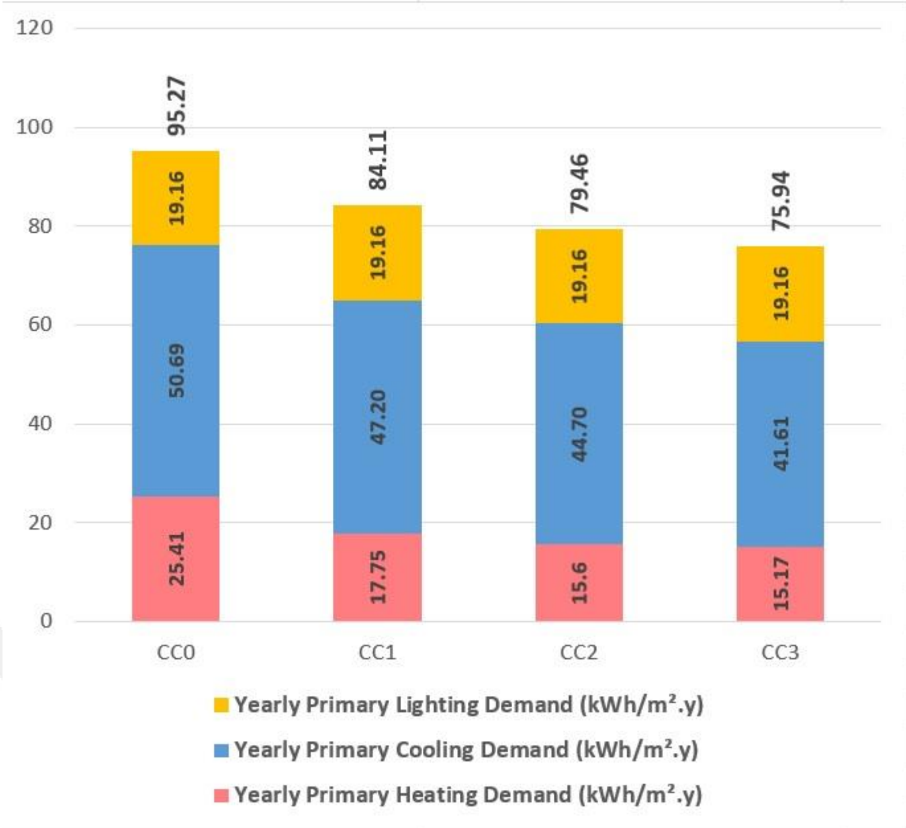


Figure 4.37 : Yearly primary energy demand results of the retrofit cases of third case study building for heating, cooling, and lighting.

In Figure 4.38 yearly primary energy demand reduction ratio of the cases in comparison to the base case is shown. As in the figure, there are high improvement ratios in respect to the base case. CC3 with the widest application area in comparison to the other cases is the best resulted case. This general result is the same as in the other case study buildings. CC1 and CC2 also resulted with high primary energy performance improvement ratios and with 11.71% and 16.6% respectively.

In comparison to the second case study building, primary energy performance improvement ratio of the cases are very similar, even CC3 (20.3%) has a higher improvement ratio than CB7 (19.5%) which is the same case in second case study building. This is very important to consider while evaluating to apply the proposed facade component on taller buildings. Because normally, same or very similar energy performance improvement results are expected. Therefore, this was tested in this case study building and the primary energy performance improvement results of CC1, CC2 and CC3 are very similar and close to the results of CB5, CB6 and CB7. In this case study building the only difference is floor number and in this kind of high-rise buildings considering the possible shading effect of surrounding blocks is very important. So, the distance between the building blocks should be considered.

Figure 4.38 : Yearly primary energy performance improvement ratio of the cases in comparison to CC0.

4.3.6 Calculation of global costs for base case and retrofit cases of third case study building and primary energy demand – global cost comparison

Global cost calculation results of advanced facade retrofit cases are shown in Figure 4.39. Cost calculations was done by using the calculation sheet in Appendix A that was prepared in accordance with part 2.1.2.4.

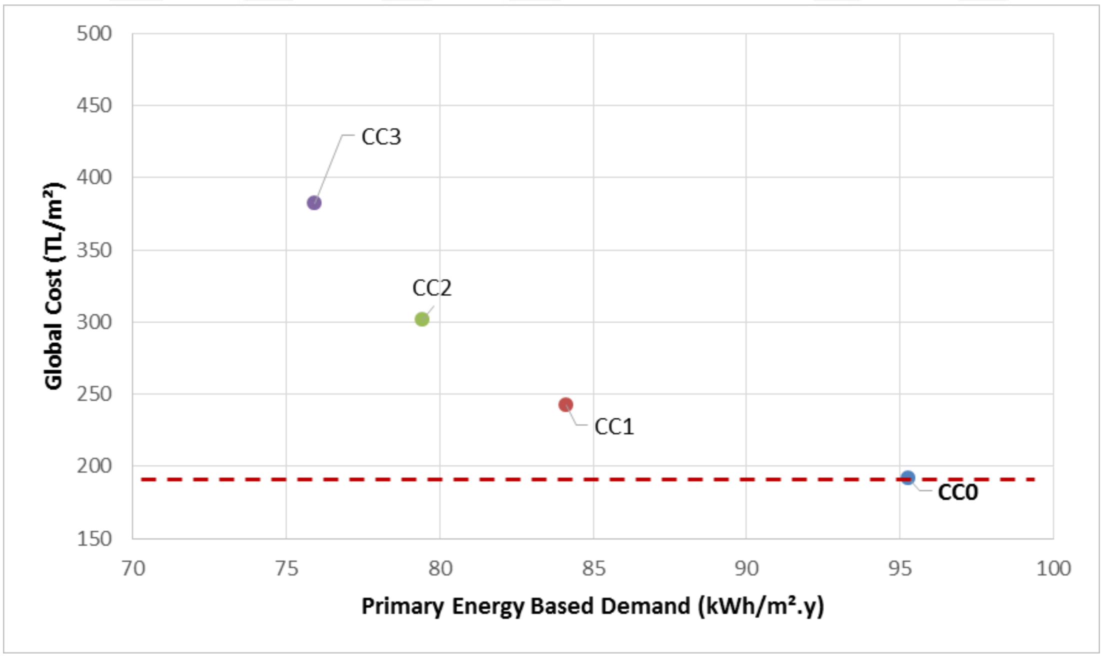


Figure 4.39 : Global cost and yearly primary energy demand comparison.

Regarding global cost, according to the results none of the cases is cost-optimum as expected as in the other case study buildings. Only the case where proposed facade component was applied on South facade (CC1) was resulted close to the cost of the case study building as in the second case study building.

These results are very similar to the results of the other case study buildings. Global cost increases as the application area increases. However, as explained in the other case study buildings, the main focus is not reaching a cost-optimum solution but reducing yearly primary energy demand while improving thermal comfort.

4.3.7 Investigation of thermal comfort condition of the third case study building and advanced retrofits

Since the building is the same with the second case study building except the contained floor number, the tendency of the discomfort hours analyzes results are expected to be the same with the second case study building. Same comfort level and requirements are valid with the other case study buildings and the investigation method is as explained in part 3.9. Even so, it is necessary to investigate the discomfort hours when the floor number is increased. Uncomfortable hours of each advanced retrofit case was designated in free-running mode. UH for heating and cooling periods separately are shown in Figure 4.40.

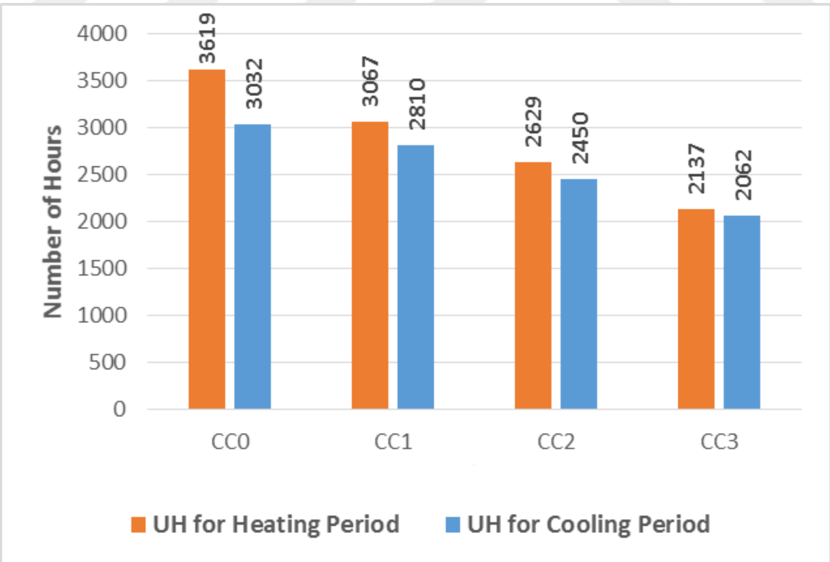


Figure 4.40 : Uncomfortable hours (UH) of CC0 and anvanced retrofits for heating and cooling periods.

According to the graph in Figure 4.40, UH for heating and cooling periods of all advanced retrofit cases are lower than CC0's. Especially in CC3, there is an important reduction amount both in heating and cooling periods. Total UH of CC0 is 6641 hours while it is 5877 hours in CC1, 5079 hours in CC2 and 4199 hours in CC3.

In Figure 4.41 UH reduction ratio for heating period in respect to CC0 is shown. There is a very high UH reduction ratio during the heating period in CC3 (40.95%). There are also important reduction amounts in CC1 (15.25%) and CC2 (27.36%), but the amount in CC3 is very high as cannot be ignored. The highest UH reduction ratio during the heating period in the second case study building was in CB7 (42.37%) which is the same case with CC3 in the scope of application areas and features of the proposed component.

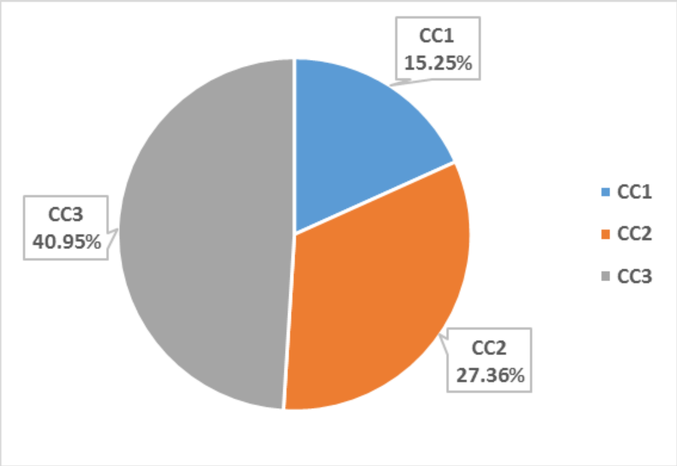


Figure 4.41 : Reduction ratio of UH in respect to CC0 for heating period.

UH reduction ratio for cooling period in comparison to CC0 is shown in Figure 4.42.

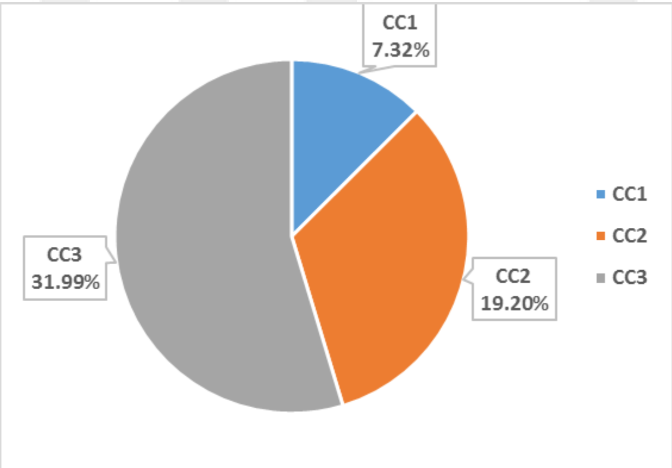


Figure 4.42 : Reduction ratio of UH in respect to CC0 for cooling period.

According to the graph in Figure 4.42, again the highest UH reduction ratio is in CC3 (32%) also in cooling period. The other cases also reduce the UH for cooling period and the reduction ratio in CC2 (19.2%) is also high, however the reduction ratio is not so high in CC1 (7.32%).

In order to examine the behavior of the cases in the scope of UH during the whole year the graph in Figure 4.43 was generated.

According to the graph, the highest UH reduction ratio for the whole year (during heating and cooling periods together) is in CC3 (36.87%) as expected. The ratio in CC2 is also very high (23.64%). CC1 could only be considered if the primary energy improvement ratio of the case is high. UH reduction ratio of CC1 is 11.64% and primary energy performance improvement ratio is 11.71%. So, this case is not a very high-performed case when it is compared to the others, however in Figure 4.39 this case is the most close case to the cost-optimality. Therefore, the selection directly depends on the owners.

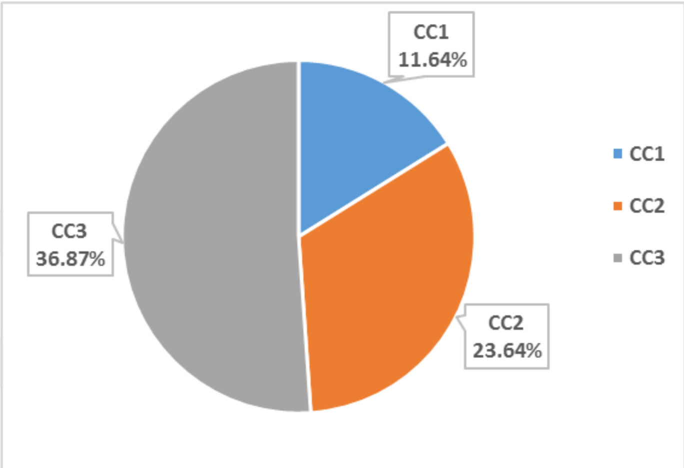


Figure 4.43 : Reduction ratio of UH in respect to CC0 for 1-year total.

In the second case study building, CB7 had the highest UH reduction ratio in total and it was 36.24%. Similar case CC3 has 36.87% of UH reduction ratio. Therefore, referring to third case study building, the results are very similar and the tendency of the results are same with the second case study building.

4.3.8 Analization of the results for the third case study building

This building was in convenience with passive design parameters and the same building with second case study building with more storey. The primary energy performance, global cost and thermal comfort results are very close to the second case study building. Luxury high-rise residential buildings have variations in terms of floor numbers. Therefore, this case was necessary to consider. According to the results, the proposed component is still very effective when there is more storey. The only concern in this case study building is to be careful about the distance between the building blocks in order to prevent shade effect.

5. DISCUSSION

In order to investigate a new approach for reaching EU's 2020 and Turkey's 2023 renewable energy targets through a new façade component, the calculation methodology adopted from Directive EPBD 2010/31/EU was applied and the results of the national investigation project were accepted as baseline [7, 16]. The aim of the study is providing a different point of view to renewable energy technologies while offering a proper way for luxury high-rise residential buildings to reach the targets together with constraining the indoor thermal comfort in an acceptable range and revealing an alternative method for improving the energy performance of similar building types in Mediterranean climate. However, new advanced façade solution can be effective in other climates with different operational scenarios.

Luxury high-rise residential buildings are high performed buildings in terms of building envelope thermo-physical properties and in this study specifically façade characteristics. However, due to their central mechanical heating, cooling and ventilating systems their energy consumption is still high. Therefore, in order to reduce the HVAC loads, architectural part of the building should be improved and since the building façade is already high performed advanced retorfits should be applied. In this study, this aim was provided by proposing an advanced façade component.

There were three case study buildings were investigated by using similar cases. The main aim of the study is to propose an advanced facade component both to decrease the yearly primary energy demand of the luxury high-rise residential buildings and to reach the 2020 target of EU and 2023 target of Turkey by increasing the renewable energy use portion in the buildings. The proposed advanced facade component benefits from solar radiation to increase the solar gain through conduction to inner zones during the heating period and benefits from air circulation inside the air gap to decrease the zone inside mean air temperature during the cooling period again through conduction this time to the reverse direction (to outside). During transition periods the operation schedule of the proposed component allows to benefit from both features. Therefore, the component works directly as a renewable energy system itself.

In addition to the advanced facade component, standard facade retrofits were investigated too and all of them resulted with a very low primary energy performance improvement ratios. The basic reason of this result is luxury high-rise residential buildings have already high-performed facade features in the scope of standard requirements in terms of thermo-physical properties. So, decreasing the U-value of any facade component would not be effective on reducing the yearly primary energy demand.

The first case study building was an example for an existing case with all complex characteristics as location, direction (adjacent block) and lay-out plan. Therefore, investigations in that building were also used to show the necessity of passive design parameters and taking decisions in the design phase. Cases with proposed advanced facade component were applied on this building and very important yearly primary energy demand reduction ratios were provided. However, since the building was not designed in convenient to the passive design parameters and also designed without considering possible application of the proposed facade component from the beginning (early design stage), the existing surfaces of the facades were not enough. The window-to-wall ratio of East and West facade directions were reduced in order to provide a sufficient application area for the proposed facade component by preventing to increase lighting energy demand. There are cases without reducing window-to-wall ratio and using the existing condition of the facades, however those cases resulted with a very poor primary energy demand reduction ratio. In addition, the South facade has an adjacent block, therefore this facade direction could not be used in the analyzes. The cases where the building main facade was modelled as if it is on South direction were resulted with important primary energy demand reduction ratios and were effective to reduce the primary energy demand more than East and West facade directions application together.

The second case study building was designed in convenient to passive design parameters and considering the possible use of proposed advanced facade component. Therefore, sufficient opaque facade areas were provided in the existing condition of the second case study building and window-to-wall ratios and the building's main direction was not changed for benefitting from the proposed facade component as in the first case study building. Also, in this case study building there were two apartment units in each floor, therefore each apartment unit has three external facade areas in order to benefit from the proposed component. This situation gives very important informations about the usage of proposed advanced facade component. It is very important to provide enough opaque facade surfaces to apply the component and also passive design parameters should be considered during the early design stage including the orientation. Building facade components are totally the same with the first case study building.

The third case study building is the same building with the second one, only instead of 15 floors there are 35 floors in this building. The reason of this case study alternative is there are higher luxury high-rise residential buildings and according to the investigations their average floor number is 35 [16]. So, this type of luxury high-rise residential building should be a part of this thesis study. Additionally, the results are very similar to the second case study building however in the third case study building it is necessary to consider the distance between the buildings in order to prevent shade effect of the buildings to each other.

The importance of considering the possible use of proposed advanced facade component in the design stage and designing the building facade and layout in convenient to this parameter is shown by comparing three similar cases between all three case study buildings. Those cases are CA10, CB7 and CC3. There is proposed new facade component application on all available opaque facade surfaces of all facade directions and in the proposed component there is aluminum based selective surface application on 20 cm mass wall. The yearly primary energy performance improvement ratios in respect to their base cases of each case are shown in Table 5.1.

Table 5.1 : Yearly primary energy performance improvement ratio comparison of three similar cases in respect to their base cases.

Case Name	Primary Energy Performance Improvement Ratio (%)
CA10	5.82
CB7	19.42
CC3	20.29

The table shows the importance of considering the parameters in the design-stage. The improvement ratio difference is very high between the first case study building and the others.

Reducing the primary energy demand is a very important step for the targets of this thesis study however while reducing the primary energy demand it is very important not to increase the number of uncomfortable hours. Therefore, while determining the most appropriate cases considering reducing the energy demand together with reducing uncomfortable hours would be the best method. To this aim, all advanced case scenarios of all three case study buildings were simulated again in free-running mode and according to the results all of them reduce the number of uncomfortable hours in respect to their base cases. The cases of applying the proposed facade component on most facade surfaces are the most effective cases on reducing the number of uncomfortable hours. These results are very important because reduction in uncomfortable hours will provide reduction in HVAC loads too, therefore this will help to decrease the capacity of HVAC systems.

Cost optimality is a subject in this thesis study however the target is not providing a cost-optimum retrofit suggestion, but providing an effective retrofit suggestion on reducing the yearly primary energy demand and the number of uncomfortable hours in order to reduce the energy costs and also HVAC loads. After calculating yearly primary energy demand and global cost of each case, yearly primary energy demand and cost optimality graphs were drawn and the level of each was discussed. The occupant profile of luxury high-rise residential buildings do not seek for a cheaper apartment unit, moreover this occupant group may pay any cost amount for apartment units as long as there is luxury and comfortable features. However, monthly energy expenses is a big problem in this building typology and the occupant group do not willing to pay the high monthly dues. Therefore, it is very important to decrease the primary energy demand in order to reduce the monthly energy expenses even the method causes increase in apartment unit prices. Thus, investigating the global cost and primary energy demand relation is a subject in the thesis study but not a target. However, there can be some extra important points according to the results of this thesis study. Figure 5.1 shows the relation between initial investment cost, energy cost and global cost for the best resulted cases of second case study building in terms of primary energy performance improvement.

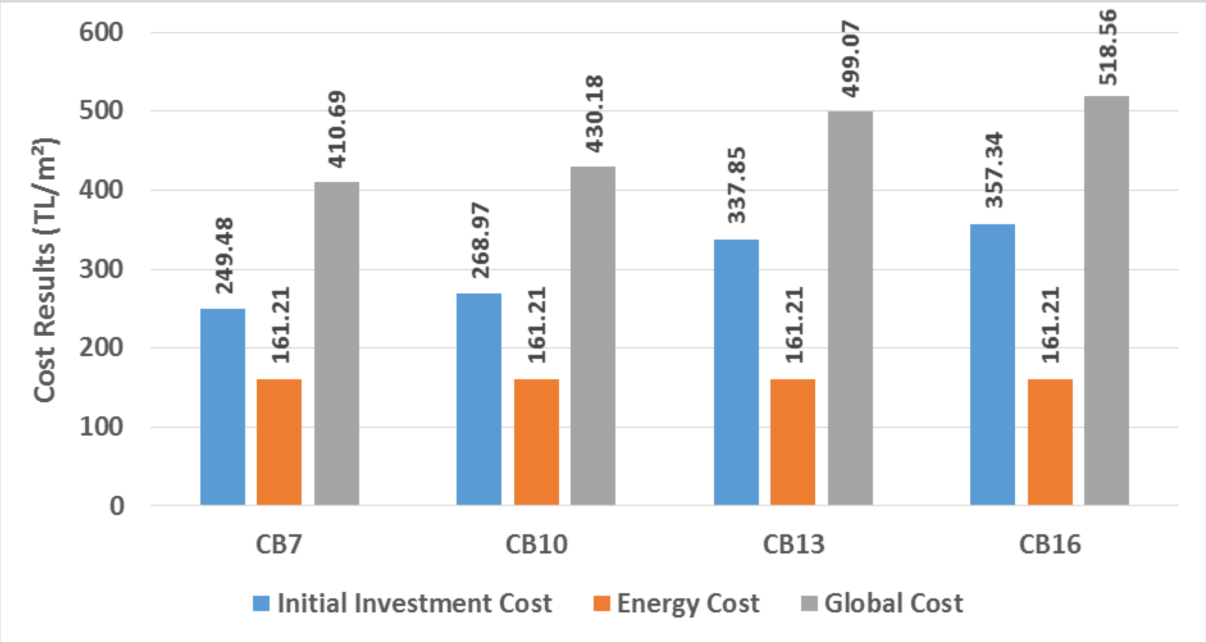


Figure 5.1 : Cost group relations for the second case study building.

According to Figure 5.1 initial investmet cost is the highest value in global cost as expected and explained. Energy cost of CB0 which is the base condition of this case study is 195.6 TL/m². So, by the application of the cases energy costs per squaremeter reduce sharply in each of them, however since the initial investment costs of the cases are high, global costs increase. Reducing energy cost (in other words reducing primary energy demand and uncomfortable hours) means decreasing the capacity of HVAC systems. So, by applying the proposed facade component, installation costs of the HVAC systems are reduced. Thus, if the costs of the HVAC systems are participated in global cost calculations in the further studies, in general there may be a reduction.

At this point, there can be some studies in order to reduce the initial investment cost of the proposed facade component application too. In this thesis study, the case study buildings were assumed as existed and there were a ceramic cladding on facade at the beginning. Therefore, in the cost calculations there are demolition and dismantling costs for the ceramic cladding and a seperate scaffolding cost to change the facade construction. However, for the new buildings there wouldn't be any demolition and dismantling costs and also scaffolding cost will be for the whole building construction. Another point is unit price of selective surface is still high, but there are studies in order to reduce its price and they will result in a short time period. In addition to these, shading device firms in Turkey are mostly international firms and the unit prices are very high. Therefore, reducing the shading device unit prices will be very effective in the cost results. So, these kinds of developments will be very effective to reduce the initial investment cost results of the proposed component in the near future.

According to the results there is not an only one specific best resulted case in this thesis study. The most evident result of the study is as mentioned, applying the proposed façade component on all possible façade areas and also South façade application is very important. However, since the performance of copper or aluminium based selective surface contained cases are very close, aluminium could be preffered according to its less price. Additionally, black paint used cases are also resulted with high enough primary energy reduction ratios, however their ability to reduce the uncomfortable hours is less than other applications. They are better during the cooling period in terms of both energy demand reduction and uncomfortable hours reduction. Even so, application with black paint can be considered, but not as the best resulted condition. Maybe according to the climatic zone of the building, the application type of the component (with selective surface or black paint) can be decided. Therefore, according to the owners' budget any application version of the component could be used, only the application area dimensions should be evaluated in order to be kept in the widest possible form.

6. CONCLUSION

The main focus in this thesis study is developing an advanced façade component that will work as a renewable energy system itself and will reduce the yearly primary energy demand of luxury high-rise residential buildings. Through this façade component, the study aims to suggest an alternative method to reach EU's 2020 target together with Turkey's 2023 target of renewable energy use.

The unique part of this thesis study is the proposed façade component. There are lots of research studies about building integrated renewable energy systems however, the investigated façade component in this thesis study was developed through this study. Thus, this component is a part of the facade and working as a renewable energy system itself and it is not investigated before. Also, the proposed component is not a resemblence of any other advanced façade component. The investigated and proposed façade component in this study is beyond a building integrated renewable energy system. It is a building construction component as a façade cladding.

The strict rules in the Directive EPBD/31/EU were oriented to benefit from alternative ways as distinct from the conventional methods. Additionally, one of the most important results of TUBITAK project was that the standard façade retrofits were not effective on reducing the yearly primary energy demand of luxury high-rise residential buildings. Therefore, these findings came together with the requirements of the Directive about renewable energy use and the necessity of a new façade component was appeared.

The developed façade component benefits from the characteristic features of selective surface and glazing directly. Nowadays, selective surface was produced in Turkey. Therefore, reaching this material is easier than before. The component takes advantage of high amount of solar radiation during the heating period as a typical feature of Mediterranean climate. Therefore, during the heating period in order to reduce the heating demand of residential zones, the developed component is beneficial. During the cooling period, it could be a problem since cooling season is hot and often humid in Mediterranean climate. However, architectural elements to block the overheating were added to the component's figuration and they work in an operational schedule. Thus, the building benefits from air circulation within the component itself and while the proposed component is cooling down itself, it takes the excessive heat from the residential zones and cooles down them too.

The component was aimed to be designed as an architectural system. Therefore, there is not any mechanical system connection to the façade component. The reason of this condition is to have a façade system, which will be as a building construction component. This was thought to lead the architects to design building facades as renewable energy systems instead of traditional solutions. There are researches with building integrated renewable energy system connected to building's heating or cooling systems. However, this unique study focuses to use the proposed component in a passive way, directly benefitting from the features of the climate naturally.

In real life, the component could work with an automation control instead of this passive use in the study again by benefitting the climatic conditions. The research was done through the opportunities of the detailed simulation tools, so other possible cases for the proposed component's ability of behaving in harmony with the real time climatic conditions was not considered. Luxury high-rise residential building typology usually have an automation control. For example, in these case studies there were day-light automation control. Thus, the system of the proposed component could be connected to any existing automation control and shading devices and air inlet-outlet vents could be on or off in accordance with both air gap and outdoor air temperature values. Within this thesis study, there were operational scenarios for shading devices and vents as a result of test simulations and the scenarios were valid through a period of season or at least a whole month. However, in real life sometimes during the heating period some days could be hotter than the seasons normal and in order to prevent over heating shading devices could be necessary to use, also reversely during the cooling period some days could be cooler than the seasons normal and shading devices or vents shouldn't be used. So, this kind of very sensitive automation may not be modelled by these simulation tools because especially it is not possible to predict the real time outdoor air temperature day by day. However, there are sensitive automation controls in terms of temperature fluctuations and they can be used in order to benefit from the special climatic features of the component the most. Therefore, the whole system should be connected to an automation control for both heating and cooling periods in real life use.

In the whole study, the occupant profile of luxury high-rise residential buildings was defined (upper and upper-middle) and the main necessity was described as reducing the high energy expenses. According to the calculation methodology in the Directive and the Supplementing Directive of EPBD 2010/31/EU cost calculations of each retrofit took part together with energy saving calculations. Cost calculations were done basing on supplementing directive of EPBD 2010/31/EU. It is important to consider global cost as a requirement of the Directive. However, the main target of this study was not designating the cost-optimum suggestion but designating the most effective case in the scope of primary energy demand reduction. Because the main problem of the occupants is high monthly energy costs. The increase in the initial investment cost of the buildings is not the main issue if the suggestion provides reduction in the monthly energy costs. But still, as explained in part 5, as a further study of this research there are a lot of ways to decrease the initial investment cost of the proposed façade component. Mainly, applying it to the new buildings is the first step in order to prevent demolition and dismantling costs together with scaffolding cost. After that, decreasing the unit prices of the materials that were used in the component will be enough to reduce the initial investment cost of the component. Additionally, application of the component reduces the yearly primary energy demands of the buildings; therefore, it reduces the loads on HVAC systems. Thus, this condition reduces the initial installation costs of the HVAC systems. This is usually a very high cost especially in this building typology. Therefore, in fact application of the component may reduce the costs. Another key point is since the proposed new façade component increases the renewable energy contribution to the building, government incentives can be used. So, further investigations may focus on cost part of this component since there is an important potential to reduce the global cost.

Another important point, especially, while proposing a new façade component considering thermal comfort is crucial. Then the findings were supported with thermal comfort analyzes, indicator to designate the most efficient scenario is energy saving potential together with improvement in thermal comfort in terms of reducing uncomfortable hours. Mainly, all of the advanced retrofits reduce the uncomfortable hours. This result is very important because reducing the uncomfortable hours directly effects to decrease HVAC loads. Therefore, HVAC systems with lower capacity would be sufficient.

In particular, the findings of this study direct the proposed new facade component as applicable on reaching EU’s 2020 target and Turkey’s 2023 target. Using this façade component is beneficial to increase the portion of renewable energy contribution to the building and increasing renewable energy use is in the scope of both targets. Additionally, for buildings as luxury high-rise residential buildings with high-performed façades in the existing condition, it is revealed that concentrating on standard façade retrofits would only increase the global cost and the energy performance improvement ratio will be bare to consider. Therefore, for these kinds of buildings choosing advanced façade retrofits would be acceptable. Having high-performed façade is not enough to decrease HVAC loads and increasing the renewable energy contribution is essential.

PV, solar panels, etc. are very common to use for renewable energy contribution to the buildings. Nowadays there are also high-tech materials such as high-tech glazing types, phase change materials, etc and there are lots of research studies on them. These materials are being used for the same reason with the renewable energy systems. The proposed façade component in this thesis study is different from all of them as being a new perspective for renewable energy benefitted building components. The proposed component is not an additional system to the building façade and also, it is not a single material layer as the others. It is close to a functioning component. During the heating period only benefits from the characteristics of selective surface and glazing together for solar radiation, during the cooling period benefits from shade effect and air circulation. It can be applied on the building façade as any other façade component in the market. Basically, the component should be constructed together with the building. It is not a later addition to the building façade.

This research study has possible impacts on the other Mediterranean countries. Turkey with varied climatic conditions is one of the representative of Mediterranean climate countries. Since the proposed new façade component is convenient to apply on luxury high-rise residential building facades for primary energy demand reduction in Turkey, it will be also convenient to use it in the other Mediterranean countries or also in other climates with different operational scenarios.

Further investigations could be developed on that subject only focusing on one case type in this study and by this reducing the variations in the cases. Possible variations for component layers were tested within this thesis study and performance results were provided. Instead of this kind of case types, this time case study building types and climates could be enhanced. Additionally, analyzes on the cost part of the component is necessary since there is an important cost reduction potential.

In addition to all of these, the entire approach that was explained to follow in order to reduce the primary energy demand and uncomfortable hours of the luxury high-rise residential buildings is very effective according to the results. Each step of the approach directs the user to an energy efficient application. Therefore, architects may have this approach as a guideline while designing a luxury high-rise residential building. The approach could be served as a booklet with step by step explanations in detail with examples. Another way to serve the approach could be a computer software to design the building or a website that includes the steps of the approach and the designer may follow the instructions on that area. Some of the architects may not willing to apply any approach or doesn’t have any interest to increase renewable energy use, therefore policy makers should prepare legal regulations in terms of creating obligations. At this point, the steps of the approach may help to generate a regulation. In order to check whether the requirements of the regulation is being followed, a website may be provided that includes the steps of the approach. The designer is obliged to register the building to that website and follow the instructions. At the end, the website may give a kind of certificate to the building that means the building was designed in convenient to the current regulation.

This approach is very important for the country’s energy saving targets. As explained in the approach, proposing a new component or applying a component to the building façade is not an obligation. In this thesis study, façade application was necessary because the building’s widest outdoor area was the façade surfaces. In all of the luxury high-rise residential building cases this will be the same, however it is not an obligation to propose a new façade component. Existing renewable energy systems or high-tech materials may be applied too by following the steps of the approach. Also, the application areas do not have to be the opaque façade areas of the building, they can be the transparent façade areas too. The approach also can be applied to the other building typologies by some modifications.

The number of this kind of research should be increased and inspire the industry on using the building components as renewable energy systems itself. This research also could provide a new business area for architects especially on façade design area.

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APPENDICES

APPENDIX A: Global cost calculation sheet.

APPENDIX A: Global cost calculation sheet.

1	B	C	D	E	F	G	H
2	Initial Investment Explanation	Unit Price	Amount	Total Cost	Lifespan		
3		C3	D3	C3*D3	X years		
4				0.0 TL			
5				0.0 TL			
6				0.0 TL			
7				0.0 TL			
8				0.0 TL			
9				0.0 TL			
10				0.0 TL			
11				0.0 TL			
12				0.0 TL			
13							
14	Replacement Explanation	Unit Price	Amount	Total Cost	Lifespan		
15		C15	D15	C15*D15	X years		
16				0.0 TL			
17				0.0 TL			
18				0.0 TL			
19				0.0 TL			
20				0.0 TL			
21				0.0 TL			
22				0.0 TL			
23				0.0 TL			
24							
25		Subscription/Access Fe	Demand	Unit Price	Demand Cost		Total
26	Energy Demand - Heating (natural gas)		0.00 kWh	0.109775	D26*E26		C26+F26
27	Energy Demand - Cooling (electricity)		0.00 kWh	0.366371	0.00 TL		0.0 TL
28	Energy Demand - Lighting (electricity)		0.00 kWh	0.366371	0.00 TL		0.0 TL
29							
30							
31	Calculation period:		30 years				
32	Inflation Rate (R_i):		8.1%				
33	Market Interest Rate (R):		14.3%				
34	Real Interest Rate (R_R)		5.78%				

35								
36				COST			Payments Belonging to Building	Payments Belonging to Occupant
37	INITIAL INVESTMENT COST							
38	0	its initial investment cost	→	E3	→		E38	
39	0	its initial investment cost	→	0.0 TL	→		0 TL	
40	0	its initial investment cost	→	0.0 TL	→		0 TL	
41	0	its initial investment cost	→	0.0 TL	→		0 TL	
42	0	its initial investment cost	→	0.0 TL	→		0 TL	
43	0	its initial investment cost	→	0.0 TL	→		0 TL	
44	0	its initial investment cost	→	0.0 TL	→		0 TL	
45	0	its initial investment cost	→	0.0 TL	→		0 TL	
46	0	its initial investment cost	→	0.0 TL	→		0 TL	
47	0	its initial investment cost	→	0.0 TL	→		0 TL	
48								
49				COST	Discount Rate			
50	REPLACEMENT COST							
51	0	its replacement cost	F15	E15	(1/(1+D34))^D51		E51*F51	
52	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
53	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
54	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
55	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
56	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
57	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
58	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
59	0	its replacement cost	0 years lifespan	0.0 TL	1.0000		0 TL	
60								
62	THE VALUE OF THE INVESTMENT AT THE END OF THE CALCULATION PERIOD			0.0 TL	0.1851	-	E62*F62	
65	Energy Costs							
66	Heating	its energy expenses	Natural gas	H26	14.0884			E66*F66
67	Cooling	its energy expenses	Electricity	H27	14.0884			E67*F67
68	Lighting	its energy expenses	Electricity	H28	14.0884			E68*F68

Owner	Occupant
(SUM(H37:H47;H51:H59))-H62	0 TL

TOTAL
H71+J71

Figure A.1 : Global cost calculation sheet of the thesis study [Yılmaz et al. (project team), 2015].

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PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

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