ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

LIFE CYCLE ASSESSMENT OF RETROFITTING PROCESS FOR A DISTRICT

M.Sc. THESIS

Hüseyin SÖZEN

Energy Science and Technology Division

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Thesis Advisor: Assoc. Prof. Dr. Hatice SÖZER

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

BİR YERLEŞKENİN İYİLEŞTİRME ÇALIŞMALARININ YAŞAM DÖNGÜSÜ DEĞERLENDİRMESİ

YÜKSEK LİSANS TEZİ

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Enerji Bilim ve Teknoloji Anabilim Dalı

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Hüseyin SÖZEN, a M.Sc. student of ITU Institute of Energy student ID 301161038, successfully defended the thesis entitled "LIFE CYCLE ASSESSMENT OF RETROFITTING PROCESS FOR A DISTRICT", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 16 November 2018
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To my family,

FOREWORD

Special thanks to my advisor Assoc. Prof. Dr. Hatice SÖZER for her precious time and support.

December 2018

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(Environmental Engineer)

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ABBREVIATIONS

BIM **:** Building Information Modeling
CED **:** Cumulative Energy Demand
EN **:** European Norm
EPS **:** Expanded Polystyrene
GWP **:** Global Warming Potential
ISO **:** International Organization for Standardization
LCA **:** Life Cycle Assessment

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LIFE CYCLE ASSESSMENT OF RETROFITTING PROCESS FOR A DISTRICT

SUMMARY

In the thesis, a case study area was examined based on energy consumption and environmental impact during its life time via life cycle assessment (LCA) methodology. There are 79 residential buildings that share similar structure in the area; hence, one of them was selected as reference that the investigated building results were used for whole district. The building was built at the end of 1980s. Detailed energy performance analyzes were performed; besides, the energy efficiency retrofitting strategies were defined based on these energy models. These retrofitting strategies were applied to the building to improve energy performance, decrease released greenhouse gases and increase renewable energy source percentage in overall in 2015. In the analysis, the building life time was estimated 75 years. The first 25 years were considered with baseline conditions, and the next 50 years were considered with retrofitted conditions.

The aim is investigating a residential area based on its energy consumption and environmental impact during its life time from cradle-to-grave via LCA methodology. For this purpose, ISO 14040 and EN 15978 standard were used to develop the methodology. ISO 14040 defines general methodology of LCA; besides, EN 15978 specializes it based on building application. Also, EN 15978 methodology was created based on ISO 14040. Therefore, both standard were combined and used for the thesis methodology. Two scenarios were defined in the thesis. The first one is called as baseline scenario. In this scenario, beginning situation of the building was examined during 75 years from 1990 to 2065. The second scenario is called as retrofitted scenario that investigated building from 1990 to 2065. Nevertheless, retrofitted scenario was divided into two part. The first part is between 1990 and 2015 (25 years); besides, the second part is between 2015 and 2065 (50 years). Hence, the first part was examined based on beginning condition of the building, and the second part was examined based on retrofitted conditions. The building life time was divided into 3 stages as product, use and end of life stage in both scenario based on EN 15978 methodology. The building was examined as a whole with materials that were used, energy consumption, transportation and end of life steps. It is means that system boundaries of the thesis was defined as cradle-to-grave from raw materials extraction to disposal in the thesis. Already developed BIM and energy performance model of the buildings were used to calculate the amount of materials that were used in the buildings and energy consumption. In addition, two indicators were defined to demonstrate the results of LCA. These are called as cumulative energy demand (CED) and global warming potential (GWP). The reason for this selection is related with aim of the thesis. Energy consumption of the building and released greenhouse gases from the building were presented clearly by helps of defined indicators.

The results were obtained according to defined indicators after all input and output were collected based on defined system boundaries, the developed model was run. Total CED results of baseline scenario is 23,718,772 MJ/75years. Contribution from stages based on percentage is 5% from product stage, 94% from use stage and 1% from end of life stage. Total GWP results of baseline scenario is 2,216,050 kgCO_2eq./75years. Contribution from stages based on percentage is 5% from product stage, 83% from use stage and 12% from end of life stage. After baseline scenario results were obtained, retrofitted scenario results were also gotten. Overall CED of retrofitted scenario is 14,036,986 MJ/75years; besides, contribution from use stage is 82%, from product stage is 18% and from end of life stage is less than 1% for CED indicators. Overall GWP of retrofitted scenario is 1,325,967 kgCO_2eq./75years; besides, contribution from use stage is 66%, from end of life stage is 20% and from production stage is 14% for GWP indicators. After all results were obtained for both scenario, a comparison was made to show retrofitting strategies impact. Thus, CED of the buildings decreased 41% with helps of retrofitting during building life time. The reduce rate for GWP is 40% in retrofitted scenario.

The results of the thesis show overall CED and GWP of the building; also, the results demonstrate all phases of the building from manufacturing materials that were used to disposing of all wastes from the buildings. Also, stages of building life time were analyzed individually to demonstrate their impact on total. As it mentioned before, the building was retrofitted during its usage time. These retrofitting strategies also were investigated in retrofitted scenario. Thus, the importance and impact of retrofitting was demonstrated in the thesis. Based on the results, these kind of strategies can be used to reach energy efficient and more environmentally districts or cities.

BİR YERLEŞKENİN İYİLEŞTİRME ÇALIŞMALARININ YAŞAM DÖNGÜSÜ DEĞERLENDİRMESİ

ÖZET

Enerji eldesi, artan enerji ihtiyacı ve geleneksel enerji kaynaklarının giderek azalması nedeni ile ülkeler için büyük bir sorun haline gelmiş durumdadır. Enerji genel olarak sanayide, ulaşımda ve binalarda kullanılmaktadır. Binalardaki kullanılan enerji toplam birincil enerji harcamasının %25-30'una denk gelmektedir ve Türkiye'de son yıllarda bina sektöründe büyük ölçekli yatırımlar yapmaktadır. Buna bağlı olarak, binalarda enerji yönetimi konusunda gerekli tedbirlerin alınması için yeni yapılan binaların enerji verimli inşa edilmesine yönelik yönetmelikler tanımlanırken var olan binaların enerji performansı da yapılan yenileme çalışmaları ile iyileştirilmektedir.

Tezde yürütülen çalışmanın amacı, vaka çalışması olarak seçilen bir yerleşkedeki binaların fiziksel koşullarının yaşam döngüsü değerlendirmesi (YDD) yöntemi ile analiz edilmesidir. Binalar yaşam süresi boyunca birincil enerji tüketimi ve çevresel etkileri açısından beşikten mezara yaklaşımı ile ele alınmıştır. İncelenen yerleşke Manisa'nın Soma ilçesinde bulunmakta ve binalar Soma'da bulunan termik santralin lojmanları olarak kullanılmaktadır. Yerleşkede 79 adet bina bulunmaktadır ve bu binaların yapısal özellikleri ve enerji performansları birbirlerine benzerlik göstermektedir. Bu nedenle tüm yerleşkenin etkisini ortaya koymak için bir bina referans olarak seçilmiş ve incelenmiştir. İncelenen binalar 1980'li yılların sonuna doğru inşa edilmiş, 2015 yılında enerji verimliliği açısından iyileştirme çalışmaları yapılmasına karar verilmiştir. İyileştirme çalışmalarının temel amacı binanın enerji performansı iyileştirmek ve metre kare başına düşen enerji tüketimini azaltmaktır. Bunun yanında yapılan iyileştirmeler ile bina kullanımı kaynaklı karbondioksit salınımı azalımı ve yenilenebilir enerji kaynaklarının toplam kullanımdaki yüzdesinin arttırılması hedeflenmiştir. Buna göre, enerji performansının iyileştirilmesi için yapılan uygulamalar aşağıdaki gibidir.

- Cam ve çerçeve değişimi
- Dış cepheye izolasyon uygulaması
- Sıcak su için güneş enerjisi panelleri kullanımı
- Radiant ısıtma uygulaması
- LED uygulaması
- Merkezi ısıtma kaynağı olarak atık ısı kullanımı

Yapılan uygulamalar ile bina dış kabuğunun ısıl geçirgenlik değerlerinin düşürülmesi hedeflenmiştir. Temel senaryoda pencerelerde tek cam kullanılırken iyileştirilmiş senaryoda çift cam uygulaması yapılmıştır. Ayrıca pencere çerçevesinin malzemesi ahşapken Poli Vinil Clorür (PVC)'e değiştirilmiştir. Dış cepe izolasyonu için binaların dış duvarlarına Expanded Polystyrene Foam (EPS) malzemesi uygulanırken, çatı ve zemin için taş yünü malzemesi uygulaması yapılmıştır. Güneş enerjisinden yararlanabilmek için çatılara ısıl güneş enerji sistemleri ve bileşenleri entegre edilmiştir. Isıl güneş enerji sistemi sıcak kullanım suyu temini için uygulanmıştır. Yeni

ısıtma sistemi için radiant ısıtma sistemi uygulaması yapılmıştır. Aydınlatma için standart ampuller LED ile değiştirilmiştir. Son olarak ise merkezi ısıtma sisteminin enerji kaynağı değiştirilmiştir. Temel senaryoda var olan merkezi ısıtma sistemi enerji kaynağı olarak linyit kullanırken bu kaynak iyileştirilmiş senaryoda atık ısı olarak belirlenmiştir. Atık ısı yerleşkeye yakın konumda bulunan termik santralden elde edilmektedir. Bunun için yerleşke ile termik santral arasında yeni bir merkezi ısıtma boru hattı döşenmiştir.

Tezin yöntemi oluşturulurken iki standarttan yararlanılmıştır. Bunlar ISO 14040 ve EN 15978'dir. ISO 14040, Uluslararası Standard Organizasyonu tarafından 2006 yılında YDD yöntemini tanımlamak için yayımlanmıştır. Ancak, bu standart genel olarak yöntem açıklaması yaparken daha çok ürün temelli açıklamalarda bulunmuştur. Bu yüzden 2011 yılında British Standard Institute tarafından EN 15978 yayımlanmıştır. EN 15978, ISO 14040 yöntemini temel alarak YDD yöntemini binalar özelinde tekrardan ele almış ve bir hesaplama yöntemi tanımlamıştır. Bu yüzden iki yöntem de bir arada kullanılarak tezin yöntemi belirlenmiştir. EN 15978 standardına göre bina yaşam döngüsü üç aşamaya bölünmüştür. Bunlar ürün, kullanım ve yaşam sonu aşamalarıdır. Buna göre ürün aşamasında binada kullanılan tüm malzemelerin ve kullanılan enerjisinin ham madde eldesi, ham madde taşıması, üretimi ayrıca ana malzemelerin taşınması ve bina yapım adımları ele alınmıştır. Kullanım aşamasında binada kullanılan operasyonel enerji miktarı ve binadaki malzemelerin standart bakım ve değişim süreçleri ele alınmıştır. Son aşama olan yaşam sonu aşamasında ise binada kullanılan malzemeleri ve bina yıkıldıktan sonra oluşan yıkıntı atıklarının taşınması, işlenmesi ve bertaraf edilmesi süreçleri ele alınmıştır. Bu şekilde ilk başta belirtildiği gibi bina beşikten mezara yani malzemelerinin üretim aşamasında yıkıntı atıklarının işlenip bertaraf edilmesine kadar bir bütün olarak incelenmiş ve sonuçlar elde edilmiştir. Binaların envanter analizi oluşturulurken, kullanılan malzeme miktarları hesaplamak için daha önceden geliştirilmiş olan binaların yapı bilgi modellemesi (BIM) modelleri ve enerji harcamalarını hesaplamak için de yine daha önceden geliştirilmiş olan enerji performansı modelleri kullanılmıştır. Sonuçların eldesi için iki farklı gösterge seçilmiştir. Bunlardan biri kümülatif enerji ihtiyacı (KEI) ve diğeri de küresel ısınma potansiyelidir (KIP). Bu iki gösterge iyileştirme çalışmalarının amaçları doğrultusunda seçilmiştir. Buna göre, kümülatif enerji ihtiyacı binada kullanılan toplam birincil enerji ihtiyacını verirken, küresel ısınma potansiyeli binadan salınan sera gazı miktarını karbondioksit eşdeğerinde vermektedir.

Bina yaşam döngüsü karmaşık bir süreçtir ve yaşam süresi boyunca birçok malzeme ve süreç girdi olarak sisteme dahil olur. Bu karmaşıklığı önlemek için çalışmada bazı kabuller yapılmıştır. Yapılan kabuller aşağıdaki gibidir:

- Kullanılan malzemeler farklı üreticilerden temin edilmiştir. Üretici firmaların konum bilgileri veri eksikliğinden dolayı elde edilememiştir. Bu sebepten dolayı malzemelerin hepsinin İzmir taşındığı kabulü yapılmıştır.
- Binaların yapım aşamasında harcanan enerji ihtiyacı veri eksikliğinden dolayı elde edilememiştir. Bu yüzden yapım aşamasında sadece oluşan inşaat atıkları dikkate alınmıştır.
- Bina yıkımı sırasında harcanan enerji miktarı literatür bilgilerinden yararlanılarak elde edilmiştir.

Binanın yaşam döngüsü değerlendirmesi yapılırken iki farklı senaryo tanımlanmıştır. Bunlar sırası ile temel senaryo ve iyileştirilmiş senaryo olarak adlandırılmıştır. Temel senaryoda bina 1990 yılında inşa edildiği hali ile 2065 yılına kadar yani 75 yıl süre ile incelenmiştir. Bu süreçte sadece yapılması zorunlu olan cam değişimi, dış boya gibi temel bakım ve onarım faaliyetleri sistem sınırları içerisine dahil edilmiştir. Bunların dışında ilk yapım sürecinde kullanılan malzemelerin ham madde eldesinden başlanarak bina yaşam sonunda oluşan atıkların bertarafına kadar beşikten mezara yaklaşımı ile binanın 75 yıllık yaşam döngüsü ele alınmıştır. İyileştirilmiş senaryoda ise bina yaşamı ikiye bölünmüştür. Birinci bölüm binanın 1990 yılındaki ilk inşasından 2015 yılına kadar geçen süredir. 2015 yılından sonra ise bina iyileştirilmiş şekilde 2065 yılına kadar kullanılmaya devam etmiştir. Bu 50 yıllık süreç ise iyileştirilmiş senaryonun ikinci kısmını oluşturmaktadır. Buna göre, iyileştirilmiş senaryoda binada kullanılan ve sistem sınırlarına dahil edilen tüm malzemelerin yanında ayrıca iyileştirilme için kullanılan malzemeler, binanın kullanım aşaması ve bu süreçte yapılan tüm bakım ve onarım çalışmaları ve son olarak da bina yaşam sonunda oluşan atıklar incelenmiştir.

Sonuçlar, tüm girdi ve çıktılar sistem sınırları çerçevesinde belirlendikten sonra geliştirilen modelin çalıştırılması ile tanımlanan göstergelere göre elde edilmiştir. Toplam KEI temel senaryoda 23.718.772 MJ/75yıl olarak elde edilmiştir. Bu harcamanın %5'i ürün aşamasından, %94'ü kullanım aşamasından ve %1'i de yaşam sonu aşamasından kaynaklanmaktadır. Toplam KIP ise 2.216.050 kgCO_2eq./75yıl olarak hesaplanmıştır. Bu salınımın da %5'i ürün aşamasından gelirken, %83'ü kullanım aşamasından, %12'si ise yaşam sonu aşamasından kaynaklanmaktadır. Temel senaryo sonuçları elde edildikten sonra, iyileştirilmiş senaryo sonuçları da aynı şekilde elde edilmiştir. Toplam KEI iyileştirilmiş senaryodan 14.036.986 MJ/75yıl olarak elde edilmiştir. Bu harcamanın %17'si ürün aşamasından, %82'si kullanım aşamasından ve %1'de yaşam sonu aşamasından kaynaklanmaktadır. Toplam KIP ise 1.325.967 kgCO_2eq./75yıl olarak hesaplanmıştır. Bu salınımın %14'i ürün aşamasından gelirken, %66'ü kullanım aşamasından, %20'si ise yaşam sonu aşamasından kaynaklanmaktadır. İki senaryo içinde tüm sonuçlar elde edildikten sonra, iyileştirme çalışmalarının etkisini göz önüne koymak için iki senaryonun sonuçları bir biri ile karşılaştırılmıştır. Buna göre, binanın KEI'si iyileştirme çalışmaları sonucu %41 azalmışken, bu azalma oranı KIP için %40'dır. Ayrıca her bir malzeme ayrı ayrı analiz edilmiştir. Malzeme bazlı sonuçlara göre en çok enerji harcamasına sebep olan malzemelerin beton, tuğla olduğu görülmüştür. Bu durum malzeme bazlı karbondioksit salınımı için de aynı şekildedir. Ayrıca iyileştirilmiş senaryoda kullanılan LED ürününün de enerji harcaması ve karbondioksit salınımı miktarı diğer malzemelere oranla fazladır. Geri dönüştürülebilen malzemelerin geri dönüşüm süreçleri kaynaklı enerji geri kazanım ve karbondioksit azaltma potansiyeli bulunmaktadır. Bu potansiyel toplam enerji harcaması ve karbondioksit gazı salınımı ile kıyaslandığında düşük seviyede kalmaktadır. Ancak geri dönüşüm oranları arttırılırsa potansiyellerin artacağı öngörülmüştür.

Tezde yapılan çalışma ile incelenen binaların KEI ve KIP sonuçları elde edilmiştir. Ayrıca sonuçlar malzeme üretiminden yaşam sonu süreçlerine kadar binanın tüm aşamalarını için ve malzeme bazlı olarak ayrı ayrı da elde edilmiştir. Daha önce belirtildiği gibi iyileştirme çalışmaları bina kullanım aşamasındayken uygulanmıştır ve iyileştirilmiş senaryoda iyileştirme çalışmaları etkisi de göz önüne koyulmuştur. Böylece iyileştirme çalışmalarının önemi bu tez yardımı ile gösterilmiştir. Sonuçlara göre bu tarz çalışmaların yapılmasının var olan binaların enerji ihtiyaçlarını ve salınan sera gazı miktarını büyük oranda azaltacağı görülmüştür. Belediyeler ve ya bina sahipleri benzeri politikalar geliştirerek var olan enerji ihtiyaçlarını düşürebilir ve enerji verimli ve çevreci yerleşkeler ve şehirler hedefine daha çok yaklaşabilirler.

1. INTRODUCTION

As a developing country, Turkey makes so many investment on construction sector especially in last two decades. With help of government polies, construction sector is locomotive sector of Turkey nowadays. According to report of construction sector published in 2018 by Türkiye İnşaat Sanayicileri İşveren Sendikası (INTES), the sector has 8% percentage in economy directly; also, its percentage goes up 30% with included indirect impacts [1]. Construction sector can be divided into two categories as building and non-building. While the building sector includes building such as residential, office, public building, non-building part includes infrastructure project such as bridges, highway. Nevertheless, construction sector is also energy-dense sector due to material that used in construction, transportation, end of life of the building and operational energy consumption. And also, the sector create significant environmental pollutions. Thus, energy and environmental impact of the sector have to be taken in account carefully. In European Union and Turkey, there are some policies and regulations to reach sustainable buildings concept, energy efficient buildings and nearly zero-energy buildings. EU has made some changes on Energy Performance of Buildings Directive to defined nearly zero-energy building policy in 2010. According to the defined policy, new buildings that will be built after 2020 have to be nearly zero-energy building; also, encouragement policies will be developed for the existing building renovation [2]. Turkish legislation also has a regulation is called as Energy Performance of Buildings (In Turkish: *"Binalarda Enerji Performansı Yönetmeliği")* that was made based on the EU regulation [3]. The regulation was published in 2008, and it was reviewed in 2010 and 2011. In this thesis, a residential case study building was examined to obtain its energy and environmental impact from material production to end of building life via life cycle assessment (LCA) methodology. Hence, its sustainability and environmental impact was displayed with obtained data.

In addition to the material, transportation and end of building life impact, operational energy consumption also creates significant and negative environmental problems due to production, transportation and usage in building sector. According to Eurostat Static

Explained database [4], percentage of residential sector final energy consumption was 25.4% in overall final energy consumption in European Union (EU) in 2016. As it seen, residential sector consumes approximately one quarter of total final energy consumption; thus, this consumption has to be taken in account to decrease negative effects of energy usage. Operational energy consumption in the residential sector can be divided into two categories as: heating and electricity. While primary energy sources such as natural gas, coal are used for heating mostly, electricity is defined as secondary energy as it known. There are two methods to decrease the energy consumption. One is the energy saving that includes precautions that are applied by end-users; besides, the other is energy efficiency that means gaining energy saving without decreasing quality and social welfare. The main difference between this two methods can be explained with an example. For instance, turning of one of two lamps can be called as energy saving; however, using more efficient lamps that provide same illumination is an energy efficient strategy. While the energy saving is effective method to decrease consumption, the main effective and significant method is energy efficiency strategies.

In existing buildings, energy efficiency strategies can be applied via retrofitting work. Energy efficient retrofitting reduces operational energy consumption in buildings. Retrofitting includes both passive and active strategies to reduce consumption. While insulation can be given an example for passive strategies, photo-voltaic applying is an example of active strategies. In the thesis, life cycle assessment (LCA) methodology was used to analyze the building overall impacts and the retrofitting effects on environment and energy. LCA methodology is a common way to analyzed these kind of processes; besides, it was used many published papers for this purpose. LCA methodology examines products, processes or systems with their background and end of life; hence, it takes in account their manufacturing, transportation, usage and end of life stage as a whole and analyzed their environmental and energy effects from cradle-to-grave. Sharma et al. [5] give similar definition for LCA. According to them, LCA is a tool to make quantitative calculation on material, energy flows and their environmental impacts; besides, it includes obtaining raw material, manufacturing, use and final disposal steps. Cradle-to-grave approach was used to analyze the building effect in the thesis. Also, there are others approaches such as gate-to-grave, cradle-to-gate etc.

The some methodologies were defined to calculate environmental impact of products or processes; nevertheless, the most common one is called as ISO 14040 (Environmental management – Life cycle assessment – Principles and framework) [6] has 4 steps methodology for LCA as: Goal and scope, inventory analysis, life cycle impact assessment and interpretation. It is published by International Standard Organization (ISO). The steps are related with each other, and they have to be managed together during LCA. ISO 14040 was defined for all kind of LCA studies. However, LCA in buildings is highly complex process. Because of that, there is also a European Norm for LCA in buildings that is called as EN 15978 (Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method) in addition to the ISO 14040 [7]. This methodology was prepared based on ISO 14040; nonetheless, it is more suitable and more detail for building research. These two methodology were used in the thesis to calculate energy and environmental impact of the case study building.

2. LITERATURE REVIEW

Life cycle assessment has been used for environmental analyzes since 1960s [8]. The first modern life cycle assessment study based on environmental framework was made to analyze packaging effects by Hunt and Franklin in 1996 [9]. After that, many studies have done and published within different perspectives via using LCA methodology. While only one product or process can be examined during its life cycle; complex phenomenon such as building, waste management systems or a system that include multiple products and processes also can be analyzed based on LCA. During analysis, input and output to the system have to be defined carefully. Studies that analyze only one product or process can make this definition easier than complex circumstance such as building. Building life time usually is defined more than at least 50 years; thus, many unexpected and complicated processes occur during life time. Estimating all of input and output is getting difficult due to these reasons. On the other hand, other input and output from excepted situations are also complicated. When all these reasons are taken in account, LCA studies in buildings are more complicated, problematic and difficult than the other LCA studies [8].

2.1 Life Cycle Assessment Approaches

There are different defined approaches to define scope and make a LCA. These are listed as:

- *Cradle-to-grave:* This approach is the most extensive and detail one. A system or a product are analyzed from raw materials to disposal in cradle-to-grave approach. Hence; all production, transportation and end of life stage are taken in account. Thoma et al. [10] analyzed milk production and consumption effects on greenhouse gas emission and energy consumption via cradle-to-grave system boundaries; besides, they analyzed production, processing, packaging, transport/distribution, retail and consumer steps.
- *Cradle-to-gate:* It does not contain use and disposal phase; therefore, it is a partial life cycle assessment from cradle (raw material) to gate. The gate can

be defined in two ways. It could be a factory that manufactures product. Also, it could be a place where final product is used in. The difference between two ways is transportation/distribution stage. If the gate is defined as a place where final product is used in, distribution also have to be added to the system boundaries. Iannicelli-Zubiani et al. [11] evaluated hydrometallurgical process for electronic waste treatment within cradle-to-gate approach.

- *Cradle-to-cradle:* It is a close-loop analysis instead of open-loop. In this approach, a product is analyzed with avoiding disposal and landfill processes. Thus, it is basically a recycling approach. Ding et al. [12] made an analysis on concrete with avoiding landfill option; hence, concrete product was analyzed from production to reproduction that use recycled material as raw material.
- *Gate-to-gate:* It is also a partial LCA such as cradle-to-gate. This approach does not interested with cradle phase of products such as raw material extraction etc. it only interests with production phases such as transportation of material from on gate to another or final product life time between the factory of produced and final users. Ewemoje and Oluwaniyi [13] made a survey with this approach. They evaluated shea butter production from farm to end of packaging. Thus, they did not interested with shea production in the farmland.
- *Gate*-to-grave: This approach is used to examine end of life processes. It does not contain production phase. The system boundaries began with end user and finalized with end of life scenario. Analysis of municipal solid waste management systems can be given an example for this approach. Di Maria and Micale evaluated waste management scenario in an urban area of Italy within gate-to-grave approach [14].
- *Well-to-wheel:* This approach is related with fuel production and transportation (well-to-tank) and environmental impact during consumption (tank-to-wheel) [15]. Because of that, it is not related with building sector and the topic of this thesis.

2.2 Standards Related with LCA

Assessing a product, process or a building are complex and complicated methodology during its life time based on environmentally impacts and energy flow. While the life cycle thinking has been in literature since 1960s, the first modern LCA study was performed to analyze environmental effect of packaging system of cola in 1996 by Hunt and Franklin [8, 9]. From the beginning, many organizations or enterprises had tried to standardize a methodology for LCA. International Standards Organization (ISO) has published a standard for LCA is called as ISO 14040 (Environmental management-Life cycle assessment-Principles and framework) in 2006 [6]. According this standard, LCA methodology has four main steps: goal and scopes definition, life cycle inventory, impact assessment and interpretation as it seen Figure 2.1. Nonetheless, methodology for buildings has some differences from a standard product production. Because of that, a new methodology has improved for building case studies. This methodology is called as EN 15978 (Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method) that is a European norm, and it was published by BSI standard Publication [7]. The norm divides the building life time into different life stages as it seen in Table 2.1.

In the thesis, both ISO 14040 and EN 15978 methodologies were used to analyze life cycle impact of the residential buildings. LCA has comprehensive steps. Because of that, some software from various countries are developed to analyze to environmental impacts of materials and processes. These are can be listed as: GABI, SimaPro, Athena etc. In the thesis, SimaPro software was used for the calculation. SimaPro was developed based on ISO 14040 standard; thus, all steps were explain in detail at below.

- **Goal and Scope Definition:**

In this step, goal and scope of the LCA are explained in detail. The reasons why the study is done are clarified. Products, processes and their life cycle are defined. Functional unit is defined as product, weight, area etc.; thus, comparison with other studies can be made easier and more efficiently. System boundaries of the study are set because results can be changed based on different system boundaries even if the same product or process is analyzed. Life cycle of some products are complicated. Because of that, some assumptions have to be defined to make LCA. These assumptions are made in this step clearly; hence, complication are prevented. Thus, all reason to make the analysis and scope of the study explain in goal and scope definition step.

Table 2.1 Building life time stage based on EN 15978.

Stage	Step
Product	A1:Raw materials extraction A2:Transport A3:Manufacturing
Construction	A4:Transport A5:Construction&Installation
Use stage	B1:Use B2:Maintenance B3:Repair B4:Replacement B5:Refurbishment B6:Operational Energy B7:Operational Water
End of Life	C1:De-construction/Demolition C2:Transport C3:Waste processing C4:Disposal

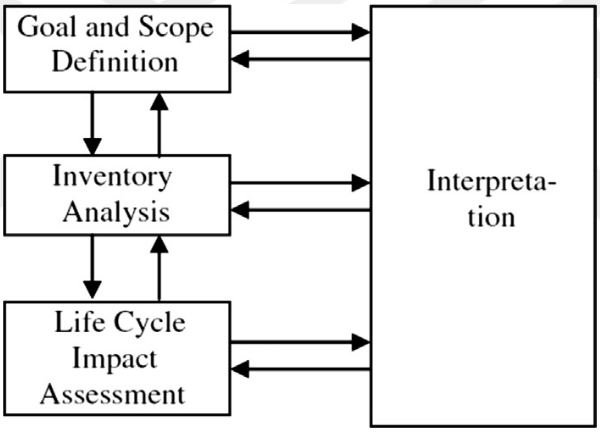


Figure 2.1 : LCA steps based on ISO 14040 methodology.

- **<u>Inventory Analysis:</u>**

After the goal and scope are set, inventory analysis is done. All materials, processes, energy flow and end of life scenarios are explained in this step. Because of that, this step has really significant impact on the results. Data collection can be exhaustive period especially for the buildings. Buildings contain many materials, processes and uncertain processes. Based on system boundaries and assumption, inventory list of the product or building is done in this step.

- **<u>Life Cycle Impact Assessment (LCIA):</u>**

In this step, impact assessment methods are selected to analyze according to goal and scope of the study. There is two option for selecting methods: developing new methods or using already developed methods; also, the most LCA experts prefer using the developed methods [41]. Also, the indicators are set based on used methods. They can be defined based on goal of study. For instance, if the study related with the energy consumption; cumulative energy demand or the other indicator related with energy consumption can be selected. Or, if the study are made to analyze a water ecosystem, eutrophication indicator can be selected to show the effects of the processes on water quality.

- **Interpretation:**

This step has uncertainty analysis, sensitive analysis, contribution analysis and inventory analysis. Thus, model and verification of results and contribution from different processes and materials are analyzed in this step. Contribution and inventory analysis are significant for the future study to demonstrate materials or processes impact on the selected indicators.

2.3 LCA on Building Sector

There are various published papers and studies about LCA in building sector. While, some of them were done based on materials that are used in buildings, some of them was analyzes building as a whole that means that analyzing with materials, energy consumption, end of life, construction, some of them just analyzed only one phase such as operational energy consumption. In the thesis, the buildings that were assessed were taken in account as a whole; besides, all phases were included to the system boundaries. Bastos et al. [16] examined 3 different residential building in Lisbon (Portugal) based on building construction, retrofitting and use phase. They defined 75 years life time for building; besides, the functional unit was defined as per square meter per year and per person per year. They mentioned that, the most negatively effective impact on embodied energy and GHG emissions is from walls; also, larger buildings cause more energy consumption and GHG emissions per person, on the other hand, energy consumption and GHG emissions are lower based on per square meter. Also, their results showed that the most effected stage is use stage (69-83%) in buildings. Asif at all. [17] studied on materials effects on their energy consumption via LCA methodology in Scotland; they investigated 5 material types that are most negatively effective on energy consumption and environment. They are glass, aluminum, ceramic tile, concrete and wood. They calculated required primary energy for these 5 material types that was 227.4 GJ. Concrete had the highest impact as 65% of total embodied energy of the assessed home which has 3 bedroom and is 70 m^2, and the other most negatively effective materials can be lined up as timber (14%) and ceramic (15%). At Figure 2.2, impact of all the materials based on embodied energy is shown in percent.

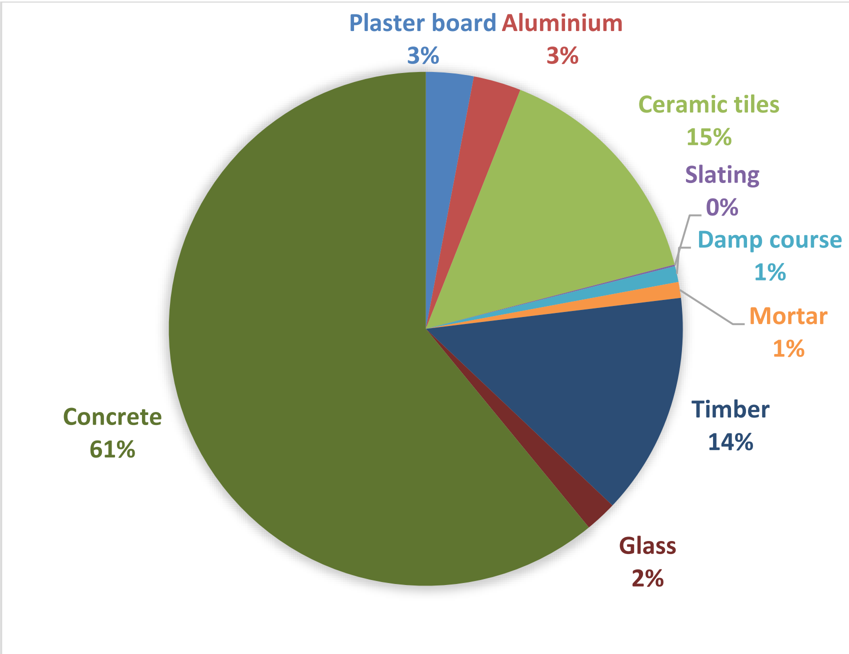


Figure 2.2 : Embodied energy distribution in M. Asif et al. survey.

Selected materials which are used at construction phase have significant effects on CO_2 emissions and relatively on environment. A survey was made in Sweden by Börjesson and Gustavsson [18] shows that GHG emissions, represent as CO_2 eq., is higher 1.5-2 times when concrete frame is used against wooden frame, when concrete does not have carbonization, and wood waste does not recover at biogas landfill. Also a survey was made in Italy shows that while concrete has major contributor on GWP, ozone layer depletion, eutrophication and smog, steel is major contributor on acidification and energy use [19]. T. Y. Chen et al [20] made a survey on two 40 story residential buildings at Hong Kong; besides, steel that is used mostly for reinforcing to concrete and also for other purposes has major impact on energy usage approximately 68%. In addition, this survey shows that used energy on manufacturing phase is approximately 90% for steel, and share of the other phases (Processing, transportation and demolition) is only 10%.

2.4 LCA on Applied Retrofitting Strategies

There are some implementations to reduce energy consumption of a building. While these implementations are being applied on a building, some environmental effects and energy consumption occur. LCA is a useful methodology to examine their impacts and advantages/disadvantages. One of the implementations to reduce energy consumption is thermal insulation. At European market, there is two major insulation group based on materials. Their market capacity is shared as 60% based on mineral and organic materials, 30% based on oil-derived materials (XPS, EPS, PUR/PIR) and 10% based on other materials [21]. Pargana et al. [22] examined some thermal insulation materials: extruded and expanded polystyrene, polyurethane, expanded cork agglomerate and expanded clay lightweight aggregates via LCA methodology. XPS (Extruded polystyrene) less than 80 mm has important effect on its two life cycle phase (raw material and manufacturing). Raw material production has influenced more than 60% on ADP (Abiotic depletion potential), AP(Acidification potential), GWP); besides, manufacturing phase has impact more than 25% on AP, EP and GWP, and more than 50% PE-Re (Consumption of primary energy, renewable), ODP (Ozone depletion potential) and POCP (Photochemical ozone creation potential)). These contributions mainly are occurred by electricity consumption. The other implementation for reducing is applying advanced glazing; therefore, u-value of windows decreases accordingly. Hee et al. [23] worked on role of windows glazing on energy efficient of building. They applied single clear, low-e revers, single low-e and double low-e glazing. The survey showed that u-value of windows decrease according to glazing type; besides, most efficient glazing type is double low-e glaze based on energy saving. Lighting energy consumption has also significant part on energy performance of buildings. Some renovations can be used to reduce that. One of that is using light emitting diode (LED) lamps. Principi and Fioretti [24] made a comparative research between compact fluorescent (CFL) and LED by LCA methodology. According to total environmental impact during all life cycle phases, LED has less impact on environment than CFL. Nevertheless, LED's manufacturing phase has more impact than CFL's, because of heavy electronic components on LED As it is mentioned before, overall environmental impacts of LED is less than CFL. CFL's GWP is 0.541 CO_2-eq./lumen, and LED's is 0.320 CO_2-eq./lumen. Solar thermal panel implementation is applied to reduce energy consumption via using solar energy for heated water demand. These panels take advantage from sun radiation to heat domestic water instead of electricity or natural gas. They use sun radiation as a natural sources; nonetheless, they have also impacts on environment during their life cycle. Ardente et al. [25] made a research to calculate solar thermal collector's payback time in terms of energy and CO_2. Based on solar radiation conditions of Palermo (Italy), energy payback time of solar collectors is lower than 2 years, and CO_2 payback time is also similar to energy like lower than 2 years. Photovoltaic (PV) application also another implementation for reducing. PV application on building is widely used technic to get advantage from sun radiation. The difference between PV and solar thermal panel is that PV uses the solar radiation to produce electricity, solar thermal panel uses the solar radiation for only heating the water. In additions, there are still some concern about PV manufacturing phase. PV can generate electricity; nevertheless, energy consumption and GHG emissions during manufacturing phase are still a problem to market. In this frame, greenhouse-gas payback time concept is occurred to compare that is PV application efficient way or not for environmental aspect. Lamnatou et al. [26] worked on integrated PV on buildings via LCA methodology to calculate energy consumption and embodied carbon. The survey showed that greenhouse-gas payback time differs based on country electricity grid. At France conditions, payback time is approximately 23-29 years, but at Spain and Ireland, its range is 3.3-5.7 years. Laleman et al. [27] analyzed GWP potential per kWh to compare PV and others energy source and Belgium electricity grid standard. As it is seen at Figure 2.3. PV causes the least GWP than the other comparison sources. PV impact changes depends on its life time. If its life time 30 years, its GWP 0.08 kgCO_2-eq./kWh. If it is 20 years, GWP is 0.12 kgCO_2-eq./kWh. In existing situation, owners of the examined buildings in the thesis use conventional HVAC system such as natural gases for heating and air conditioning for cooling. But, there is a new technique is called radiant heating and cooling system instead of conventional HVAC system. Imanari et al [28] investigated radiant systems energy consumption, cost and comport comparing with conventional system. They analyzed the applied radiant system on an office building. Results show that radiant system reduces 10% of total energy consumption for heating and cooling.

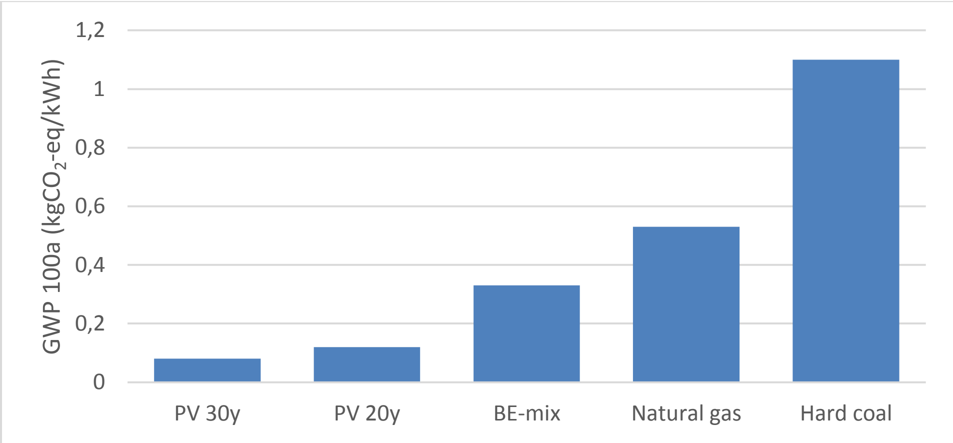


Figure 2.3 : GWP of 1 kWh electricity for various energy sources in Belgium.

Mangan and Oral [29] made a survey at 3 houses that are placed three different climatic region in Turkey. They analyzed three different retrofitting strategies: heat insulation on exterior wall, change the glazing and apply the photovoltaic (PV). They reached different u-value for each parts (wall, roof, floor and windows) via different scenario strategies. The study showed that retrofitting strategies can be examined with LCA methodology. Some LCA researches proved energy reduction with passive technics. Ramesh et al. [30] showed that increasing insulation and wall thickness causes positive effects on energy consumption. In addition, changing glazing and using low-e window or double glaze decrease window's u-value; therefore, energy consumption decrease with that [29].

Various software and database were develop to analyze processes, materials or products during their life time via LCA methodology. Some of them can be listed as: SimaPro [31], GaBi [32], BEES [33], Athena [34]. On the other hand, SimaPro and GaBi are leading LCA sector nowadays [35]. In the thesis, SimaPro software was selected to make analysis since it widely uses in LCA of building. Blengini made a survey on a demolished building in 2004 to analyze its demolish wastes management via LCA using SimaPro [36]. Balasbaneh and Marsono made a survey to assess greenhouse gas emission from building related with defined materials using SimaPro; besides, they worked on 6 different prefabricated building in Malaysian [37]. O'Brien [38] evaluated deconstruction processes of barracks in USA by comparing different scenario via SimaPro. Cabeza et al. [39] made a review on LCA, life cycle energy analysis (LCEA) and life cycle cost analysis (LCCA) on building and building sector. They investigated 62 different studies on building sector; also, they categorized all of them based on location and climate zone as in seen Figure 2.4. When they made analysis, they considered climate of the building location. Climate has important effects on building materials and operational energy consumption. For instance, if a building is in a cold climate, insulation may be necessary. Also, when they made investigation on LCA survey, they realized that life time of buildings were defined different between 10-100 years. However, 50% of studies were defined as 50 years, 19% were defined as 40 years and 9% were defined as 80-100 years. They mentioned that these differences create difficulties to comparison between the studies. In addition, one of those reviewed papers in the article was made in Turkey. It was made by Esin [40].She worked on material scale; besides, she made the investigation in Gebze and Marmara Region based on production process. Even so, Cabaze et al made their study in 2014; also, LCA studies have increased in Turkey year by year after 2014. Because of that, the number of paper related with LCA on buildings also has increased.

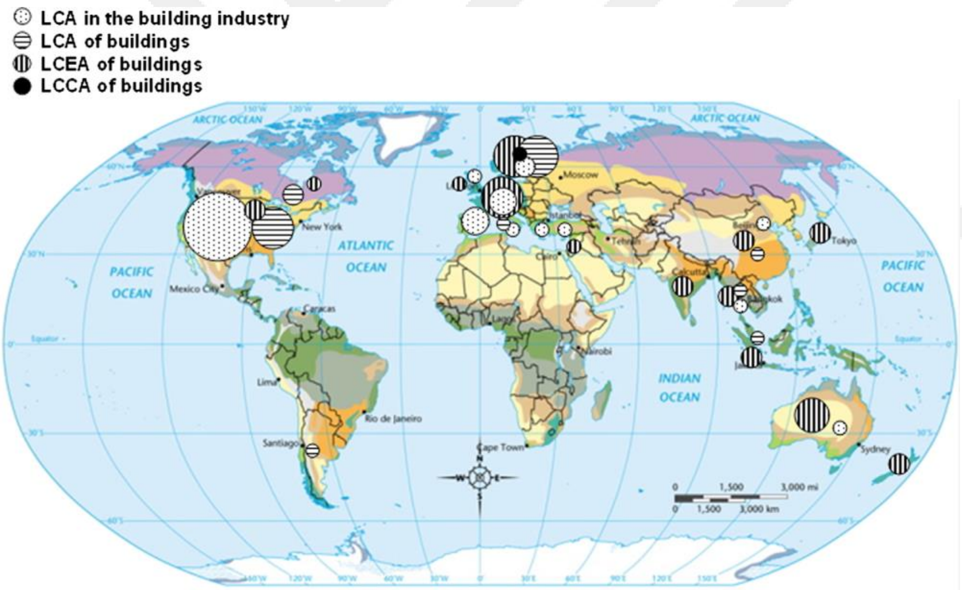


Figure 2.4 : Categorizing of reviewed papers based on location and climate zone.

3. METHODOLOGY

In this section, the case study methodology was explained in detail. The methodology of the thesis was developed based on ISO 14040 and EN 15978 standard. Methodology of the thesis were given in Figure 3.1.

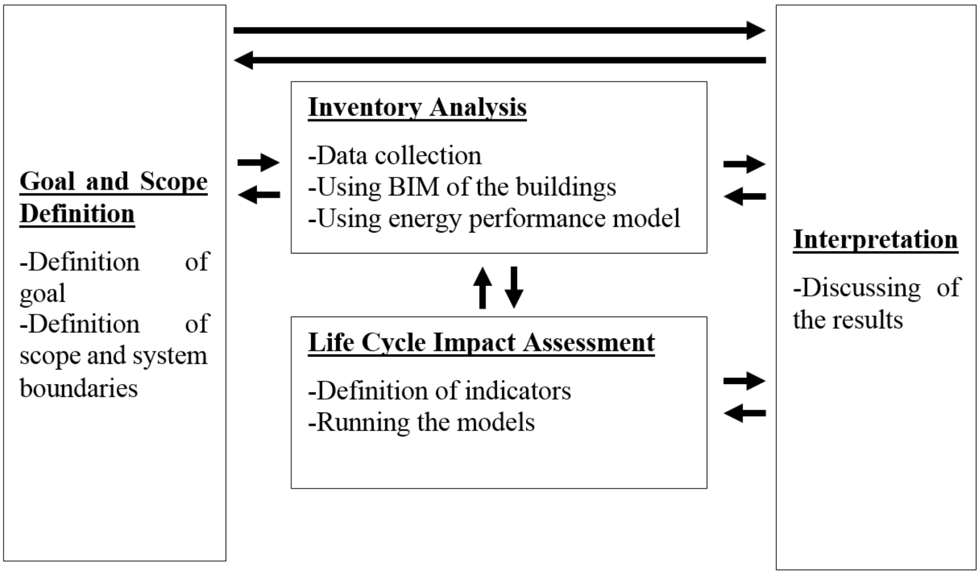


Figure 3.1 : LCA methodology by ISO 14040 standard.

3.1 Goal and Scope Definition

The goal of the thesis is analyzing energy flow and environmental effects of a retrofitted residential area within its materials, operational energy consumption and end of life stage via a selected reference building. All structure materials, replacement, maintenance, energy consumption and waste management strategies were included to the system boundaries of the thesis. Thus, the question that what are cumulative energy demand and global warming potential of a residential building was answered based on Turkey conditions. In the thesis, analyzed building can be called as actual product; nonetheless, building industry is differ than the other industry products due to its complicated processes. When a building analyze with LCA methodology, several materials, processes and estimated data have to be included to the system boundaries. The life time of the buildings was defined as 75 years; moreover, functional unit (FU) was defined as m^2.75years. Area of the buildings was taken as its conditioned area; also, it was refereed as A_{temp}. in the thesis System boundaries of the thesis are shown in Figure 3.2 in detail. Based on that, Firstly, building materials were produced and transferred to the case area. After 25 years, retrofitting processes were applied to the building to improve its energy performance and decrease its global warming potential. Demolition wastes capacity was calculated, and end of life scenario was defined based on existing situation. BIM of the building and energy performance models were used to create inventory list.

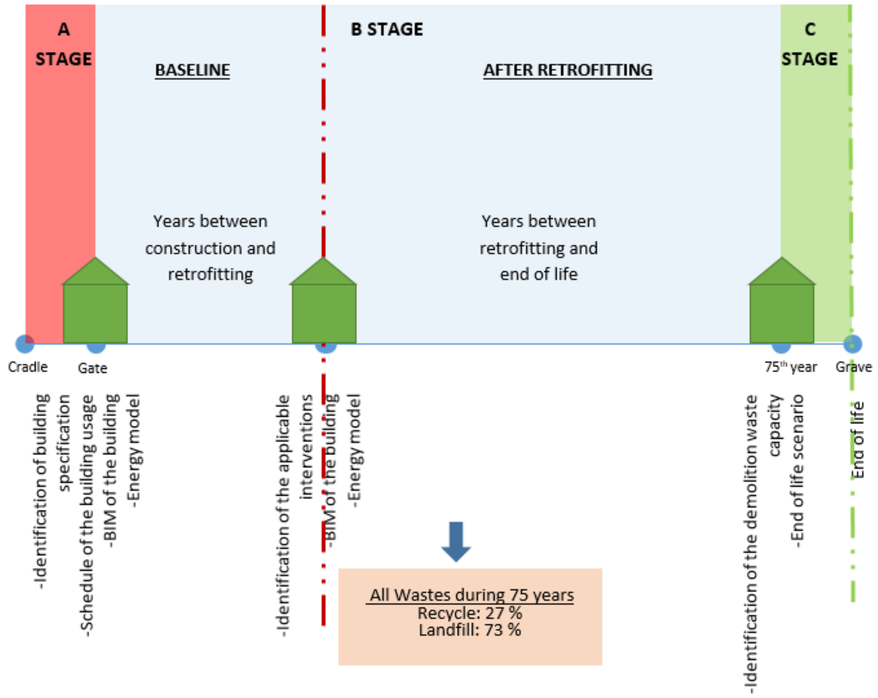


Figure 3.2 : Life cycle of building during 75 years.

3.2 Inventory

Inventory analysis is the most important step in LCA methodology because all input and output data and their amount were analyzed in this step. The weight of materials that were used in the building was calculated with help of BIM of the building. Also, unit weight of some used materials were defined in the construction agreement; thus, these unit weight were used for the defined materials. During building life time, some materials such as glazing had to be replaced or some materials such as interior/exterior paint had to be maintained. Materials life time was obtained from their catalogue information or literature. All replacement and maintenance activities were also included to the study. Beside of used materials in the building, energy consumption of the building is critical for LCA. Operational energy includes electricity and heating consumption. This consumption was taken from buildings energy performance models that were developed on eQuest software[42]. eQuest software is developed to analyze final-energy performance of buildings.

3.3 Impact Assessment

In the thesis, developed methodology was used to calculate environmental effects and energy demand of the building. The main goal of the thesis is showing energy consumption of the building during 75 years from cradle to grave. There are two types of method to calculate the energy demand as cumulative energy demand and cumulative exergy demand. The cumulative energy demand (CED) method was used to obtain energy demand of the building. Therefore, energy demand of the materials was obtained from raw material extraction to disposal. Also, operational energy demand represented only final energy consumption. Nonetheless, primary energy demand can obtain with LCA methodology as it was made in the thesis. While the CED method gives overall energy consumption, it also divides energy demand into 6 different groups. As it seen at below, CED are divided based on energy source and renewable/non-renewable.

- Non-renewable, fossil
- Non-renewable, nuclear
- Non-renewable, biomass
- Renewable, biomass,
- Renewable, wind, solar, geothermal
- Renewable, water

In addition to the cumulative energy demand, global warming potential of the building was calculated. Global warming potential represents emission of greenhouse gases to the atmosphere; besides, its unit is given with carbon dioxide equivalent (kg CO_2eq.). There are numerous gases that cause global warming; nevertheless, CO_2 is the most common one. Although quantity of methane (CH_4) in the atmosphere is less then CO_2, CH_4 effect on global warming is much more higher than CO_2. Shin et al. [43] made a survey to evaluate the greenhouses gases impact on the global warming; besides, the results show that impact of CH_4 on global warming is 2,43 times more than CO_2. Because of that, CH_4 has also significant gases that have to be included to the calculation. There are many developed calculation methods to calculate global warming potential (GWP). These are can be listed as: CML-IA, Impact 2002+, BEES+, TRACI, IPCC 2013 GWP 100a. In the thesis, IPCC 2013 GWP 100a method was used to calculate the GWP of the building. The method was developed by Intergovernmental Panel on Climate Change Methane ; also, constant to calculate 1 kg CH_4 impact is defined as 2,75 kg CO_2 in the method [44]. According to goal of thesis, only CED and GWP were calculated instead of the other environmental impact such as eutrophication acidification etc.

3.4 Interpretation

Based on EN 15978 methodology, internal verification of the results are verified by a LCA-expert that is a third-party participant [7]. However, this type of verification used in commercial study mostly. The study was made on the thesis framework in academically; hence, verification by a LCA-expert did not included to the study. Result verification was made with comparing with the literature.

One of the purpose of the thesis is evaluating a residential building based on energy consumption and environmental effects during its life time. More than that, materials and processes contribution were also investigated to understand their impacts. In this way, their positive effects on operational energy consumption and the needed energy that while they are produced can be compared with each other. For this purpose, all material types and processes also were analyzed separately to figure out their impact on energy and environment.

3.5 EN 15978

LCA methodology is created based on ISO 14040 which is an international standard. Nonetheless, methodology for buildings has some differences from a standard product production. Because of that, a new methodology was improved for building case studies. The methodology that was used in thesis is called as combination of ISO 14040 and EN 15978 (Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method). EN 15978 is a European standard, and its step can be listed as:

- **Product Stage (A1-A3)**
  - Raw material supply (A1)
  - Transport (A2)
  - Manufacturing (A3)
- **Construction Stage (A4,A5)**
  - Transport (A4)
  - Construction-insulation process (A5)
- **Use Stage (B)**
  - Use (B1)
  - Maintenance (B2)
  - Repair (B3)
  - Replacement (B4)
  - Refurbishment (B5)
  - Operational energy use (B6)
  - Operational water use (B7)
- **End of Life Stage (C)**
  - De-construction demolition (C1)
  - Transport (C2)
  - Waste processing (C3)
  - Disposal (C4)

Product Stage (A1-A3): Product stage includes raw material supply, transport and manufacturing steps. Thus, all materials that were used in building structure and applied interventions were investigated beyond their raw material extraction, transportation of raw materials and intermediate products and manufacturing of intermediate products and main products based on environmental effects. Production stage was taken in account for building structure and all interventions in the developed LCA models.

Transport (A4) step: A4 step related with transportation of material that were used in building to construction site.

Construction and Installation (A5) step: During construction of materials, wastes were generated from surplus materials. They were also added to the developed model. Energy demand of the construction and installation were not added to the system boundaries due to lack of data.

Maintenance (B2) and Replacement (B4) step: All materials have a life time; hence, they have to be maintained or replaced during building life time if it is necessary. B2 and B4 steps relates with these processes.

Operational energy (B6) step: Operational energy includes electricity and heating consumption. This consumption was taken from buildings energy performance models that were developed on eQuest software [42]; also, they were added to the developed models.

Demolition (C1) step: Structure and applied materials on buildings will become waste after their services life; hence, these wastes have to be added the LCA models based on cradle-to-grave system boundaries. In the demolition step, the amount of waste from the structure materials and applied interventions was calculated and added to the LCA models. Also, energy demand that was consumed by vehicles during demolition was investigated in the step.

Transport (C2) step: The step related with transportation of waste from the case area district to the closest and the most suitable waste treatment facilities.

Waste Processing (C3) step: All waste types have to be handled in different ways based on their types. Because of that, recyclable wastes, construction and demolition waste and the waste that has to be sent to landfill were defined carefully in this step. All waste type was analyzed in the model individually.

Disposal (C4) step: The wastes that were not recyclable or reusable were send to the closest landfill area by trucks.

4. THE CASE STUDY BUILDINGS

The building that was examined via LCA is in a campus area that has 79 residential buildings. Since all residential buildings share similar architecture, one of them was selected as a references and represented building. Investigated building has 421 m^2 gross area and 206 m^2 conditioned area. Thus, case study methodology was developed for assessment; besides, results were obtained by helps of developed models. Diagram of developed model can be seen in Figure 4.1. Model was developed based on EN 15978 standard. Materials and energy that were used in the building were taken in account from raw material to disposal; besides, energy requirement also was added to the model for whole stage. After materials were used, wastes that were generated in the building were consider in assessment.

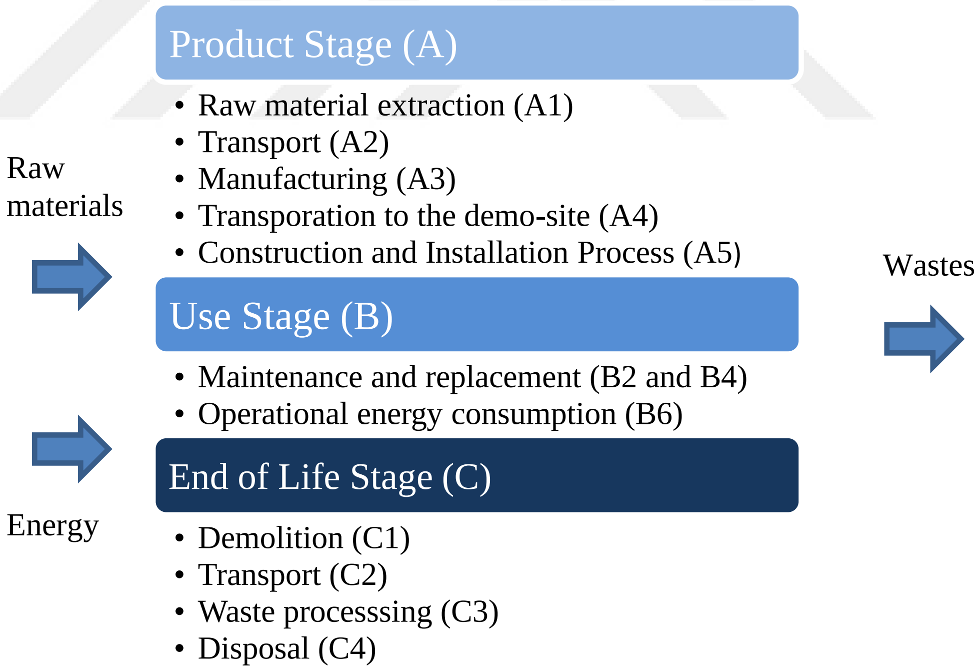


Figure 4.1 : Diagram of developed models.

All input were defined and calculated in *Section 4.3, 4.4 and 4.5* in detail. Defined input were added to the model. All input of the model were seen in Figure 4.2. As it seen, there are 5 main input: materials, maintenance/replacement, heating energy demand, electricity demand and end of life scenario; also, materials were taken in account in two group as: current building envelope materials and materials that were used in retrofitting activities. In addition, end of life scenario was divided 4 main steps: Transportation, required energy for demolition, recycling and disposal. According to Manisa and Soma Municipality waste management system, incineration process is not an option for wastes. The buildings used lignite source for heating before retrofitting; nonetheless, the source of the heating was changed to the waste heat from the closest thermal power plant against lignite by retrofitting activities. Electricity is obtained from standard region grid for both scenario. Thus, the majority of electricity was supplied from non-renewable sources such as natural gas, coal.

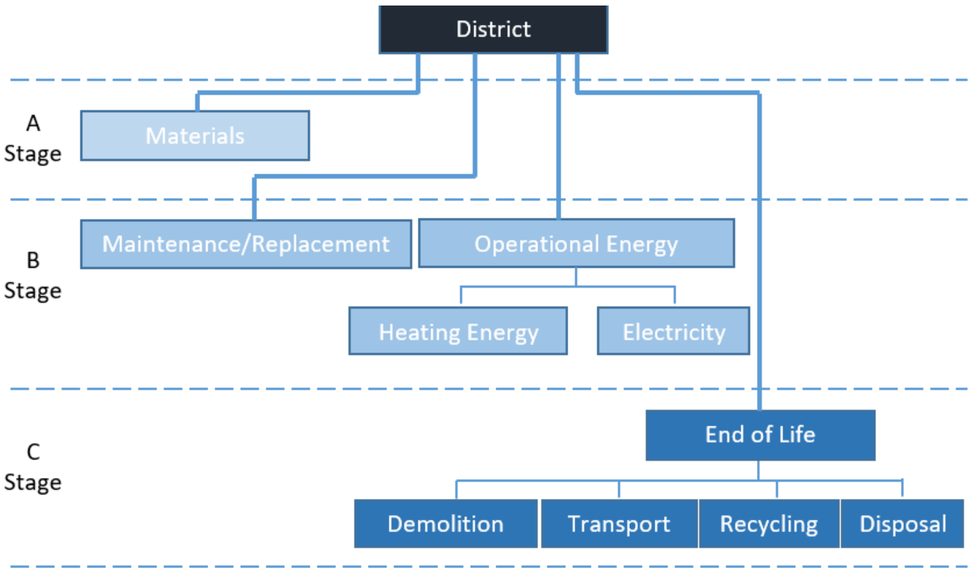


Figure 4.2 : Input of the model.

Two indicators were defined to demonstrate the results. They are cumulative energy demand (CED) and global warming potential (GWP). CED shows primary energy demand of the building; besides, GWP shows released greenhouse gas emission from the building and processes related with the building. There are various gases that have greenhouse impact on environment. GWP results were given as carbon dioxide (CO_2) equivalent to avoid confusions while the results are comparing with the other studies' results.

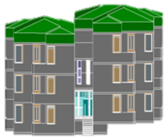
There are two scenarios that were investigated in the thesis. The first scenario is called as baseline scenario, and the second one is called as retrofitted scenario. The buildings were constructed in end of 1980s; thus, they have used during 25 years till today. In addition, their life time was defined as 50 years more from 2015. Therefore, their total life time was defined as 75 years. Whole life of the building was examined in both scenario. The difference between scenarios started after first 25 years. In both scenario, first 25 years was continuing in same condition. The building will continue its life without any interventions related with retrofitting activities in baseline scenario; nonetheless, retrofitted scenario contains retrofitting activities and their effect on building after first 25 years. Thus, energy consumption is lower than before retrofitting; also, some building equipment such as glazing, solar collector are not same or are new according to baseline of the building.

While the building was examined as a whole, results also were obtained based on material types. Hence, materials and products impact on environment and energy consumption were also demonstrated via the results. As it mentioned in *Section 3. Methodology*, materials can cause different impact on environment and energy flow. In the thesis, their impact also can be monitored via obtained result individually.

Cabeza et al. [39] divided to building two category as residential and non-residential building. Residential buildings can be defined where people live in during their life time such as single-family house; besides, non-residential houses are used for a specific purpose like as office, public services. The case study building is a residential building where is in Soma District of Manisa in Aegean region of Turkey. The building is in a campus area that has 79 residential buildings; besides, all residential building has similar structure and envelope. Thus, evaluating one of them also shows the total area effects on energy consumption and environment. Buildings' area owner is SOMA Electricity & Trading Joint Stock Company; moreover, the buildings are built for employees of the area owner company. The case study area and were given in Figure 4.3. Also, detail information related with building types and their BIM and images were given in Table 4.1 [45].

Figure 4.3 : The case study area.

Table 4.1 : Detail information of building type with their BIM and images.

Building Type	Conditioned area [m^2]	Number of building	BIM of the buildings	The image of the building
One-Storey	206	6		
Two-storey	412	32		
There-storey	617.2	33		
Duplex	185	8		
Total	36,285	79		

The analyses was made for a case study area where is in Soma District of Manisa. Case study area has 79 residential buildings; besides, all of them have similar structure. Thus, one of them was selected as a case study building to analyze the overall environmental effects of the case study buildings. The case study building was selected as one one-storey building. It has 421 m^2 gross area and 206 m^2 conditioned area The buildings was renovated with retrofitting activities; also, retrofitting activities impacts were included to the study. The buildings was 25 years old before the retrofitting, and their life time will extent 50 years more after the retrofitting based on assumption that was made. The case study building was analyzed from production of structure materials to its end of life. The building life time was divided two step. One of them is baseline step from beginning to 25 year, and the second is after retrofitting step from starting of retrofitting activities to end of the building life during 50 years. Hence, total building life time was defined as 75 years. The BIM of building, construction agreement and catalogue information of the material were used to calculate quantity of the structure and applied materials.

Some interventions were applied to the building in case study area based on retrofitting activities. These interventions' impacts were analyzed via LCA methodology based on energy consumption and environmental effect. Applied intervention were integrated to the building's envelope one by one. All passive and active interventions that were applied to the buildings were listed one by one as:

- Glass and frame changing
- Insulation (EPS and mineral wool) application
- Solar collectors and tanks application
- Radiant heating (District heating) application
- LED application
- District heating system

These interventions were investigated based on EN15978 methodology. Glasses and frames were replaced to improve u-value of windows with polyvinyl chloride (PVC) frame and double glazed windows. At baseline condition, glass was single glazing and frame material was wooden. Insulation application was done on external wall, roof and ground floor. While 5 cm EPS material was used for wall, 5 cm mineral wool was used for roof and ground floor. Solar collectors were used to take advantage of solar energy for usage water heating. For this purpose, solar collector systems were integrated on the roof of the buildings. Radiant heating system that uses surplus heat from district heating system was applied to improve energy performance of the buildings. Before the retrofitting, inhabitants in the project area used inefficient lighting systems, which were replaced with light-emitting diode (LED) within the retrofitting scope. In addition to that, a new district heating distribution line was built into the district area. The new line starts from Soma Thermal Power Plant and ends in the building's entrance. The new district heating system pipeline were given in Figure 4.4. As it seen from Figure 4.4, waste heat are transferred to the district with pump stations. An assumption was made to analyze the impact of a new district heating distribution line based on its effect on environment and energy consumption. Total length of the new line is 12 km approximately and the total conditioned area is 36,268 m^2 in district. Thus, impact of district heating distribution line was divided to all the building types based on their conditioned area. Conditioned area of the case study building is 206 m^2; hence, its part on the distribution line is approximately 60 meter. Also, heat energy was supplied from surplus heat from Soma Thermal Power Plant instead of existing central heating system. Thus, greenhouse gases emissions from lignite burning processes are prevented.

Figure 4.4 : New district heating system pipeline.

The system boundaries of the study was set to analyze whole effects of the building based on cumulative energy demand and environmentally. For this purpose, the building was investigated completely. It was built in end of 1980s. From the beginning, its structure materials were included to the model. As it mentioned before, the building life time was divided two phase as: baseline and after retrofitting. All interventions related with retrofitting strategies were included to the study. System boundaries of the study are shown in Figure 4.5 in detail. Materials and energy sources that were used in the building were investigated from raw material supply to end of life. Maintenance and replacement activities were taken in account during 75 years. For the end of building life, waste management strategies were defined based on waste types. Recyclable wastes were send to recycling facility; besides, construction and demolition wastes were handle in the closet landfill that is used for these type of wastes.

How the all steps related with EN 15978 are handled and modelled was explained in detail. All steps in A and C stage were included to the model; nevertheless, only B2, B4 and B6 steps were taken in account in B stage. B1 and B3 were eliminated due to lack of data. B5 was eliminated because there was not any plan about new integration to the buildings. Also, B7 step did not include to the system boundaries in both scenario. In Table 4.2, summary information about the building were shown based on building envelope area.

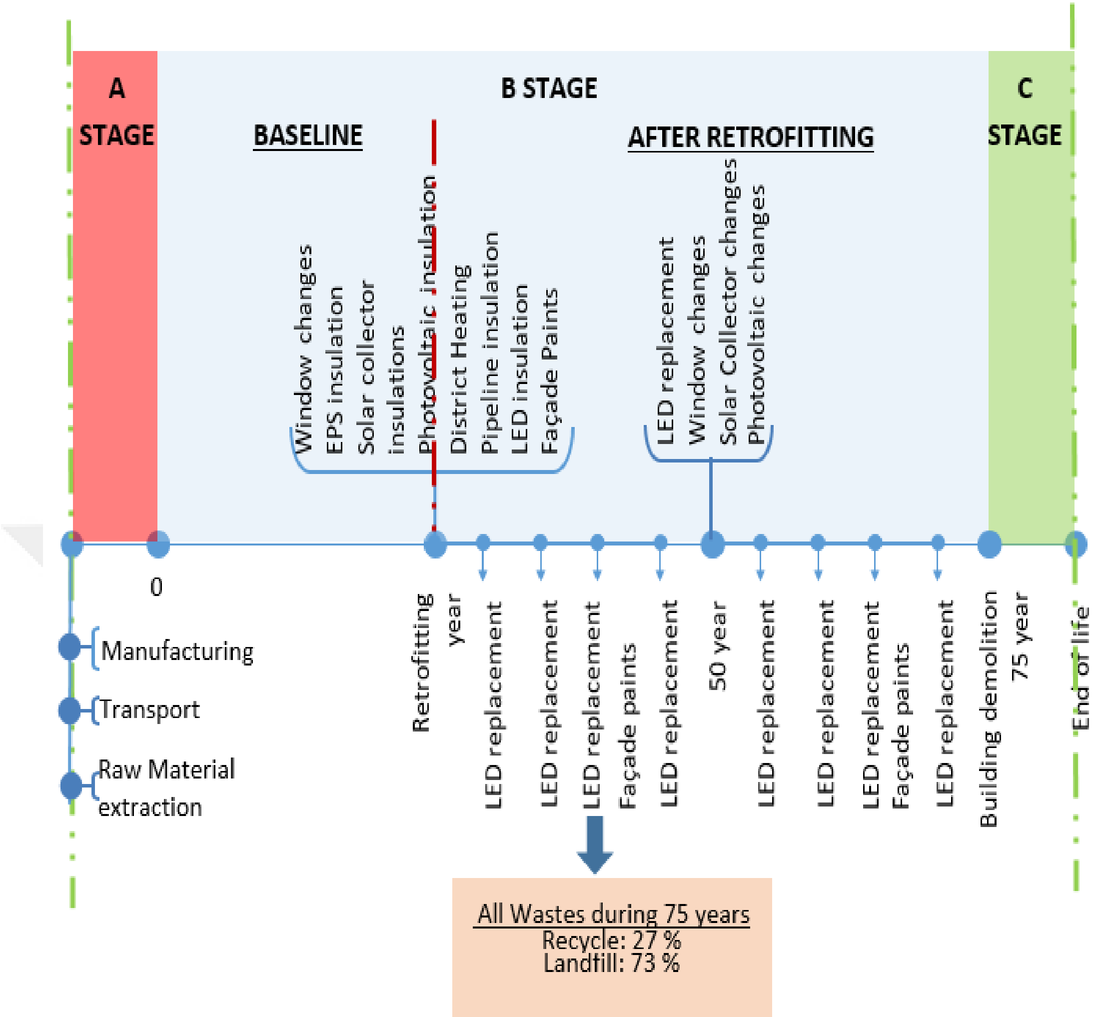


Figure 4.5 : Life cycle of building during 75 years.

Table 4.2 : Summary information about the building.

Envelope	Area [m^2]
Facade (windows and doors excluded)	241
Window	34
Door	17
Roof (pitched roof)	291

Plan of one story building is shown at Figure 4.6. As it shown from figure, there is 2 separate residential place for each block. They are separated from entrance. After entrance, the building are divided into two blocks. Blocks are symmetrical each others.Each block has one salon and two bedrooms. In addition to those, there are also kitchen and bathroom. Hence, there are two salons, 4 bedrooms, 2 kitchens and 2 bathrooms in the building.

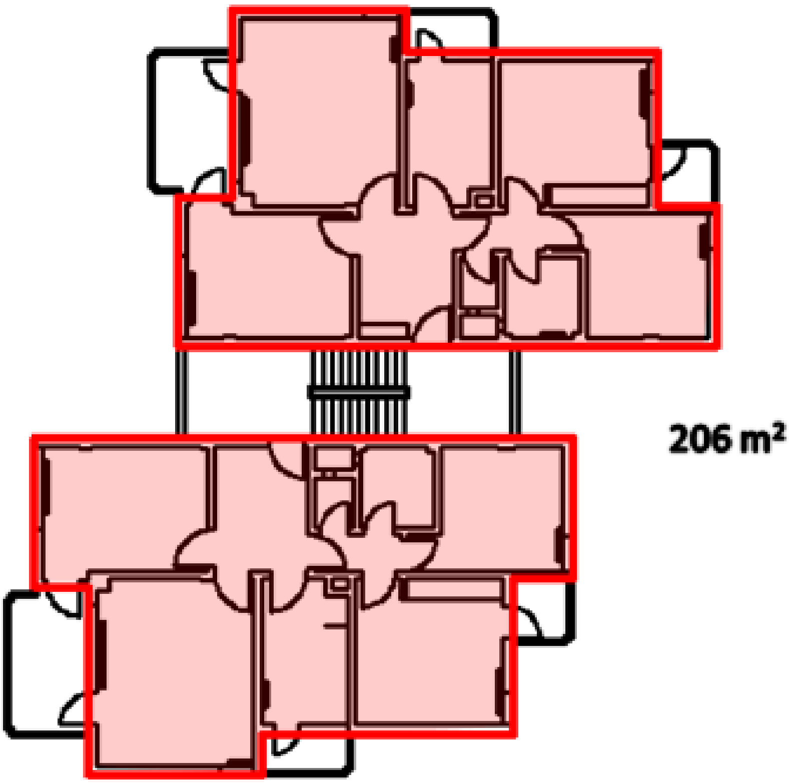
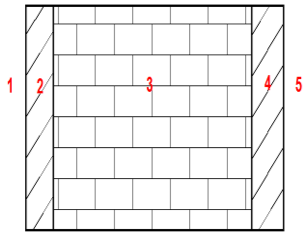
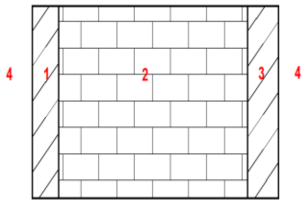
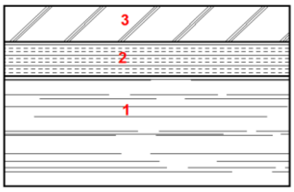
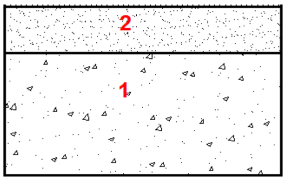
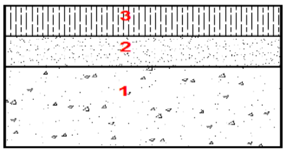
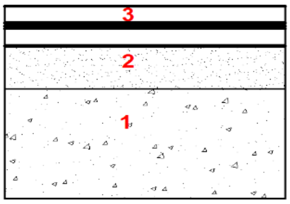


Figure 4.6 : Plan of one-storey building.

4.1 Building Envelope Characterization

Building envelope has critical effects on energy consumption. Because of that, envelope was examined carefully. Building envelope and its thermal characteristic are listed at Table 4.3. These data are for current situation (It is means that they are not include retrofitting); besides, all of them are same for each one-story building. Before retrofitting, external wall did not have any insulation materials. There are only main part of wall (brick), plaster and paint for the walls. Roof was designed as pitched roof, and it has waterproofing membrane between tile and main structure of roof. The main structure of roof was selected as wooden material; besides, its finish material is roofing-tile. In addition internal floors only have concrete, brick, cement finish and tile finish. Floor of the building were designed as concrete, cement finish and tile finish. Lastly, windows were designed as single glazing type; besides, their frame were made by wooden. Before retrofitting, the buildings gotten exhausted because of non-repair or non-maintenance as it seen from their envelope pictures. Also, u-value of envelopes were given in Table 4.3.

Table 4.3 : Building envelope and its thermal characteristic.

Envelope	Detail	Image
External wall	1. Internal paint 2. Internal plaster (2 cm) 3. Brick wall (25 cm) 4. External plaster (2 cm) 5. External paint U-value = 1.786 W/m²K	
Internal wall	1. Internal plaster (2 cm) 2. Brick wall (15 cm) 3. External plaster (25 cm) 4. Paint (2 cm) U-value = 0.45 W/m²K	
Roof	1. Pitched roof 2. Membrane (Waterproofing-3mm) 3. Tile U-value = 0.732 W/m²K	
Ground floor	1. Concrete 2. Cement finish U-value = 2.839 W/m²K	
Internal floor (Type 1)	1. Concrete 2. Cement finish 3. Tile finish U-value = 1.83 W/m²K	
Internal floor (Type 2)	1. Concrete 2. Cement finish 3. PVC finish U-value = 1.83 W/m²K	
Window	Single glazed U-value = 2.34 W/m²K	

4.2 Selected Strategies for Renovation

Renovation process has 2 different strategies. One of them is active strategies, and the other is passive strategies. Both strategies were used for the case study building.

Walls have,

- Brick wall
- Adhesives
- Thermal insulations (EPS foam)
- Mechanical fixing
- Reinforced layer: with glass fibre mesh
- Primer coat
- Finishing coat

after renovation. Its figure shown at Figure 4.7.

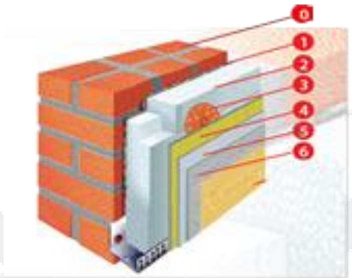


Figure 4.7 : Section view of the insulation system.

Envelope insulation is 5 cm of EPS (expanded polystyrene); also, double glazed windows is used. U-values changed with these strategies; therefore energy consumption change according to that. New u-values after renovation were shown at Table 4.4.

Table 4.4 : U-values after renovation.

Existing Condition	Exterior wall	Windows	Roof	Ground Floor	Interior wall
U Value [W/m^{2}K]	0.42	1.2	0.2	0.5	0.4

4.3 Energy Performance Analysis

Building energy analysis is made for current situation and after renovation situation. A software is called "*Equest*" was used for calculation models [42]. All u-values are defined based on building envelope as it seen at Table 4.5.

Table 4.5 : Current situation u-values.

Existing Condition	Exterior wall	Windows	Roof	Ground Floor	Interior wall
U Value [W/m^{2}K]	1.786	2.34	0.732	2.839	0.453

The building is a residential, and it is being use for 7 days a week and 24 hours a day. It is one-story house. Useful are is 217.72 m^2, and height is 2.7 m. Conditioned are is equal %94.6 of total useful area. People who live inside of the building use lignite for heating. According to these data, electric consumption and lignite consumption is calculated by the software annually. Electricity consumption can be seen in Table 4.6 and lignite consumption can be seen in Table 4.7.

Table 4.6 : Monthly electricity consumption for the building.

kWh	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pumps&Au	115	104	115	112	115	112	115	115	112	115	112	115	1,358
Misc.Equip.	311	279	305	300	308	297	311	305	300	311	295	311	3,632
Area Lights	338	304	335	327	337	325	338	335	327	338	324	338	3,966
Total	764	687	756	738	760	734	764	756	738	764	730	764	8,956

Table 4.7 : Monthly lignite consumption for the building.

kWh	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Spa. H.	6,418	5,026	4,141	2,397	1,079	144	0	0	32	481	2,629	4,589	26,939
Hot W.	290	275	305	290	270	234	217	202	193	214	229	264	2,983
Total	6,708	5,302	4,446	2,687	1,347	378	217	202	226	695	2,857	4,856	29,923

The software also gives range of consumption based on purpose of use as a graph. These graphs are shown at Figure 4.8. Electricity consumption causes from area lighting and equipment that use electricity mostly; also, lignite was used for heating and water heating. Nonetheless, when the water heating consumption is compared with space heating, its consumption was really lower than space heating.

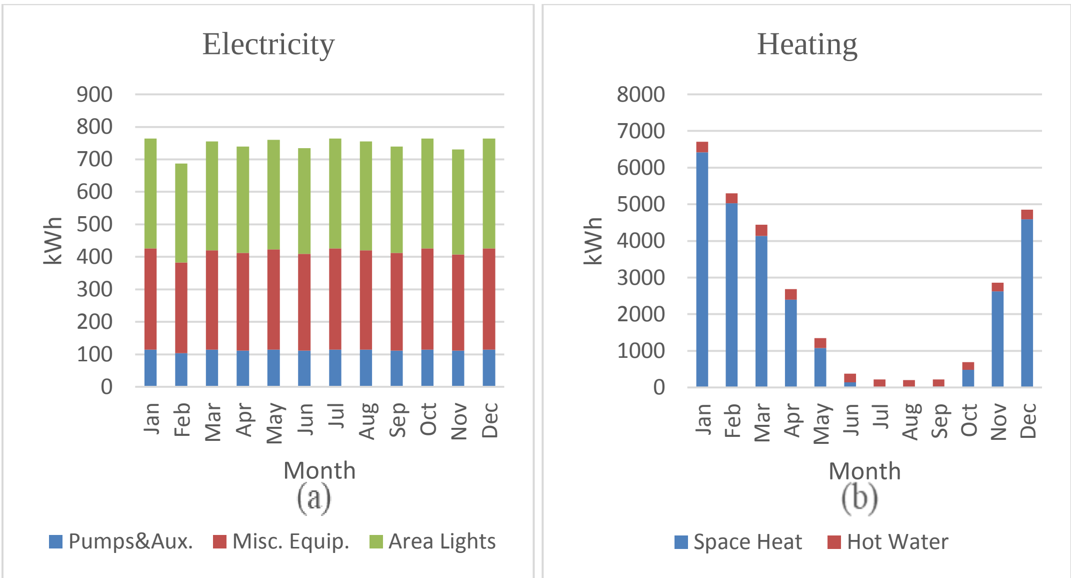


Figure 4.8 : Consumption profile of electricity(a) and lignite(b).

After applied intervention were implemented, energy model of the building was developed for retrofitted version. Electricity and heating consumption were given in Table 4.8 and 4.9 monthly and annually.

Table 4.8 : Monthly electricity consumption after renovation for the building.

kWh	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pumps&Au.	115	104	115	11	115	11	115	115	111	115	111	115	1,352
Misc.Equip.	231	207	226	223	229	221	231	226	223	231	218	231	2,698
Area Lights	121	109	120	117	120	116	121	120	117	121	116	121	1,415
Total	467	419	461	451	464	448	467	461	451	467	445	467	5,465

Operational energy during building life time was also included to the LCA model. Operational energy includes electricity and heating consumption. This consumption was taken from buildings energy performance models that were developed on eQuest software [42]. Nonetheless, the building used lignite as a heating source from beginning to retrofitting. After that, it started to use waste heat from the closest thermal power plant to heat energy; besides, this situation was taken into account in the LCA model. All operational consumption can be seen in Table 4.10.

Table 4.9 : Monthly heating consumption after renovation for the building.

kWh	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Spa. H.	1,615	1,102	659	158	47	0	0	0	0	26	495	1,037	5,140
Hot W.	290	275	305	290	270	234	217	202	193	214	229	264	2,983
Total	1,905	1,377	964	448	317	234	217	202	193	240	724	1,301	8,124

Table 4.10 : Operational energy consumption at baseline and retrofitted step.

Energy Consumption	Baseline Step – Energy Consumption during 25 years (kWh)	Retrofitted Step – Energy Consumption during 50 years (kWh)
Electricity	223,900	273,250
Heating	748,075	406,200

4.4 Materials

The weight of building structure materials were obtained from BIM of the building. The image of the BIM of the building can be seen in Figure 4.9. BIM of the building was developed by Revit software [46]. When the building structure materials were taken in account, only basis materials were added to the LCA model.

Basis material can be listed as: cement, ceramic tile, concrete, wood, glazing, masonry-brick, interior/exterior paint, plastic, plaster, roofing tile, wool and metal. Interior design materials such as sink, cupboard etc. did not included to the study. All structure materials were entered to the BIM of the building layer by layer; besides, their weight were gotten from the model. According to calculation, structure material type and their weight can be seen Table 4.11 and Figure 4.10. The total weight of the structure materials is 542 ton. All of them were calculated and added to the model. Transportation of the used structure materials to site area also was included tot the model with an assumption. There is a city is called İzmir that is 130 km away from the building; besides, an assumption was made that all structure materials were transferred from İzmir to the case study area. Hence, the transportation distance was defined as 130 km.

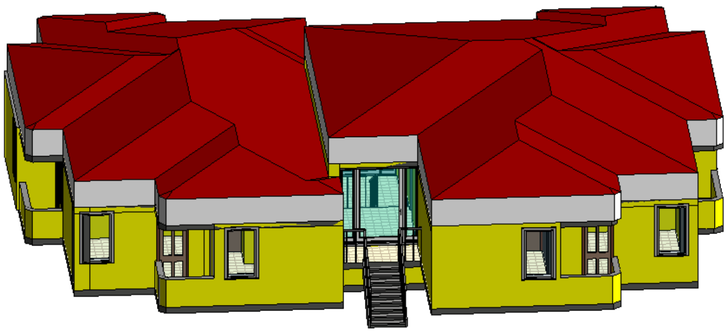


Figure 4.9 : BIM of the case study building.

Table 4.11 : The weight of basis structure materials that were used in the building.

Material Type	Weight (Ton)
Cement	33
Ceramic Tile	14
Concrete	246
Door-wood Frame	0.02
Glass	1
Masonry-brick	180
Paint	0.5
Plastic	2
Roof-wood	13
Plaster	32
Roofing Tile	18
Wood Frame Window	2
Wool	0.1
Metal	1
Entrance Door Glass	0.1

The total weight of the structure materials is 542 ton. The amount of brick is 246 ton, and the amount of brick is 180 ton. Thus, 79% of total amount comes from the concrete and brick. If the main structure materials of the building were taken in account, this results can be called as normal and expected. The lightest materials are paint, entrance door glass, wool and door frame. Also, the amount of recyclable materials (glass, metal and plastic is 4 ton.

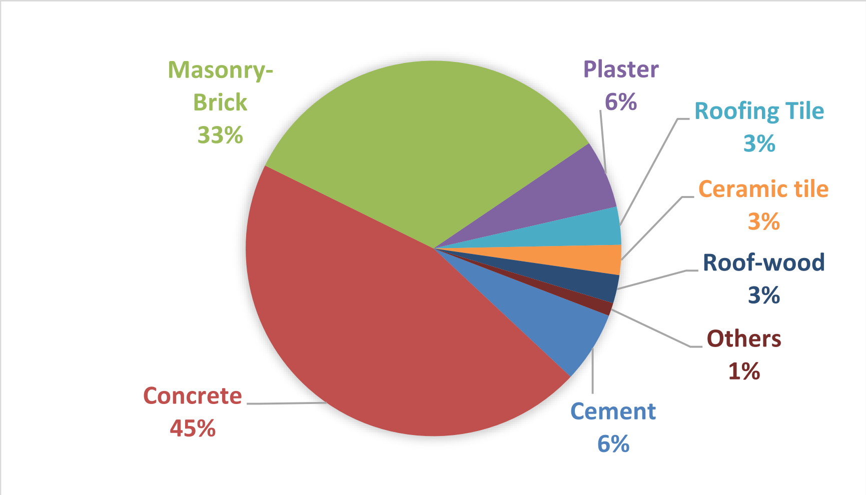


Figure 4.10 : The weight of basis materials that were used in the building.

The building was retrofitted to improve its energy performance in 2015. Some interventions were applied to the building in case study area based on retrofitting activities. These interventions' impacts were also analyzed via LCA methodology. Applied interventions were listed as:

- Glass and frame changing
- Insulation (EPS and mineral wool) application
- Solar collectors and tanks application
- Radiant heating (District heating) application
- LED application
- District heating system

The weight of the applied materials were calculated likewise baseline step. BIM of the buildings also were used in after retrofitting step for same purpose. In addition to the first application, some materials have to be replaced or maintained during building life time based on their life time. Replacement/maintenance time can be seen in Table 4.12 for the material type. Life time of materials were obtained from literature or their catalogue information. The weight of the materials that were used in retrofitted activities can be seen in Table 4.12, and their percentage based on weight can be seen in Figure 4.11.

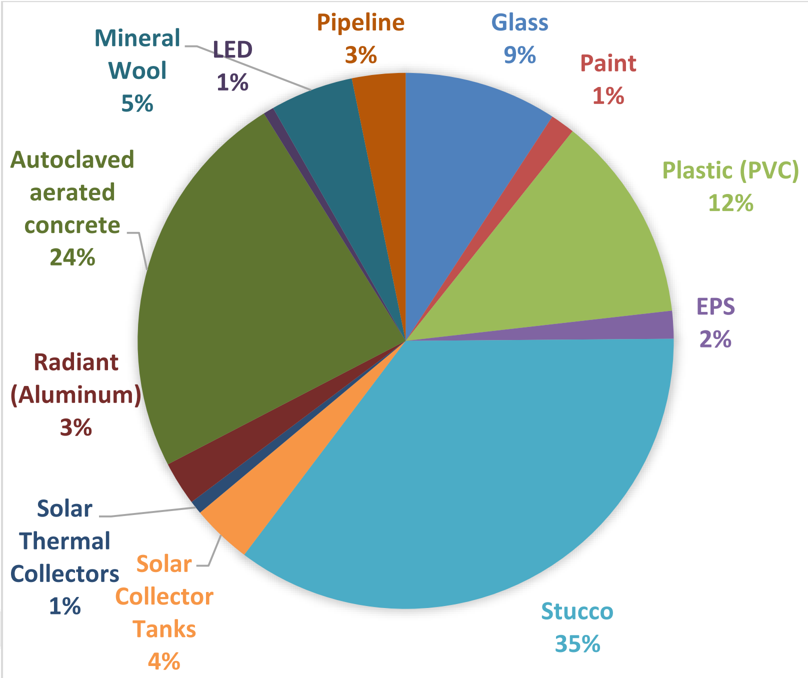


Figure 4.11 : Material percentage based on weight.

Table 4.12 : The weight of the materials that were used in retrofitting activities.

Materials	Replacement/ Maintenance	Weight (kg)
Glass	2 times	2,284
Paint	3 times	369
Plastic (PVC)	2 times	3,097
EPS	-	415
Stucco	-	8,778
Solar Collector Tanks	2 times	900
Solar Thermal Collectors	2 times	200
Radiant Heating System	-	657
Aerated Concrete	-	5,885
LED	11 times	158
Mineral Wool	-	1,242
Pipeline	-	799
Total		24,784

4.5 End of Life

All materials will be wastes after their life time; therefore, their waste management scenarios was defined in the LCA model. Waste type of the materials were categorized according to recyclable and construction and demolition. The closet recycling facility is 66 km away, construction and demolition area is 5,5 km away. Based on the Turkey condition, recyclable materials (Glass, metal and plastic) can be recycled 25%; besides 75% of them are send to landfill area. Also, demolition waste recycle rate is 25%, and the other part is send to landfill area [47]. Thus, waste management scenario was set based on these rate. Also, energy consumption during demolition was added to the model based on literature. Kuikka [48] calculated demolition energy demand for a school with some assumption in Sweden. For instance, one-storey diesel demand was calculated as 1,139.6 kg = 54,700.8 MJ according to these assumption.

5. RESULTS AND DISCUSSION

Two scenarios were defined to investigate the district as baseline and retrofitted. In baseline scenario, the building was investigated during 75 years as in baseline condition. In retrofitted scenario, the building was evaluated during 25 years as in baseline condition. After that, the major retrofitted strategies were applied to the building to improve its energy efficiency. After that time, the building continues its life time as in retrofitted conditions. Hence, retrofitted scenario was examined into two parts. The results were obtained from developed LCA models for both scenario based on defined indicators. Also materials that were used in the building were investigated separately.

5.1 Baseline Scenario Results

The building was built in end of 1980s; therefore, it is defined that use phase of the building has started in 1990. Life time of the building was defined as 75 years. Thus, the building was examined during 75 years from 1990 to 1965 in baseline scenario via LCA methodology. After building has built, only necessary maintenances and replacements were taken in account in the thesis. Chancing glazing, light etc. can be given an example for these activities. Demolition wastes and wastes that were generated during 75 years were added to the end of life scenario of the building. Based on defined indicators, results were obtained.

5.1.1 CED results of the baseline scenario

Soma District has not natural gas grid; besides, the region is a lignite mine zone. Thus, the buildings in the district use lignite for heating. Also, the building is heated by central heating system that uses lignite as source. In baseline scenario, it was assumed that this situation will not change in the future; besides, assessment was made based on this assumption. In addition, defined electricity grid system for Turkey in Ecoinvent database was selected as electricity source. All materials and waste scenario were added to the model.

CED results were calculated by the developed model. Thus, primary energy consumption of the building was obtained from raw materials to disposal. The results are given in Table 5.1; also, their distribution based on percentage are seen in Figure 5.1. Based on Table 5.1, products stage line represents all materials that were used in the building from raw materials extraction to manufacturing phase. This stage contains both materials that are used in beginning such as concrete, metals and their transportation and construction steps. Thus, it shows A1, A2, A3, A4 and A5 steps based on EN 15978 standard. Use stage contains both electricity and heating consumption, and it is represented as B6 steps in EN 15978. Additionally, it contains materials that are related with maintenance and replacement activities such as glazing, lighting etc. Finally, end of life contains demolition, transport, waste processing and disposal steps, and these are called as C1, C2, C3 and C4 steps in EN 15978.

Table 5.1 : CED results of baseline scenario during 75 years.

Stage	Consumption (MJ)
Product Stage	1,177,091
Use Stage	22,400,000
End of Life Stage	141,681

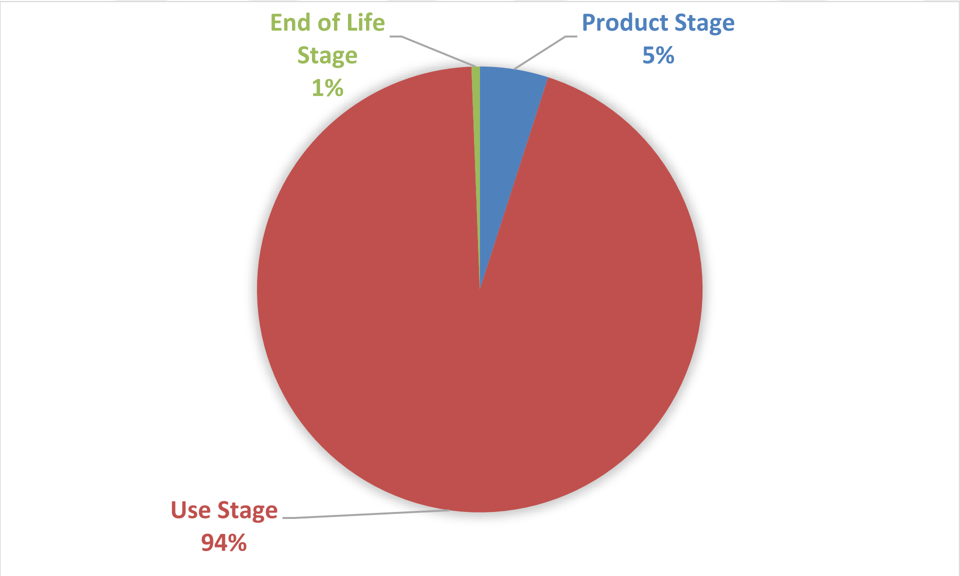


Figure 5.1 : CED result distribution based on percentage.

Based on the Figure 5.1 share of operational energy consumption on CED is higher than some literature data. Utama and Gheewala investigated a high rise residential building in Indonesia, besides, their results showed that contribution from operational energy consumption is around 71-81% in overall energy consumption [49]. Also, Scheur et al. [50] examined a university building via life cycle assessment methodology; moreover, end of life stage of the building was only 0.2% of total primary energy. Thus, share of end of life shows similarity with literature, and product phase is lower relatively some published studies. Share of operational energy consumption increases as time as building life time lengthen out. Turkish electricity grid supplies electricity from non-renewable sources such as coal, natural gas mostly. This situation increases primary energy demand of 1 MJ final energy. Therefore, 94% can be called as expected result.

In Table 5.1, CED results were given as raw data; nonetheless, CED results of baseline scenario are given with m^2.75years and m^2.year in Table 5.2 to show the results based on square mater and annual.

Table 5.2 : CED results of baseline with m^2.75years and m^2.year units.

Stage	CED (MJ/m^2.75years)	CED (MJ/m^2.year)
Product Stage	5,714	76
Use Stage	108,738	1,450
End of Life Stage	688	9

In addition overall impact of the building on energy consumption and environment during 75 years, impact of material types also were investigated individually. Results are obtained based on production of materials, transportation between factories to the site area and end of life steps as in seen Table 5.3. End of life stage was divided as waste transportation to the related facilities, recycling processes and sanitary landfill steps. Main structure of the investigated building consisted of brick and concrete. Hence, the mass of these two materials is 78% of total mass of all materials. The results also shows that the most effected materials on primary energy consumption are brick and concrete. After brick and concrete, plastic has also significant impact on energy consumption. Both material transportation and waste transportation relates only amount of transported material and road. Due to that, brick and concrete also have high impact on transportation. Moreover, CED of transported recyclable materials is higher than materials that are handled in the landfill facility due to length of the road. Also, glass, metal and plastic materials have positive effect on energy consumption. Turning into raw materials again “it means recycling processes of them” decrease their overall energy consumption. Although energy consumption of production processes of them is still more than regained energy from recycling, they were not send to the sanitary landfill area at least. Besides, demolition wastes also recycle in related facilities, overall regain energy is still in consumption side. Even so, obtaining raw materials from recycling consume less energy than obtaining raw materials from nature.

Table 5.3 : CED results of materials in baseline scenario.

Material Type	Product Phase (MJ)	Transportation (MJ)	Waste Transport (MJ)	Recycle (MJ)	Landfill (MJ)
Brick	597,000	42,300	3,120	2,720	62,700
Cement	31,100	6,650	490	428	9,860
Concrete	232,000	49,000	3,610	5,380	72,700
Glass	16,500	252	223	-5,880	145
Metal	24,800	216	191	-4,360	125
Others	21,800	3,050	225	0	5,970
Plaster	29,800	6,380	740	446	9,450
Plastic	114,000	309	273	-27,100	458
Wool	1,910	24	2	0	35

Harding et al.[51] showed that plastic production from petroleum needs high amount energy. When overall impact of materials taken in account. After brick and concrete, plastic has the highest consumption because of the production processes. The impact of materials are differ from each other based on used amount or production and disposal steps. Although, the amount of plastic, metal and glass are close each other, CED of plastic is higher than the others as it seen in Figure 5.2. Besides, the most negatively effective materials on primary energy consumption as mentioned previously are listed respectively as: Brick, concrete, plastic, cement, plaster, others, metal, glass and wool. Their impact percentage is given in Figure 5.3.

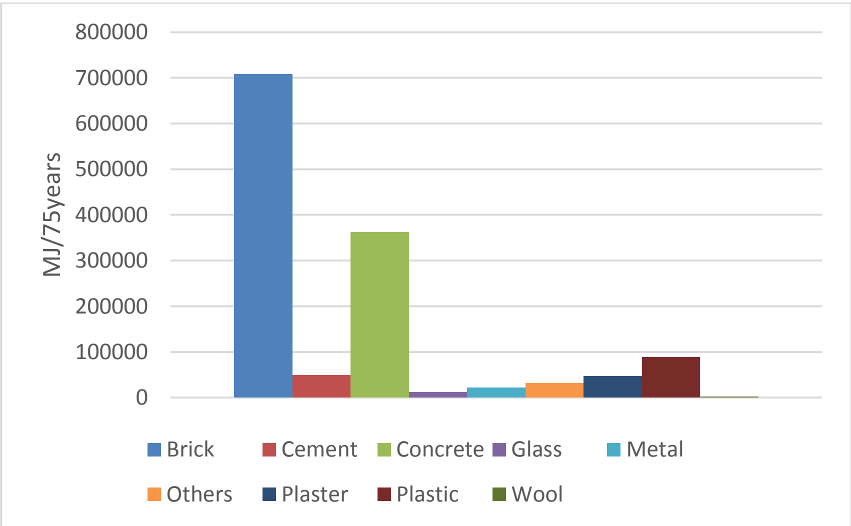


Figure 5.2 : CED results of materials in baseline scenario.

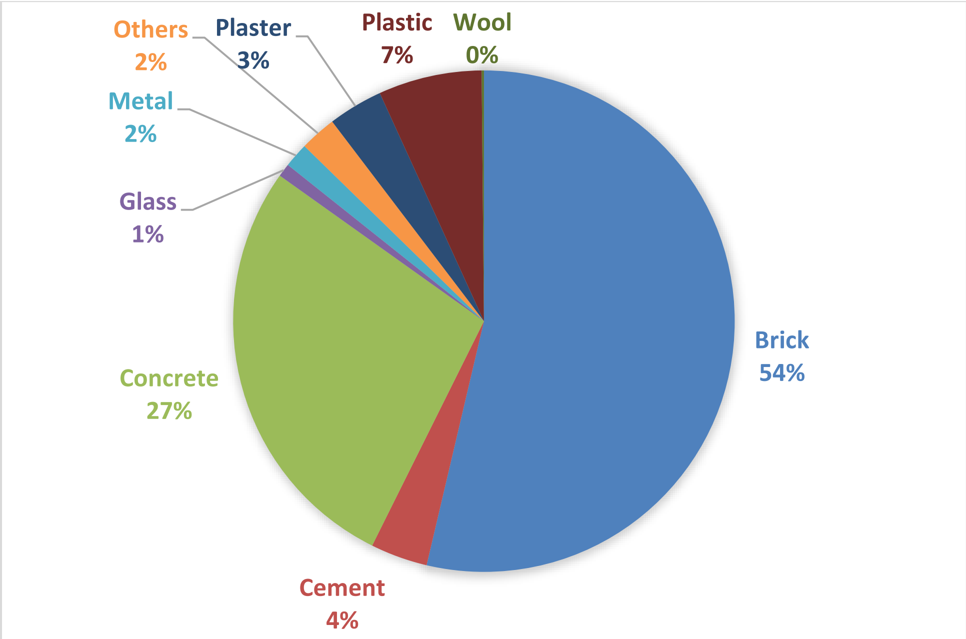


Figure 5.3 : CED result of material based on impact percentage.

5.1.2 GWP results of the baseline scenario

Global warming potential (GWP) is an indicator for released greenhouse gases. There are various gases that cause greenhouse impact; however, carbon dioxide (CO_2) is the most common one. Whereas there are another gases such as methane (CH_4) that has more greenhouse impact on environment, GWP results were given in CO_2 equivalent. In other word, impact of other gases were recalculated by multiplying with conversion constant. There is a thermal power plant that uses lignite as source in the region; besides, the inhabitants take advantage from lignite for heating in the residences. Hence, the amount of emitted greenhouse gases is critical in the district. Local authorities have to be taken in account the amount of carbon emission; furthermore, they have to manage to decrease it in district level with new policies and project. Because, obtaining heat energy from lignite, it is means that burning lignite, causes significant carbon emission. 1 MJ energy from lignite released 0.171 $kgCO_2eq$ greenhouse gases to the environment [52].

Like in CED results of baseline scenario, GWP results have obtained for 75 years firstly. 75 years were divided different periods as: Product, use and end of life stage as it seen Table 5.4. These different periods represents same EN 15978 steps in CED results section. Consequently, GWP of baseline scenario was examined from cradle-to-grave for the building.

Table 5.4 : GWP results of baseline scenario during 75 years.

Stage	Emission ($kgCO_2eq.$)
Product Stage	110,008
Use Stage	1,850,000
End of Life Stage	256,042

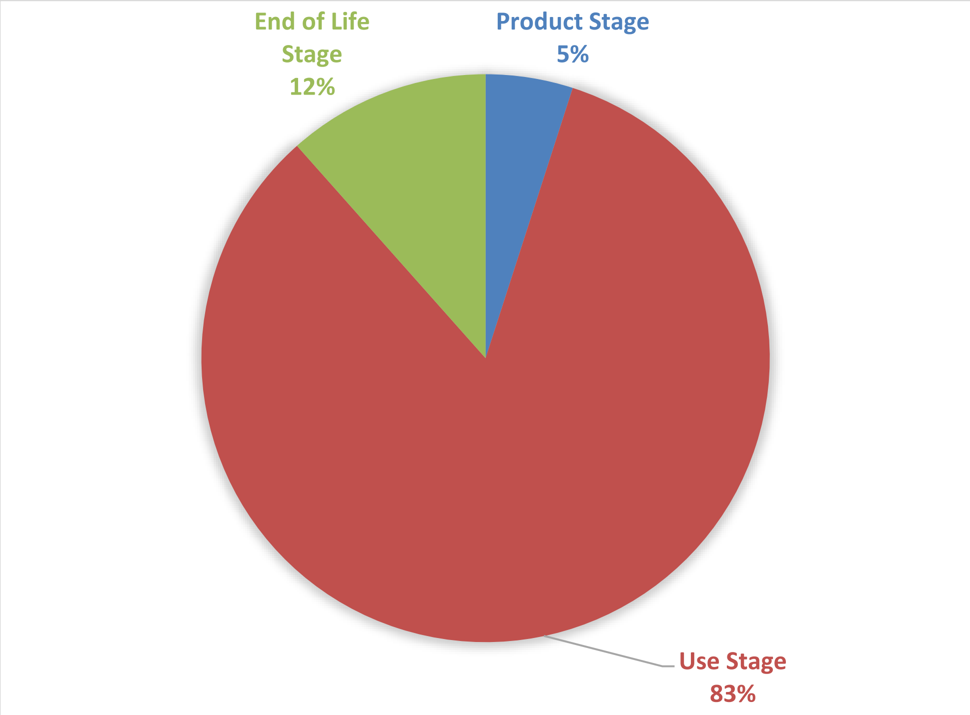


Figure 5.4 : GWP result distribution based on percentage.

Exact results were given in Table 5.4; also, their impacts were compared with each other in Figure 5.4 percentile. The highest emission came from use stage and operational energy consumption due to using lignite and electricity sources in Turkey. Atilgan and Azapagic [53] proved that with their calculation. Electricity production from fossil sources releases 109,000,000,000 $kgCO_2eq.$ greenhouse gases to the atmosphere in every year; besides, this is a huge amount. While product phase result is higher than end of life result in CED, this comparison is different in GWP results. Landfill processes can be showed the reason for this situation. Although production of materials create huge carbon dioxide emission, landfill activities for wastes cause more pollution for environment. Thus, impact the GWP of end of life stage is higher than product phase as it seen Figure 5.4.

In addition to the above results, GWP results were given in square meter unit for 75 years and one year to show the results based on square meter and annual in Table 5.5.

Table 5.5 : GWP results of baseline with m^2.75years and m^2.year units.

Stage	GWP ($kgCO_2eq. /m^2.75years$)	GWP ($kgCO_2eq. /m^2.year$)
Product Stage	534	7
Use Stage	8,981	120
End of Life Stage	1,243	17

GWP results based on materials types were also obtained and showed in Table 5.6. The materials life time was divided 5 different steps as production, transportation from factories that they are produced to the building site area, transportation after they become waste, recycling processes and sanitary landfill. The last 3 stage can also be compound as end of life stage. According to results, the most negatively effective process is landfill activities of concrete; besides, landfill activities of brick also released serious carbon dioxide emission. Based on the used amount in the building, production results of brick and concrete is higher than other materials. Also, some materials such as plastic released more greenhouse gases while their production time due to their raw materials and manufacturing processes. Transportation for materials and waste transportation caused less emission than the other steps. Only transportation of brick and concrete materials caused high global warming; besides, the reason for that is that their amount is weightier than the other materials. Also, recycling processes had positive effect on decreasing GWP on recyclable materials (Glass, metal and plastic).

Table 5.6 : GWP results of materials in baseline scenario.

Material Type	Product Phase ($kgCO_2eq$)	Transportation ($kgCO_2eq$)	Waste Transport ($kgCO_2eq$)	Recycle ($kgCO_2eq$)	Landfill ($kgCO_2eq$)
Brick	55,800	2,390	192	176	99,700
Cement	5,190	376	30	28	15,700
Concrete	27,400	2,770	223	349	116,000
Glass	1,260	14	14	-410	4
Metal	2,620	12	12	-462	4
Others	1,120	172	14	0	9,320
Plaster	4,980	360	29	28	15,000
Plastic	5,390	18	17	-709	728
Wool	135	1	0.1	0	56

When overall GWP impact of the materials were compared with each other, brick released the highest emission; also, emission of concrete is really high and close to the brick's like it is seen in Figure 5.5 and 5.6. After these, the other can be listed as:

cement, plaster, others, plastic, metal, glass and wool. The only difference between CED and GWP results based on materials is related with cement and plastic. While CED of plastic is higher than CED of cement, GWP of plastic is lower than GWP of cement. Furthermore, 89% of GWP of materials came from brick, concrete and cement, and, the other material released only 11% of greenhouse gases.

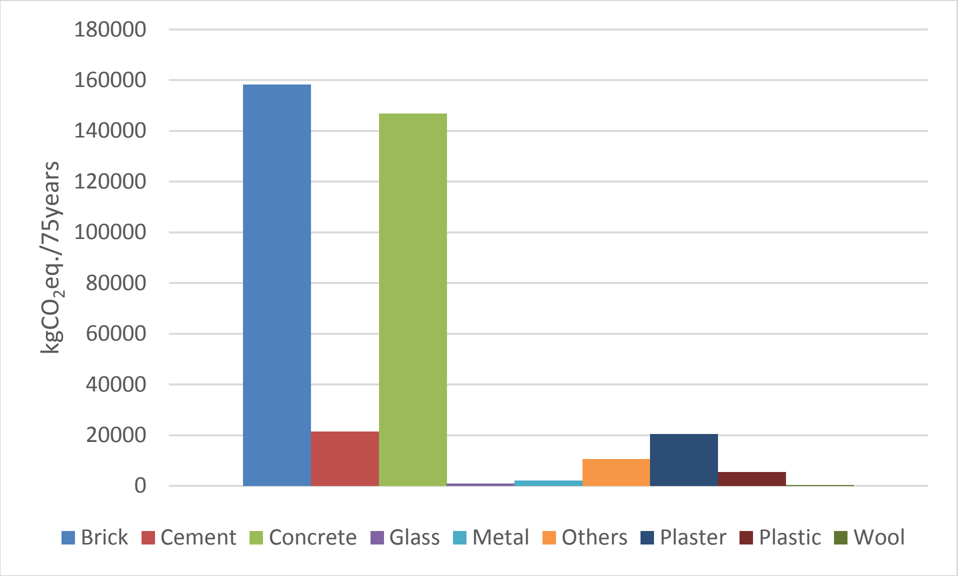


Figure 5.5 : GWP results of materials in baseline scenario.

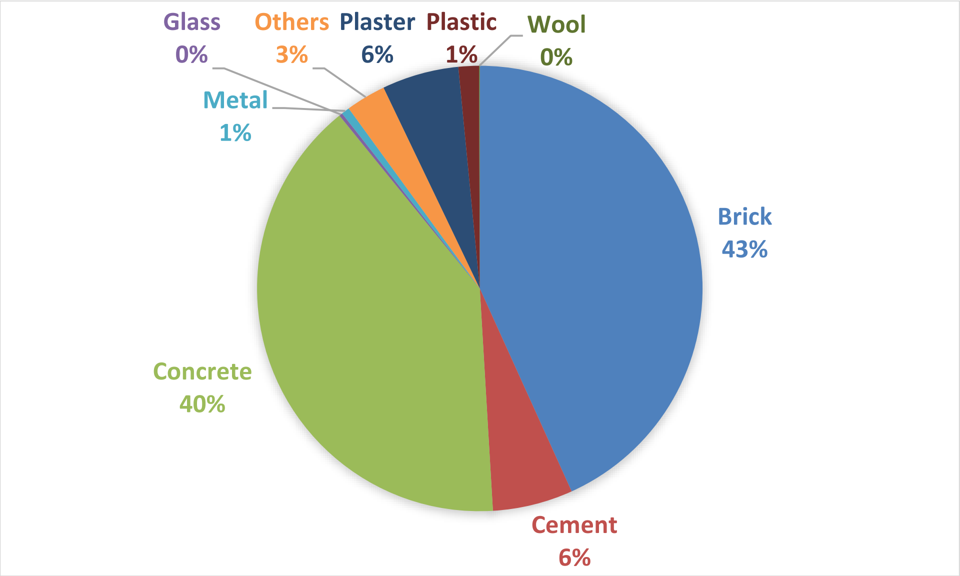


Figure 5.6 : GWP result of material based on impact percentage.

5.2 Retrofitted Scenario Results

The building life time was divided two part in retrofitted scenario. As it mentioned before, the building was built in end of 1980s; besides, it had been continuing its life during 25 year as built. It was retrofitted to improve energy performance and decrease carbon dioxide emission from the building in 2015. After this moment, the building will continue its life till 2065. It means that its life time extended 50 year more after retrofitted activities were applied. In retrofitted scenario, all these circumstances were taken in account; also, LCA model of this scenario was developed based on defined scenario. Thus, first 25 years is same with baseline scenario, and last 50 years were performed as retrofitted in the model.

5.2.1 CED results of the retrofitted scenario

CED results of 75 years were given in Table 5.7 based on stages; in addition, their distribution was given in Figure 5.7 based on percentage.

Table 5.7 : CED results of retrofitted scenario during 75 years.

Stage	Consumption (MJ)
Product Stage	2,420,026
Use Stage	11,560,000
End of Life Stage	56,960

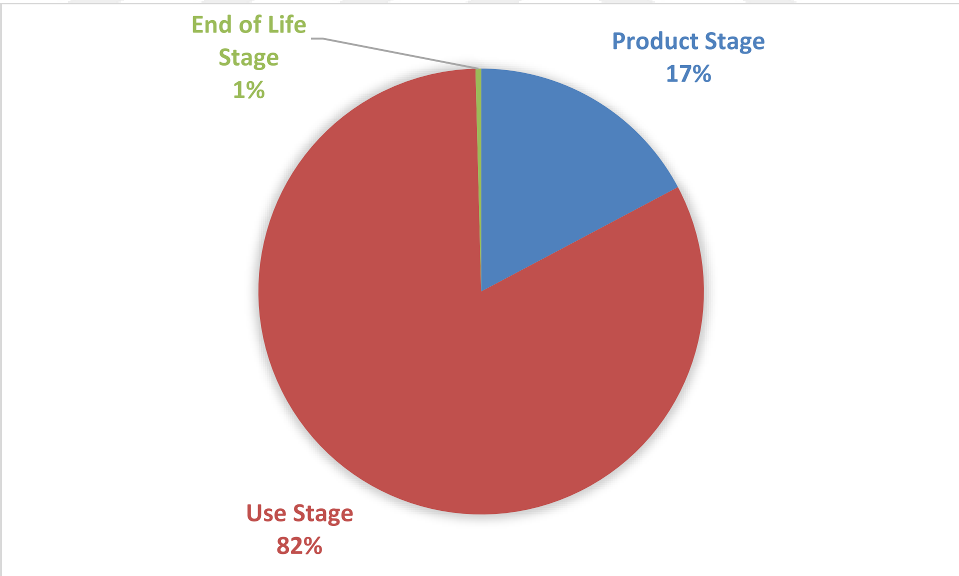


Figure 5.7 : CED result distribution based on percentage.

As it seen in Figure 5.7, operational energy consumption caused the major energy consumption during 75 years. Consumption in product stage has 17% impact on overall consumption. Moreover, end of life stage is comparatively low than use and product stage. While impact of product phase increased, operational energy impact decreased compared with CED results of baseline scenario. There are three reasons for that. The first reason is chancing heating energy source in retrofitted scenario. The building site area started to use waste heat from the thermal power plant in spite of lignite. Although 0.813 MJ primary energy is required to produce 1 MJ final energy from waste heat, 1.93 MJ primary energy is required to produce 1 MJ final energy from coal [52]. The second reason is improved energy performance of the building. Energy model of the building showed that energy consumption of the building decreased around 65% by helps of retrofitting activities. Third reason is energy-intense materials that were used in retrofitting activities. Some materials such as LED, solar collector etc. are high-tech products; therefore, manufacturing of them needed more energy consumption. When all these reasons were taken in account, the difference on percentage distribution can be called as expected results. In addition, CED results were given in m^2.75years and m^2.years unit in Table 58. As expected, use stage was lower than baseline scenario, and product stage is higher than baseline results.

Table 5.8 : CED results of retrofitted with m^2.75years and m^2.year units.

Stage	CED (MJ/m^2.75years)	CED (MJ/m^2.year)
Product Stage	11,748	157
Use Stage	56,117	748
End of Life Stage	275	4

Overall CED results of retrofitted scenario were obtained and showed above. In addition to that, all materials that used in the building also were analyzed individually. The results were represented in Table 5.9; besides, their consumptions were divided based on product phase, transport, waste transport, recycling and landfill. Brick has major impact as baseline scenario due to their amount. Nevertheless, the second highest negatively effective materials is not concrete, it is LED. LED is high-tech lighting system. Because of that, production of it causes significant energy consumption. After LED, concrete had also important impact on energy consumption. All of the other materials that were used in retrofitting also consumed energy different from each other. These differences resulted from technology level and raw materials of materials. Also materials that have recyclable part cause regained energy from recycling processes. These materials can be listed as: EPS, glass, LED, pipe, plastic, solar tank, solar collector, and metal. Regained energy subsidized some part of primary energy that used in the building. But, this subsidizing has not so much impact when the overall CED was considered.

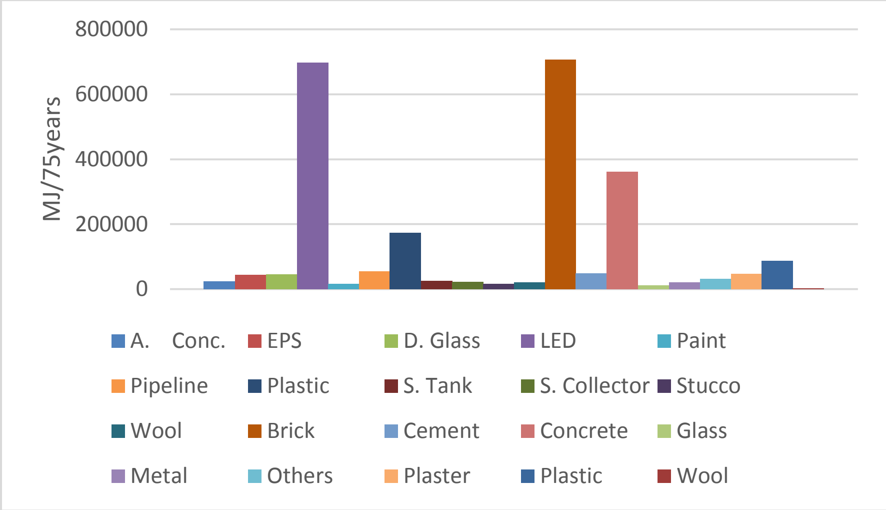


Figure 5.8 : CED results of materials in retrofitted scenario.

Table 5.9 : CED results of materials in retrofitted scenario.

Material Type	Product Phase (MJ)	Transportation (MJ)	Waste Transport (MJ)	Recycle (MJ)	Landfill (MJ)
A. Conc.	20,100	1,170	87	129	1,740
EPS	50,600	83	73	-7,280	123
D. Glass	54,600	455	403	-10,600	675
LED	698,000	32	28	-738	67
Paint	16,400	73	5	0	104
Pipeline	55,200	159	141	-1,400	236
Plastic	225,000	617	546	-54,300	916
S. Tank	28,200	179	159	-3,620	103
S. Collector	23,000	40	35	-805	23
Stucco	11,100	1,750	129	113	2,600
Wool	20,100	247	18	0	367
Brick	597,000	42,300	3,120	2,720	62,700
Cement	31,100	6,650	490	428	9,860
Concrete	232,000	49,000	3,610	5,380	72,700
S. Glass	16,500	252	223	-5,880	145
Metal	24,800	216	191	-4,360	125
Others	21,800	3,050	225	0	5,970
Plaster	29,800	6,380	740	446	9,450
Plastic	114,000	309	273	-27,100	458
Wool at B.	1,910	24	2	0	35

In Figure 5.8, CED results of all materials are seen and compared. As it mentioned before, brick, LED and concrete were reason the majority of energy consumption the others consumed energy based on technological level and their amount. Even so, there was not a material that regain energy with on overall. All of them caused a consumption more or less.

5.2.2 GWP results of the retrofitted scenario

GWP results of retrofitted scenario were obtained from the model during 75 years; also, the results were represented based on stages as CED results. The exact results were given in Table 5.10, and their distribution based on percentage were showed in Figure 5.9. The major effective stage is use with 66%. End of life stage also affected the environment with 266,188 kgCO_2eq. during 75 years; besides, its percentage was 20% on overall impact. Production phase was close to end of life with 14%.

Table 5.10 : GWP results of retrofitted scenario during 75 years.

Stage	Emission (kgCO_2eq.)
Product Phase	188,779
Operational Energy	871,000
End of Life	266,188

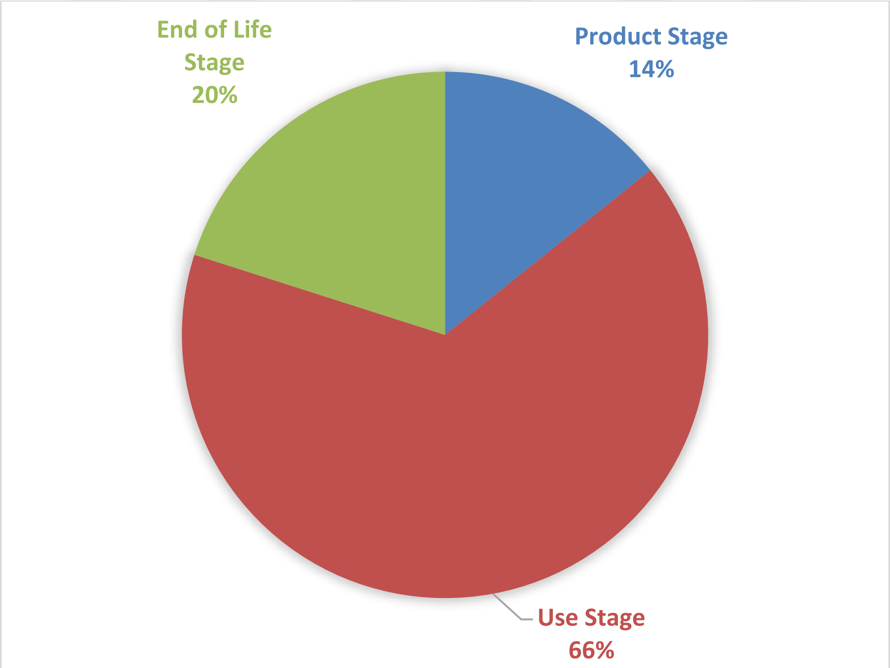


Figure 5.9 : GWP result distribution based on percentage.

The reason for differences between operational energy of baseline scenario and retrofitted scenario impact is chancing heating resource from lignite to waste heat. While 1 MJ energy from waste heat releases 0.0344 kgCO_2eq., 1 MJ energy from lignite releases 0.171 kgCO_2eq.[52] Also, the other stage percentages were increase based on this circumstance.

GWP results were also given with m^2.75years and m^2.year unit to ease comparison with the other published studies in Table 5.11.

Table 5.11 : GWP results of retrofitted with m^2.75years and m^2.year units.

Stage	GWP ($kgCO_2$eq. /m^2.75years)	GWP ($kgCO_2$eq. /m^2.year)
Product Phase	916	12
Operational Energy	4,228	56
End of Life	1,292	17

In addition to overall results, released greenhouse gases from the materials that were used in the building also were calculated material by material; besides, their life time was divided based on life period. All results were showed in Table 5.12; moreover, the comparison between materials was made in Figure 5.10. As expected, brick, concrete and plastic had highest pollution in product stage. Brick and concrete had significant impact in transportation and waste transportation due to their amount. The materials have recyclable part such as plastic decreased greenhouse effects on environment via recycling processes; nonetheless, their overall effect still increased global warming because of production, transportation and landfill steps. Concrete and brick had important influence on environment in landfill stage due to their amount. Also, others materials had effect on global warming based on their raw materials and production processes.

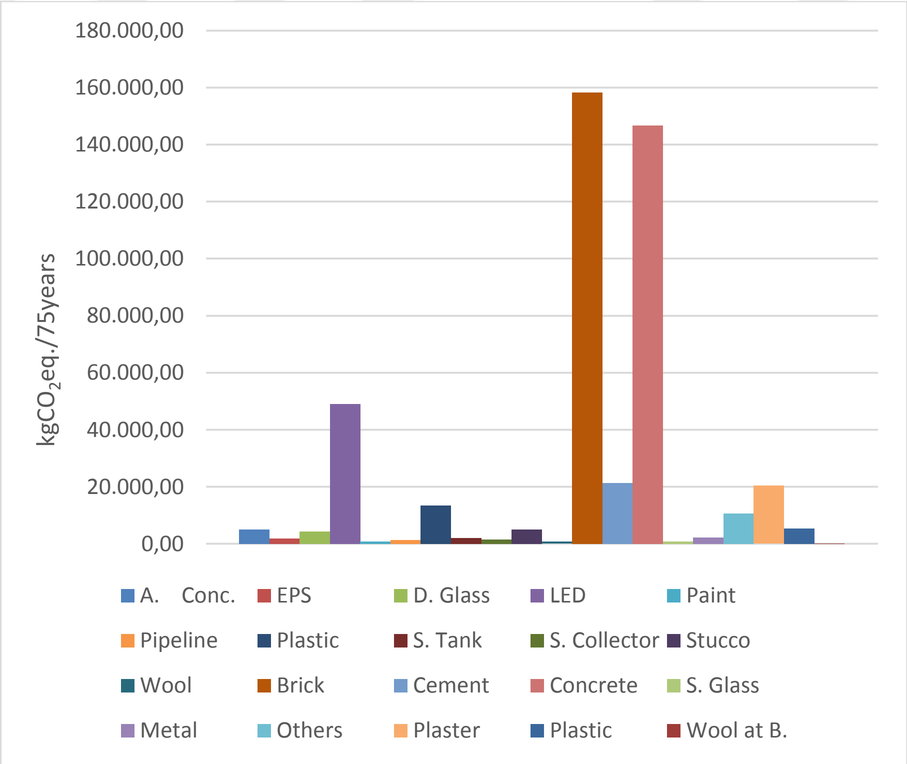


Figure 5.10 : GWP results of materials in retrofitted scenario.

Table 5.12 : GWP results of materials in retrofitted scenario.

Material Type	Product Phase ($kgCO_2eq$)	Transportation ($kgCO_2eq$)	Waste Transport ($kgCO_2eq$)	Recycle ($kgCO_2eq$)	Landfill ($kgCO_2eq$)
A.Conc.	2,770	67	5	8	2,270
EPS	1,860	5	5	-190	195
D. Glass	3,930	26	25	-743	1,070
LED	49,100	2	2	-52	75
Paint	836	4	1	0	38
Pipeline	1,240	9	9	-366	376
Plastic	10,500	35	34	1,420	1,460
S. Tank	2,440	10	10	-384	3
S.Collector	1,610	2	2	-85	1
Stucco	772	99	8	7	4130
Wool	135	1	1	0	584
Brick	55,800	2,390	192	176	99,700
Cement	5,190	376	30	28	15,700
Concrete	27,400	2,770	223	349	116,000
S. Glass	1,260	14	14	-410	4
Metal	2,620	12	12	-462	4
Others	1,120	172	14	0	9,320
Plaster	4,980	360	29	28	15,000
Plastic	5,390	18	17	-709	728
Wool	135	1	0.1	0	56

5.3 Comparison of Two Scenarios

In the thesis, the building was examined in terms of energy consumption and global warming potential from raw materials to disposal. Current situation of the building at beginning was taken in baseline scenario; besides, retrofitted based on energy performance situation was taken in retrofitted scenario. Based on final operational energy consumption, energy consumption of baseline situation was 189 kWh/m^2.year, and energy consumption of retrofitted situation is 66 kWh/m^2.year for building in use consumption. Thus, the reduction rate on final energy consumption is 65%. Nonetheless, this rate is just correct for final energy. The thesis LCA methodology was taken in account all materials, processes and end of life stage in addition to the final energy consumption. Therefore, the building energy consumption and its greenhouse gases impact were evaluated as whole from cradle-to-grave. The building life time was defined as 75 years. In baseline scenario, the building will continue their life till 2065 with current situation at beginning. Only necessary maintenance and replacement such as painting, chancing glazing activities will be done till demolition. On the other hand, the building lived 25 years with current situation at beginning; also, it will continue their life as retrofitted 50 years more till 2065. Thus, the first 25 years is same in both scenario.

5.3.1 Comparison of CED results

CED results of both scenario were obtained and compared in Table 5.13 and Figure 5.11 in detail. CED results of the building in baseline scenario is 426 kWh/m^2.year; moreover, CED results of the building in retrofitted scenario is 252 kWh/m^2.year based on the developed LCA models. These results were gotten based on primary energy. Thus, the reduction rate of CED is 41% in retrofitted scenario. There are two reasons for difference between reduction rate based on final energy consumption and scenarios. The first one is that LCA methodology is considers of whole processes from cradle to grave; nonetheless, final energy consumption is just related with final operational energy use. The second reason is that energy performance of retrofitted building is 66 kWh/m^2.year; nevertheless, the building used at only last 50 years with this performance in retrofitted scenario. Before that, it continued its life as current condition at beginning. Because of these, the reduction rate is lower than final energy reduction rate.

Table 5.13 : Comparison of CED results of both scenario.

Stage	Baseline Scenario (kWh/m^2.year)	Retrofitted Scenario (kWh/m^2.year)
Product Stage	21	43
Use Stage	403	208
End of Life Stage	3	1
Total	426	252

As it seen in Table 5.13 and Figure 5.11, the building stages were also investigated individually in addition to the total consumption. While energy consumption contribution is 19 kWh/m^2.year from product stage in baseline scenario, it is 41 kWh/m^2.year in retrofitted scenario. In other words, it is increased 116% in retrofitted scenario. Various materials were used during retrofitting. Due to that, production of new materials such as solar collectors, LED increased energy consumption of the building overall. The amount of basis materials of building is so much higher than retrofitting materials; besides, they were examined in both scenario. This difference comes from extra materials that were used in retrofitting. Most of the materials that were used during retrofitting strategies are energy-dense material such as LED. Impact of their product phase on primary energy demand are higher that standard building structure materials such as concrete.

The most important and effective part on CED is use stage consumption that means energy is used during building life time. There were two sources for consumption in use stage. These were maintenance/replacement processes and operational energy demand. While the maintenance/replacement processes consumed energy, the main contributor was operational energy demand. It is 403 kWh/m^2.year in baseline scenario and 208 kWh/m^2.year in retrofitted scenario. Thus, energy mainly consumed in this stage for both scenario. The percentage of CED of operational energy is 94% in baseline stage in overall; besides, it is 82% in retrofitted scenario. The reasons for this differences is chancing heat energy source, improved energy performance via retrofitting activities and energy-intense materials that were used during retrofitting.

Finally, end of life stage was examined for both scenario. CED of end of life is 3 kWh/m^2.year in baseline and 1 kWh/m^2.year in retrofitted scenario. When the amount of waste are taken in account, Retrofitted scenario's is weightier than baseline's due to materials that were used extra. However, CED of end of life in retrofitted scenario is lower than baseline. The reason for that is regained energy from recycling processes. Most of materials that were used in retrofitting are recyclable, and they influence the energy consumption of end of life positively.

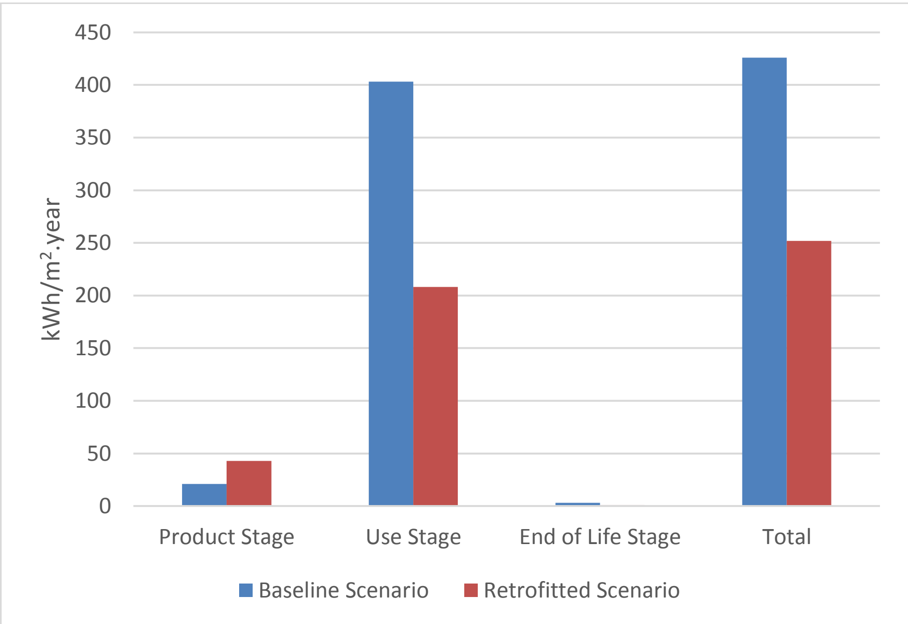


Figure 5.11 : Comparison of CED results of both scenario.

A comparison was also made based on material types. The results were given in Table 5.14. CED results of material types were given depend on their life time (production, transportation and end of life) in *Section 5.1.1* and *5.2.1*. Because of that, comparison was made according their overall results during their whole life time from cradle-to-grave. In addition, increase rates were calculated and added on to Table 5.14. Some materials did not used in baseline scenario; thus, their consumption was shown with '-' in Table 5.14.

According to results, energy consumption of some materials such as brick, cement are same in both scenario. The reason for that is that they used with same amount in both scenario. Moreover, the amount of some materials such as glass, plastic increased in retrofitted scenario; hence, their consumption also increased. Because of that, its amount and primary energy demand increased directly. Increase rate of wool is the highest rate in comparison. In addition to wool, energy consumption of glass, others and plastic also increased. Some materials such did not used in baseline scenario. Because of that, there was not a consumption for these materials in baseline scenario. When the overall consumption of all materials were taken in account, the total primary energy consumption were increased in retrofitted scenario around 88%.

Table 5.14 : Comparison of CED results based on materials.

Material Type	Baseline Scenario (MJ)	Retrofitted Scenario (MJ)	Increase rate (%)
Brick	707,840	707,840	0
Cement	48,528	48,528	0
Concrete	362690	362690	0
Glass	11,240	56,773	405
Metal	20,972	20,972	0
Others	31,045	47,628	53
Plaster	46,546	46,546	0
Plastic	87,940	260,719	196
Wool	1,970	22,702	1,052
A.Conc.	-	23,226	-
EPS	-	43,599	-
LED	-	697,368	-
Pipeline	-	41,736	-
Radiant	-	33,383	-
S. Tank	-	25,021	-
S. Collector	-	22,293	-
Stucco	-	15,692	-
Total	1,318,771	2,476,716	88

5.3.2 Comparison of GWP results

Greenhouse gases emission of both scenarios were compared to demonstrate retrofitting impact. The GWP results were shown in Table 5.15 and Figure 5.12 based on the building life time. Producing new materials for retrofitting increased released greenhouse gases in product stage in retrofitted scenario approximately 70%. Because the amount of retrofitting materials are less in comparison with main structure materials of the building, main effective stage on decreasing is operational energy stage. The decreasing is around 53%. The building used lignite as source for heating in baseline scenario; nevertheless, new pipeline was constructed from thermal plant to the building to used waste heat for heating. Thus, stopping using lignite also influenced decreasing GWP of the building. Results of end of life are also related with the amount of the wastes. Therefore, they are close each other in both scenarios. Finally, while total greenhouse gases emission from the building was 143 kgCO_2eq./m^2.year, this amount is 86 kgCO_2eq./m^2.year in retrofitted scenario. It is means that, reducing rate of GWP is around 40%. All result and the amount of reduction also can be seen in Figure 5.12.

Table 5.15 : Comparison of GWP results of both scenario.

Stage	Baseline Scenario (kgCO_2eq./m^2.year)	Retrofitted Scenario (kgCO_2eq./m^2.year)
Product Stage	7	12
Use Stage	120	56
End of Life Stage	17	17
Total	143	86

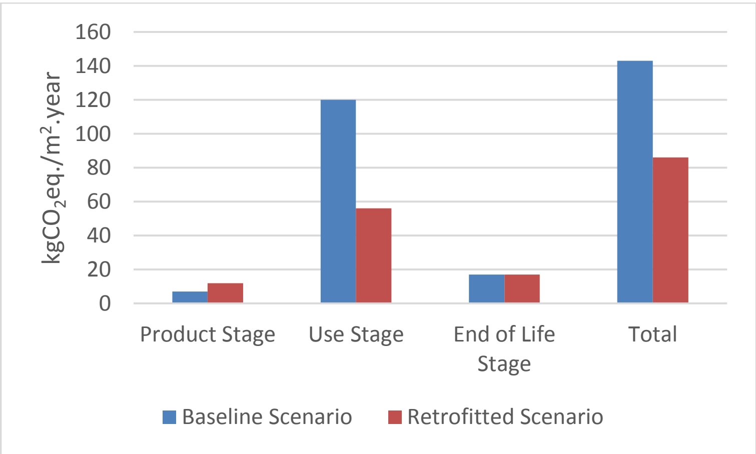


Figure 5.12 : Comparison of GWP results of both scenario.

GWP results of materials were also investigated. All results were demonstrated in Table 5.16. Because the amount of some materials were same in both scenarios, their results are same. These materials can be listed as: brick, cement, concrete, metal and plaster. Moreover, the amount of some materials was increased in retrofitted scenario; thus, their GWP also were increased. Increase rate of glass is 488%, others is 8%, plastic is 247% and wool is %376. Some materials were used in the building in retrofitted scenario first time; hence, they do not have a GWP results in baseline. The most effective materials based on GWP is LED due to its high-tech production technic. Consequently, cumulative GWP of all used materials in baseline scenario is 366,050 kgCO_2eq; besides, cumulative GWP of all used materials in retrofitted scenario is 454,967 kgCO_2eq. Thus, the increase rate of GWP related with materials is 24%.

Table 5.16 : Comparison of CED results based on materials.

Material Type	Baseline Scenario (kgCO_2eq)	Retrofitted Scenario (kgCO_2eq)	Increase rate (%)
Brick	158,258	158,258	0
Cement	21,324	21,324	0
Concrete	146,742	146,742	0
Glass	882	5,190	488
Metal	2,186	2,186	0
Others	10,626	11,505	8
Plaster	20,397	20,397	0
Plastic	5,443	18,892	247
Wool	192	913	376
A.Conc.	-	5,620	-
EPS	-	1,874	-
LED	-	49,127	-
Pipeline	-	1,268	-
Radiant	-	3,047	-
S. Tank	-	2,079	-
S. Collector	-	1,530	-
Stucco	-	5,017	-
Total	366,050	454,967	24

6. CONCLUSION

In the thesis, a case study residential house was investigated via life cycle assessment (LCA) methodology. The building was built in end of 1980s. It was retrofitted to improve its energy performance, decrease greenhouse gases from it and increase renewable energy source percentage in overall energy consumption. Thus the building was investigated to show its environmental impact on environment and primary energy consumption. Also, two scenarios were analyzed to demonstrate retrofitting impact. The first scenario is called as baseline scenario. In this scenario, the building was assessed based on beginning situation during 75 years. Main structure of building such as brick, concrete etc., only necessary maintenances and replacements, operational energy consumption and end of life stage were added to the system boundaries of the scenario. The second scenario is retrofitted scenario. In this scenario, building was continuing its life within beginning situation during 25 years. After 25 years, the retrofitting activities were applied to the building; besides, it will continue life time 50 years more till demolition with retrofitted version. Thus, the retrofitted scenario has 2 part as beginning situation (0-25 years) and retrofitted situation (25-75 years). The results of both periods create results of retrofitted scenario.

The building investigated based on EN 15978. Thus, energy consumption and global warming potential were calculated in overall also stage by stage. The first stage is A (Product) stage. In this stage, producing of materials that were used in the building, their transportation and construction & installation were taken over. Maintenance, replacement and operational energy used were taken in account in B (Use) stage. Lastly, impact of demolition of materials, their transportation, processing and disposal steps were examined in C (End of life) stage. The CED results based on stage were given for baseline scenario in Figure 6.1 and for retrofitted scenario in Figure 6.2. As it seen from figures, operational energy consumption is comparatively higher than the other stages.

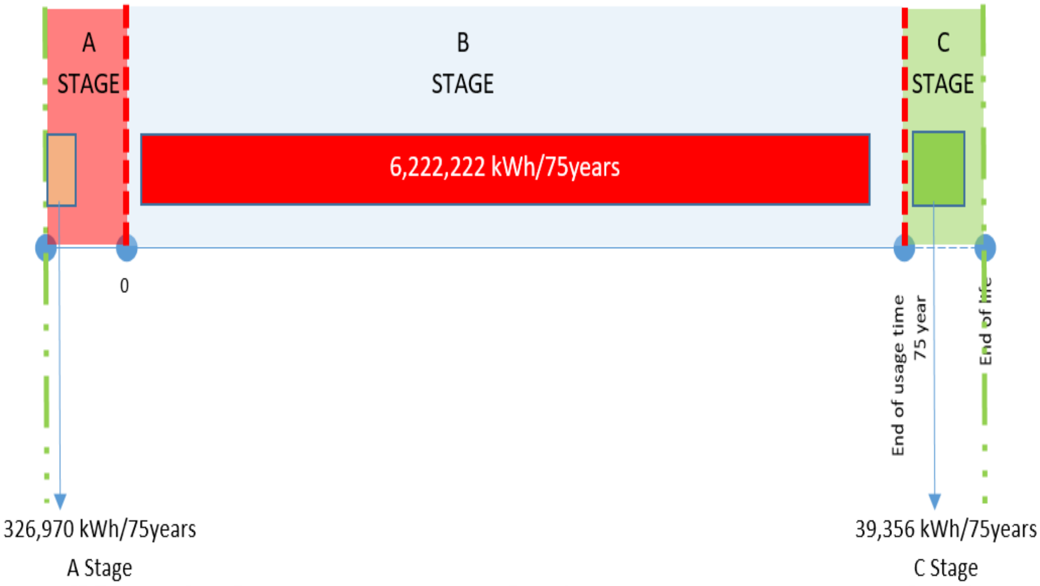


Figure 6.1 : CED results of baseline scenario.

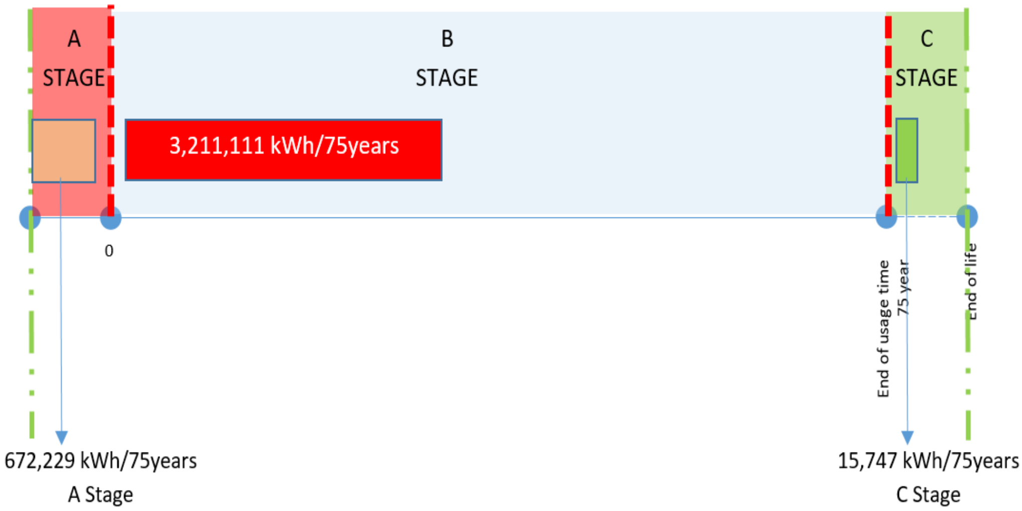


Figure 6.2 : CED results of retrofitted scenario.

In Table 6.1, results of stages were given selected indicators (CED and GWP). Also their contributions were shown based on percentage in Table 6.1. Based on the results, B stage took the majority in both scenario for both indicators. Nonetheless, B stage is more dominant in baseline scenario because of using lignite as heating sources and energy performance of buildings. Contribution of B stage decreased in retrofitted, but it is still really high than other stage for both indicators. Contribution of A stage in retrofitted scenario is higher than baseline due to extra and high-tech materials that were used for retrofitting. CED results of C stage is too low in both scenario, while GWP results of C stage are higher. The reason for that is releasing greenhouse gases from waste handling processes.

Table 6.1 : Contribution from stages.

	Baseline Scenario				Retrofitted Scenario			
Stages	CED	%	GWP	%	CED	%	GWP	%
A Stage	21	5	7	5	44	17	12	14
B Stage	403	94	120	83	208	82	56	66
C Stage	3	0.6	17	12	1	0.4	17	20
Total	426	100	143	100	252	100	86	100

* CED: kWh/m^2.year
**GWP: kgCO_2eq./m^2.year

CED of baseline scenario is 426 kWh/m^2.year, and CED of retrofitted scenario is 252 kWh/m^2.year. Thus, the CED reduction rate is 41%. While some extra materials were produced and used because of retrofitting, there is still reduction on cumulative energy consumption by helps of retrofitting strategies. When GWP of scenario are taken in account, there is also reduction in GWP of the building by helps of retrofitting. This reduction rate is around 40%.Althoug produced materials and their end of life scenario released more greenhouse gases in retrofitted scenario, stopping lignite use and improving energy performance of the building decrease overall GWP of the building. Retrofitting strategies had 3 main aims as: improving energy performance of the building, decreasing greenhouse gases emission from the building and increasing renewable energy source percentage in overall energy consumption. The results of this thesis showed that retrofitting strategies have reached their aim. CED of the building decreased around 41%, GWP of the building decreased around 40% and using renewable energy source was increased by using solar collectors.

The building is in a site are in Soma District; besides, there are 79 residential buildings in this area. The analysis that was made in the thesis can be also used for other buildings; hence, the contribution of retrofitting activities to reach energy efficient district and cities also were tested. Moreover, the results have showed that retrofitting activities are useful to reach zero-energy district and cities. Thus, municipalities and authorized have to be aware of these kind of works.

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