COMPARISON OF BEST AND LEED GREEN BUILDING RATING SYSTEMS THROUGH COST BASED OPTIMIZATION

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ABSTRACT

COMPARISON OF BEST AND LEED GREEN BUILDING RATING SYSTEMS THROUGH COST BASED OPTIMIZATION

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Buildings have significant effects on climate change due to vast resource consumption and pollution generation. Improving the effective use of limited resources and constructing environmentally friendly buildings are important in the realm of mitigations for climate change. Several countries have their green building rating systems tailored towards their regulations, distinctive climatic conditions, unique cultures and traditions, diverse building types and ages, or wide-ranging environmental, economic, and social priorities. Today in the world, the most popular green building rating system is based on the LEED system of USA. Turkey has developed its own rating system, BEST, in August 2019. This study aims to compare LEED and BEST rating systems using a cost-based optimization. The study also aims to propose a guideline to stakeholders while choosing the green building features to obtain green building certificates in Turkey at the least cost. In the study, an optimization model is developed in which cost-related data, electricity consumption, and water usage analyses are integrated. The model is solved using LINGO. The optimization model is run for case studies involving 4-, 5-, 7-, and 12-storey buildings in Ankara for a total of 16 scenarios. Results show that Good and

Excellent certification levels of BEST are feasible choices considering water and electricity savings of residents over a period of 10 years. The Good certification level is the most feasible choice with its significantly cheaper initial cost with respect to Excellent level and considerably high savings. Moreover, the only certification level that compensates the investment cost after 10 years is the Good level. The least feasible choice is the Very Good level with the highest initial cost and considerably low savings. Furthermore, building systems/materials/equipment selected for any of BEST certification levels are not sufficient to achieve the Platinum level of LEED, but Certified, Silver, and Gold levels are achievable.

Keywords: Climate Change, Green Buildings, LEED, BEST, Cost Optimization

ÖZ

BEST VE LEED YEŞİL BİNA DEĞERLENDİRME SİSTEMLERİNİN MALİYET BAZLI OPTİMİZASYON METODUYLA KARŞILAŞTIRILMASI

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Binaların iklim değişikliği üzerindeki etkisi, büyük kaynak tüketimi ve kirlilik oluşumu nedeniyle yadsınamaz boyuttadır. Sınırlı kaynakların etkin kullanımının iyileştirilmesi ve yeşil binalar olarak adlandırılan çevre dostu binaların inşa edilmesi, iklim değişikliğinin etkilerinin azaltılmasında önemli bir yere sahiptir. Birçok ülkenin kendi yasalarına, farklı iklim koşullarına, benzersiz kültür ve geleneklerine, bina türlerine, bina yaşlarına ve geniş kapsamlı çevresel, ekonomik ve sosyal önceliklere göre uyarlanmış yeşil bina değerlendirme sistemleri bulunmaktadır. Bugün dünyada en popüler yeşil bina değerlendirme sistemi, ABD'nin LEED sistemidir. Türkiye, Ağustos 2019'da ulusal değerlendirme sistemi olan BEST'i geliştirmiştir. Bu çalışma, maliyet tabanlı bir optimizasyon kullanarak LEED ve BEST değerlendirme sistemlerini karşılaştırmayı amaçlamaktadır. Çalışma aynı zamanda tüm paydaşlara Türkiye'de yeşil bina sertifikalarını en az maliyetle elde etmek için malzeme seçiminde yararlanabilecekleri bir rehber olmayı amaçlamaktadır. Çalışmada optimizasyon aracı olarak LINGO kullanılmıştır. Maliyet verileri, elektrik ve su tüketim analizleri LINGO'ya aktarılmıştır.

Optimizasyon modeli, Ankara'da bulunan bir vaka çalışması için ayrı ayrı 16 senaryo için çalıştırılmıştır. Sonuçlar, 10 yıl içinde konut sakinlerine kazandırdığı su ve elektrik tasarrufu düşünüldüğünde, BEST'in İyi ve Mükemmel seviyelerinin diğer seviyelerden daha uygun seçimler olduğunu göstermektedir. İyi seviyesi, Mükemmel seviyesine göre çok daha ucuz başlangıç maliyeti ve yüksek tasarruf miktarı ile en uygun seçimdir. 10 yıl sonra yatırım maliyetini karşılayan tek sertifika seviyesinin de İyi seviyesi olduğu görülmüştür. En az uygulanabilir seçim, en yüksek başlangıç maliyeti ve düşük tasarruf miktarı ile Çok İyi seviyesidir. Ayrıca sonuçlara göre, BEST'in herhangi bir seviyesi LEED Platin seviyesine ulaşamamaktadır, ancak LEED'in Onaylı, Gümüş ve Altın seviyelerine ulaşılabilmektedir.

Anahtar Kelimeler: İklim Değişikliği, Yeşil Binalar, LEED, BEST, Maliyet Optimizasyonu

To my dearest family

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Finally, climate change is one of the top priority problems of today. It is a big delusion to think that this is the problem of our children or grandchildren, in fact, the problem is today's problem and the fight for its solution must begin immediately. I hope that this study will be a step in the fight against climate change and pave the way for new studies. I would like to thank all the scientists who have worked and will work to combat climate change. It is quite a privilege to follow the footsteps of them whose studies I hope will one day win our fight against climate change.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

ABBREVIATIONS

$A_{re}(l)$	Amount of renewable energy system *l* to be installed
CR_h	Total credits gained from health and comfort category
CR_a	Total credits gained from operation and maintenance category.
CR_e	Total credits gained from energy consumption category
CR_{in}	Total credits gained from innovation category.
CR_m	Total credits gained from materials category
CR_r	Total credits gained from renewable energy category
CR_w	Total credits gained from water consumption category
CR_h	Total credits gained from life category.
$C_{ew}(t)$	Initial cost of green material *t* that impact both energy consumption and water consumption of the building ($)
$C_{ewn}(t)$	Initial cost of non-green material *t* that impact both energy consumption and water consumption of the building ($)
$C_e(m)$	Initial cost of green material *m* that impact energy consumption of the building ($)
$C_{en}(m)$	Initial cost of non-green material *m* that impact energy consumption of the building ($)
$C_{rw}(j)$	Initial cost of rainwater system *j* that impact water use of the building ($)
$C_{es,ideal}(k)$	Initial cost of green system *k* in building structure that impact energy consumption of the building and are in line with more up to date study published in 2016 by order of Izoder ($)
$C_o(n)$	Initial cost of the other system *n* that doesn't impact the building related calculations such as energy and water ($)

$C_{re}(l)$	Initial cost of renewable energy system *l* that impacts the energy consumption of the building ($)
$C_{esn}(k)$	Initial cost of non-green system *k* in building structure that impact energy consumption of the building ($)
$C_{es,tse}(k)$	Initial cost of green system *k* in building structure that impact energy consumption of the building and are in line with TSE (Turkish Standardization Institute) Standard in force published in 2006 ($)
$C_w(i)$	Initial cost of green system *i* that impact water use of the building ($)
$C_{wn}(i)$	Initial cost of non-green system *i* that impact water use of the building ($)
$I_{ew}(t)$	Binary variable for choosing green material *t* that affects both energy and water consumption
$I_{ewn}(t)$	Binary variable for choosing non-green material *t* that affects both energy and water consumption
$I_e(m)$	Binary variable for choosing green material *m* that affects energy consumption
$I_{en}(m)$	Binary variable for choosing non-green material *m* that affects energy consumption
$I_{es,ideal}$	Binary variable for choosing green system *k* in building structure that impact energy consumption and are in line with more up to date study published in 2016 by order of Izoder
$I_o(n)$	Binary variable for choosing other system *n* that doesn't impact the building related calculations such as energy and water
$I_{re}(l)$	Binary variable for choosing renewable energy system *l*
$I_{rw}(j)$	Binary variable for choosing rainwater system *j* that impact water use
$I_{esn}(k)$	Binary variable for choosing non-green system *k* in building structure that impact energy consumption of building.

$I_{es,tse}(k)$	Binary variable for choosing green system *k* in building structure that impact energy consumption and are in line with TSE (Turkish Standardization Institute) Standard in force that published in 2006
$I_w(i)$	Binary variable for choosing green system *i* that impact water consumption
$I_{wn}(i)$	Binary variable for choosing non-green system *i* that impact water consumption
NPV	Net present value
$U_{ew}(t)$	Water consumption of green systems *t* that affects the consumption of both water and energy per one household in a year (m^3/year*household)
$U_{ewn}(t)$	Water consumption of non-green systems *t* that affects the consumption of both water and energy per one household in a year (m^3/year*household)
U_{eGB}	The total energy use of the green building in a year (kwh/year)
U_{eNGB}	The total energy use of the non-green building which has no green system in a year (kwh/year)
$U_{rw}(j)$	Water consumption of rainwater system *j* per one household in a year (m^3/year*household)
$U_w(i)$	Water consumption of green system *i* per one household in a year (m^3/year*household)
U_{wGB}	The total water use of the building per one household in a year (m^3/year*household)
$U_{wn}(i)$	Water consumption of non-green system *i* per one household in a year (m^3/year*household)

CHAPTER 1

INTRODUCTION

Anthropogenic activities have triggered a rise of 1.02°C over the pre-industrial global surface temperature in 2021 (NASA, 2021a). This caused a change in climate, which resulted in both long-term and short-term climate variations (UNFCCC, 2008). Therefore, concerning countries have assembled conventions, signed protocols and agreements in order to prevent devastating effects of the climate change. The most important of these conventions, agreements and protocols are as follows in chronological order: United Nations Framework Convention on Climate Change (1992), Kyoto Protocol (1995) (UNFCCC, 2021), 2030 Agenda for Sustainable Development (2015), Paris Agreement (2016) (United Nations, 2020), The European Union Green Deal (2019) (European Commission, 2019) and European Climate Law (2020) (European Commission, 2020).

The Mediterranean Basin, which Turkey is situated in, is one of the places most affected by the detrimental consequences of climate change (IPCC, 2007). Additionally, economic, industrial and urban growth of Turkey results in a huge increase in emissions of CO_2 (IEA, 2018). These CO_2 emissions are also the inevitable triggers of climate change. Turkey, being aware of the danger, introduced its national contribution to the UN Climate Change Framework Convention (2015) and planned climate related strategies and activities within several national plans such as in 11th Development Plan of Turkey (2019-2023) (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2019) and Climate Change Strategy of Turkey (2010-2023) (T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı, 2010).

The place of buildings among the factors affecting climate change is very crucial. In their lifecycle, they contribute a substantial share in consuming natural resources, carbon emissions, environmental damage and climate change. Green building rating systems were published to minimize the negative impacts of the traditional buildings. Certified buildings are qualified as being of lower energy use, provide a better living environment and help the overall reputation of a property (Doan et al., 2017). It is recognized that each system is distinctive, and bears the characteristics of the country in which it was designed for. Therefore, countries are encouraged to design or adopt a rating system suited to their local and regional contexts (WGBC, 2016).

In Turkey, the most commonly used green building rating systems are LEED, based in USA, and BREEAM, based in UK. In 2019, ÇEDBİK (Çevre Dostu Yeşil Binalar Derneği – Environmentally Friendly Green Buildings Association) has published the very own green building rating system of Turkey, BEST (Binalarda Ekolojik ve Sürdürülebilir Tasarım – Ecological and Sustainable Design of Buildings). As of today, only 23 buildings were given BEST certification in Turkey (ÇEDBİK, 2021). Being a very young green building rating system, there are few studies in the literature on BEST.

Cost is the biggest obstacle to build a green building. Hence, it is very crucial for all stakeholders to embrace the importance of building green and also to understand the ways to get greener for lower costs (Portnov et al., 2018). AlAwam and Alshamrani studied 200 buildings by transforming their LEED scores into monetary worth, based on the degree of certification obtained, building space, and building type. With 95% confidence level, the study's output revealed the largest cost premium as \$38.6/LS.m^2 (LEED scores' cost per square meter) for platinum level educational buildings, while the lowest cost was calculated as \$10.6/LS.m^2 for the platinum level of residential certification. It was shown that premium costs can be reduced by 70% for educational buildings and 60% for commercial buildings (AlAwam & Alshamrani, 2021). Another research examined the upfront construction costs for two banks with LEED certification and eight banks with no LEED certification in western Colorado in USA that have similar building sizes and types (Mapp et al., 2020). The goal of the study was to evaluate expenses and estimate the expenditures directly related to LEED certification. The research considered the overall construction costs. According to the study, the building costs of LEED certified bank buildings were similar and close to non-certified banks with the help of an experienced project team. Furthermore, the direct cost of pursuing LEED certification was estimated to be less than 2% of the entire project cost (Mapp et al., 2020). Nyikos et al. (2015) studied numerous companies that have established green policies to finance sustainable design. Construction and utility costs were collected for LEED certified buildings. Using simple correlation and descriptive statistics, the study discovered that operational costs in LEED certified buildings were $0.70/sq.ft lesser than non-certified buildings, energy costs were 31% lesser, and cost premiums varied from 2.5% to 9.4% more, with an average of 4.1% (Nyikos et al., 2015).

This study aims to compare LEED and BEST rating systems using a cost-based optimization for different buildings. There are no studies in the literature examining BEST with cost-based optimization. An optimization model is developed for this purpose which aims to provide a desired level of green building certification level according to BEST using the optimum combination of materials/equipment/systems with the least cost. Moreover, the corresponding LEED certification levels of each materials/equipment/systems combination obtained through optimization for a building that achieves a given BEST certification level are found. The outcomes in terms of BEST and LEED certification levels are compared.

In this study, initially, four reference buildings were selected by considering the apartments built by TOKI (Housing Development Administration of Turkey) in Ankara in recent years. The optimization model selected the optimum materials/equipment/systems combination to achieve a desired BEST level based on the data obtained from energy analysis, water analysis, material costs, assumptions, and system constraints. Additionally, water and electricity savings from going green were evaluated for each case. Chosen materials/equipment/systems for BEST certification were then assessed to calculate the corresponding LEED level of certification. Lastly, corresponding BEST and LEED certification levels that can be achieved were compared for each case study.

CHAPTER 2

LITERATURE REVIEW

2.1 Initiatives Relevant to Climate Change in the World

Scientific researches show us that the impacts of climate change have been currently observed sooner than expected. In our everyday lives, this becomes even more apparent (United Nations, 2019). Impacts of the climate action failure is accepted as the most vicious risk within the 2020 global risks followed by weapons of mass destruction, biodiversity loss, extreme weather, and water crisis, in order. Whereas, in 2012, the impact of climate change action failure was not even in the top 5 global risks in the impact list (World Economic Forum, 2020).

Countries signed the "United Nations Framework Convention on Climate Change" (UNFCCC) in 1992 as a framework for international cooperation to tackle climate change by limiting global mean temperature rises and the subsequent climate change, as well as dealing with implications that were already unavoidable at the time (UNFCCC, 2021). According to the Convention, there are three categories that countries can involve in. These are Annex-I, Annex-II, and Non-Annex. Annex-I countries are obligated to reduce their GHG emissions, develop sinks, and report the measures taken to prevent climate change. 42 countries are involved in this category. In addition to the responsibilities of the Annex-I countries and Annex-II countries are also obliged to promote and financially support developing countries to implement environmentally friendly technologies. 23 countries are involved in this category. Non-Annex countries are encouraged to reduce their GHG emissions, cooperate in research and sustain sinks. However, unlike Annex-I and Annex-II countries, they are not subjected to any obligations. 154 countries are involved in this category (T.C. Dışişleri Bakanlığı, 2021) .

Countries began negotiating in 1995 to intensify the global response to climate change, and two years later, in 1997, the “Kyoto Protocol” was ratified. Parties of the Kyoto Protocol are legally required to meet emission reduction goals. The first commitment cycle of the Protocol began in 2008 and terminated in 2012. The second commitment period started on January 1, 2013, and expired in 2020. The Kyoto Protocol now has 192 signatories and the Convention now has 197 signatories (UNFCCC, 2021).

In 2015 United Nations developed the “2030 Agenda for Sustainable Development” to protect the world and improve the lives and prospects of everyone in the world. The Agenda consists of 17 goals and 169 targets, including climate goals, to be implemented in a 15 years plan. The years between 2020 and 2030 was announced as the Decade of Action in September 2019 to implement all of the goals (United Nations, 2020).

On November 2016, “Paris Agreement” was entered into force. The Agreement was accepted as a legally binding international agreement and it gathered 196 countries into a common objective to undertake cautions to manage the climate change. The Agreement aims to keep the temperature ascend to well below 2^oC, preferably 1.5^oC, at the end of the century by promoting the global response for climate change. According to the agreement, countries were obliged to submit their climate change action plans, in other words their “Nationally Determined Contributions” (NDCs), to prevent climate change by 2020. Also, countries of concern were encouraged to submit their “Long-Term Low Greenhouse Gas Emission Development Strategies” (LT-LEDS) by 2020 (UNFCCC, 2015b).

The United Nations claims that even in the scenario of implementing all current unconditional NDCs under the Paris Agreement, carbon budget limit for the 1.5^oC level will be exceeded before 2030 (United Nations, 2019).

European Union (EU) released the "European Union Green Deal" in December 2019 as a response to climate change and environmental degradation. This new action aims to transform EU into fair and prosperous community with competitive, modern, and resource efficient economy. These hopefully result in zero net greenhouse gas (GHG) emissions in 2050 and decoupled economic development from resource use. In March 2020, the "European Climate Law" was proposed in line with the EU Green Deal in order to transform the political commitment to legal obligation. According to the law, EU will invest in environmentally-friendly technologies, support industries to make innovations, ensure cleaner, healthier and cheaper public transportation, decarbonize energy sector, develop more energy efficient buildings, and advance the global environmental standards (European Commission, 2019). Also, the law has proposed a new EU target for 2030. According to the target, GHG emissions are proposed to be reduced by 55% at minimum, compared to the 1990's emission levels (European Commission, 2020).

In the World Energy Outlook Report disseminated in October 2020 (IEA, 2020), the International Energy Agency predicted that due to the COVID-19 pandemic related lockdown actions and economic effect of the pandemic, CO_2 emissions are expected to decrease by 7%, and clean energy investments decline by 8% in 2020. As projected in the "Stated Policies Scenario" (STEPS), emissions of CO_2 will backtrack in 2021 and surpass 2019 levels in 2027, and finally escalate to 36 gross tonnages in 2030. These projections are far from the immediate peak and required drop in emissions required to meet climate goals, including the ones in the Paris Agreement (IEA, 2020). Carbon dioxide concentrations measured in the specific dates of concern are presented in Table 2.1. The average rate of change and the latest annual average anomaly of some variables affected by climate change are presented in Table 2.2.

Table 2.1 CO_2 concentration values in milestones (NASA, 2021b)

Year	**Milestone**	**CO_2 concentration (ppm)**
1956	Mauna Loa CO_2 Observation Station established in Hawaii. Yearly observations began.	315.97
1994	United Nations Framework Convention on Climate Change entered into force.	358.82
December 2005	Kyoto Protocol entered into force.	381.09
December 2015	Paris Agreement was adopted.	402.72
December 2019	European Green Deal was adopted.	412.71
December 2019	Covid-19 emerged.	412.71
March 2020	Covid-19 was announced as pandemic.	413.27
January 2022	Current day.	417.00

Table 2.2 Average rate of change and latest annual average anomaly of states in the world (NASA, 2021b)

Variable	**Average rate of change / Latest annual average anomaly**
Sea level	3.4 mm increase per year
Antarctica mass variation	152 billion metric tons per year
Greenland mass variation	276 billion metric tons per year
Artic Sea ice minimum	13.0 % per decade
Global temperature	1.02^{o}C

2.2 Initiatives Relevant to Climate Change in Turkey

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Turkey is located in the Mediterranean Basin, which is among the regions that will be most affected by the negative effects of climate change (IPCC, 2007). The Mediterranean Basin is experiencing rapid warming. A stable and reliable climate change process is expected to occur in this area, particularly in summer, with rising temperatures and a notable drop in precipitation (Giorgi & Lionello, 2008). Furthermore, forecasts show that the frequency and severity of heatwaves are increasing (Kuglitsch et al., 2010) as well as the extremes of daily temperature (Erlat & Türkeş, 2013). A decreasing trend, combined with a shift in diurnal temperatures and winter precipitation, is projected for the number of frost days (Erlat & Türkeş, 2012).

With the decision of the UNFCCC in the 7th Conference of the Parties held in Marrakech in 2001, Turkey was removed from the Annex-II countries and became an Annex-I country. Parties of the Convention were invited to recognize the special conditions of Turkey, which put Turkey in a different position than all other Annex-I countries. Turkey was not a party to the UNFCCC when the Kyoto Protocol was first enacted. Therefore, Turkey was not included in the Annex-B list of the Protocol, where Annex-I Parties were strictly obligated with quantified emission limitations or reduction obligations mentioned in Annex-B. Therefore, in the first obligation period of the Protocol covering the years 2008-2012, Turkey did not have any quantified emission limitation or reduction obligation. Following the acceptance of this special position, Turkey became a party to the UNFCCC on May 24, 2004. Afterwards, Turkey officially became a party to the Kyoto Protocol for the UNFCCC on August 26, 2009 as well (T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı, 2010). Very recently, Paris Agreement was endorsed by the Turkish Parliament and in force as of October 7th, 2021. Furthermore, the ratification of the Paris Agreement, which was accepted at the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change and signed on behalf of the Republic of

Turkey on April 22, 2016, together with the declaration, became final on 6 October 2021 with the law no. 7335 (Resmi Gazete, 2021). According to the Turkish Ministry of Foreign Affairs, although we are not a party yet, a GHG reduction target has been determined within the framework of our National Intended Statement of Contribution. Accordingly, it is aimed to decrease GHG emissions by up to 21% from the increase by 2030. In addition, Turkey has a target of achieving net zero emissions by 2053. Being a party to the agreement is expected to strengthen Turkey's access to green technology and investment opportunities in the future (Deutsche Welle, 2021).

According to the Climate Change Performance Index Report, Turkey has the performance of *"high"* in the overall rating of Renewable Energy when compared with the efforts of 61 countries. Among those, the three best performing countries are Latvia (4th), Sweden (5th) and Denmark (6th), while the three lowest performing countries are Malaysia (59th), Islamic Republic of Iran (60th) and Russian Federation (61st) (Greenwatch, 2020). Countries in the first 3 are not presented as no country did well enough. In this ranking, Turkey rose from 15th in 2019 (Greenwatch, 2019) to 13th place in 2020 (Greenwatch, 2020).

Turkey has the performance of *"low"* in the rating of GHG Emissions when compared with the efforts of 61 countries. Among those the three best performing countries are Sweden (4th), Egypt (5th), and United Kingdom (6th), while the three lowest performing countries are the Republic of Korea (59th), Chinese Taipei (60th), and Saudi Arabia (61st) (Greenwatch, 2020). In this ranking, Turkey rose from 37th in 2019 (Greenwatch, 2019) to 31st place in 2020. The reason why there is no country placed in the top 3 is, again, that no country does enough to stop climate change properly (Greenwatch, 2020).

Turkey performs *"low"* in the overall rating of Energy Use when compared with the efforts of 61 countries. Among those the three best performing countries are Malta (4th), Morocco (5th) and Mexico (6th), while the three lowest performing countries are Saudi Arabia (59th), Canada (60th), and the Republic of Korea (61st) (Greenwatch, 2020). In this ranking, Turkey rose from 49th in 2019 (Greenwatch, 2019) to 47th place in 2020 (Greenwatch, 2020).

Turkey performs *"very low"* in the overall rating of Climate Policy when compared with the efforts of 61 countries. Among those the three best performing countries are Portugal (4th), Finland (5th), and Morocco (6th), while the three lowest performing countries are Turkey (59th), United States (60th), and Australia (61st) (Greenwatch, 2020). Turkey has kept its place same with 2019 by ranking 59th in 2020 (Greenwatch, 2019, 2020).

According to the report, Turkey has the performance of *"very low"* in the overall score, which consists of GHG emissions (40% weighting), renewable energy (20% weighting), and energy use (20% weighting) (Figure 2.1). Among the countries compared, the three best performing countries are Sweden (4th), Denmark (5th), and Morocco (6th), while the three lowest performing countries are Chinese Taipei (59th), Saudi Arabia (60th), and United States (61st). In this ranking, Turkey rose from 50th in 2019 (Greenwatch, 2019) to 48th place in 2020 (Greenwatch, 2020).

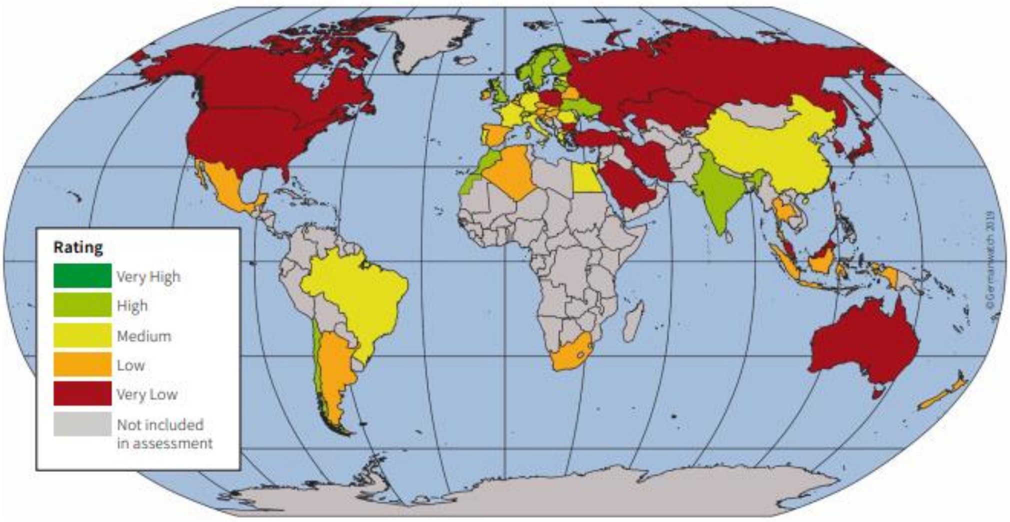

Figure 2.1. Overall climate performance assessment map (Greenwatch, 2020)

In parallel with Turkey's rapid economic development, industrialization, and urbanization, there was an increase of 188% in CO_2 equivalent emissions between the years 1990 – 2018 (IEA, 2018). Regarding that, new environmental commitments and regulations have been enforced in Turkey in recent years (UNFCCC, 2015a).

According to the 11th Development Plan (2019-2023), several measures will be taken to control the activities that contribute to climate change. Some of these will be carried out within the framework of the NDCs with the principles of common but differentiated responsibilities and relative capabilities in international climate change negotiations. Examples of these measures are combating climate change in sectors that cause GHG emissions in accordance with national conditions, and increasing the resilience of the economy and society to climate risks by increasing the capacity for adaptation to climate change. Moreover, Climate Change Action Plans for the 7 regions of Turkey would be prepared. The plan for the Black Sea Region is scheduled to be the first for preparation (T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı, 2019).

Turkey continues its activities to combat climate change within the scope of the "Climate Change Strategy (2010-2023)" such as developing policies and measures and adaptation into national development plans, limiting the rate of increase in GHG emissions without interrupting the development program harmonized with sustainable development principles, improving R&D and innovation capacity for cleaner production, and increasing competition and production in this field (T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı, 2010). In order to facilitate the activities, the ministry established a separate unit concerning climate change issues, and the name of the Ministry is changed to the Ministry of Environment, Urbanization, and Climate Change as of October 29th, 2021.

2.3 The Role of Buildings and Cities in Climate Change

Existing buildings and the construction of new buildings together account for 36% of the global final energy use and 39% of energy-related CO_2 emissions when upstream power generation is included. 82% of the final energy consumption in buildings was supplied by fossil fuels in 2015 (Abergel et al., 2017). Also, today, cities are responsible for more than 70% of global CO_2 emissions (C40 Cities, 2021). Moreover, according to a research conducted by the European Commission, public water supply accounts for 21% of the total water consumption, and buildings comprise a major part of it (European Commission, 2011).

According to the World Bank, annual population growth has increased over years since 1961. Although the rate of growth alters every year and generally has decreased since 1971, the grand total of the population has increased every single year (World Bank, 2020). Concordantly, it was projected that over 230 billion m^2 of new urban development will be constructed in 40 years. This amount is equal to addition of a city with same size as Paris to the world every week (Skidmore Owings & Merrill, 2019).

In late December of 2019, COVID-19 began to spread all over the world, which was then announced as a pandemic. During the pandemic, governments have been enforcing lockdowns which obligated people to stay in their homes most of their time. Consequently, the consumption of energy and water in residential buildings has risen up. Available data have shown that, in USA energy consumption in residential buildings increased by 6-8% as of June 2020 (International Energy Agency, 2020). Water use increased by 10% in San Francisco-USA (Cooley, 2020), 14% in Germany (Lüdtke et al., 2021), and 15% in Portsmouth-UK (Cooley, 2020). Considering all the information above, cities and buildings may have great potential for prevention of the consequences of climate change. At least, shifting from fossil fuels to renewable and clean resources can significantly reduce the contribution of buildings to climate change and reduce relevant affects. On the other hand, designing buildings and cities that use renewable energy is not enough. They must be designed in a way that energy is used wisely as well (Skidmore Owings & Merrill, 2019).

2.4 Green Buildings

World Green Building Council (WGBC) defines the green buildings as;

> "*A building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment. Green buildings preserve precious natural resources and improve our quality of life*." (WGBC, 2016).

Futures such as efficient use of energy, water and other resources, renewable energy use, pollution and waste reduction precautions, reuse and recycling, having decent indoor air quality, use of sustainable, ethical and nontoxic materials, taking environment and the life quality of residents into account in the design, construction, and operation phases of buildings, and also adaptable design to a changing environment can make a building green (WGBC, 2021).

WGBC also defines the green building rating systems as;

> *"Green building rating tools, also known as certification, are used to assess and recognize buildings which meet certain green requirements or standards. Rating tools, often voluntary, recognize and reward companies and organizations who build and operate greener buildings, thereby encouraging and incentivizing them to push the boundaries on sustainability. They kick-start the market by setting standards that then in turn elevate the ambition of government building codes and regulation, workforce training, and corporate strategies"* (WGBC, 2016).

Rating systems are diverse in their methodology and can be used during the phases of planning, designing, constructing, operation and maintenance, refurbishing, and demolition of buildings. Rating systems can often vary according to the type of buildings, such as houses, industrial buildings, or even for a whole neighborhood (WGBC, 2016).

There are around 600 green building rating system in the World (Doan et al., 2017). 54 of them were recognized by WGBC. As of 2016, 1.04 billion m^2 of green building space were certified in the world by WGBC (WGBC, 2016).

WGBC recognizes that rating systems have strong power to transform buildings towards sustainability. WGBC acknowledges that each system is different, and encourages countries to develop or adapt a rating system which suits their own local context and regional agenda (WGBC, 2016). In line with that, some countries have established their own national green building rating systems. Some of the green building rating systems are provided in Table 2.3 with their year of issues.

Table 2.3 Some of the green building rating systems in the world

Country	**Rating System**	**Year Issued**
UK	BREEAM	1990
Hong Kong	HKBEAM	1996
USA	LEED	2000
Australia	GREEN STAR	2003
Japan	CASBEE	2004
Singapore	GREEN MARK	2005
China	GBAS	2006
Germany	DNGB	2007
India	GRIHA	2007
South Africa	GREEN STAR SA	2008
Netherlands	BREEAM NL	2009
United Arab Emirates	ESTIDAMA	2010
France	HQE	2013

Table 2.3 *(cont'd)*

Country	Rating System	Year Issued
Pakistan	SEED	2016
Turkey	BEST	2019

As of July 2021, a total of 547 building projects have been certified with a green building certification in Turkey. Of them, 476 own LEED (Leadership in Energy and Environmental Design) certification (USGBC, 2022), 74 own BREEAM (Building Research Establishment Environmental Assessment Method) certification (BREEAM, 2022), 23 own BEST (Binalarda Ekolojik ve Sürdürülebilir Tasarım) certification (ÇEDBİK, 2021), 4 own EDGE (Excellence in Design for Greater Efficiencies) certification (EDGE, 2021), and 1 own DNGB (Deutsche Gesellschaft für Nachhaltiges Bauen) certification (DNGB, 2021). Therefore, among the certified buildings, 81% have the USA-based, 14% the UK-based, 4% Turkey-based green building certifications. One of the reasons why the Turkish certification system is applied less may be due to its being a fairly new system compared to other established ones. In this study, the national green building rating system of Turkey, BEST, and the most preferred green building rating system employed in Turkey, LEED, will be studied.

2.4.1 BEST (Binalarda Ekolojik ve Sürdürülebilir Tasarım) Green Building Rating System

The BEST certificate was issued by ÇEDBİK (Environmentally Friendly Green Buildings Association) in 2019. Continuing its research and studies in the field of green buildings, ÇEDBİK has created BEST-Residential, a certificate system suitable for Turkey's current conditions, to be implemented in new construction projects. Within the scope of BEST, residential buildings are evaluated under 9 main categories. These are integrated green project management, land use, water consumption, energy consumption, health and comfort, material and resource use, residential life, operation and maintenance, and innovation. The sub-categories under these main categories and credits (points) that can be acquired towards a green building certification can be seen in Table 2.4.

Table 2.4 Main categories and subcategories and credits of the BEST

	Credits
1. Integrated green project management	
1.1. Integrated design	Prerequisite
1.2. Integrated design	1-2
1.3. Environmentally-conscious contractor	2
1.4. Construction waste reduction and waste management	3
1.5. Noise pollution	2
2. Land use	
2.1. Land settlement	1-3
2.2. Disaster risk	3
2.3. Density and housing structure relationship	2
2.4. Reuse of land	3
2.5. Proximity to urban facilities	1-2
3. Water consumption	
3.1. Reducing water consumption	Prerequisite
3.2. Reducing water consumption	1-6
3.3. Preventing water losses	2
3.4. Wastewater treatment and utilization	1-2
3.5. Surface water flow	2
4. Energy consumption	
4.1. Commissioning	Prerequisite
4.2. Energy efficiency	Prerequisite
4.3. Energy efficiency	1-15
4.4. Use of renewable energy	1-7

Table 2.4 *(cont'd)*

	Credits
4.5. Outdoor lighting	1
4.6. Energy efficient domestic appliances	1
4.7. Elevators	2
5. Health and comfort	
5.1. Thermal comfort	3
5.2. Visual comfort	3
5.3. Fresh air	3
5.4. Control of pollutants	2
5.5. Auditory comfort	2
6. Material and resource use	
6.1. Environmentally friendly materials use	3
6.2. Existing building elements use	1-3
6.3. Reuse of materials	1-3
6.4. Local materials use	1-3
6.5. Durable materials	1-2
7. Residential life	
7.1. Universal inclusive design	1-2
7.2. Security	1-2
7.3. Sports and recreation areas	2
7.4. Art	1
7.5. Transportation	3
7.6. Parking area	2
7.7. Working from home	2
8. Operation and Maintenance	
8.1. Waste reallocation and user access	2
8.2. Waste technologies	1
8.3. Building use and maintenance manual	1
8.4. Tracking of consumption values	2

Table 2.4 *(cont'd)*

	Credits
9. Innovation	
9.1. Innovation	1
9.2. Approved consultant	1
TOTAL	110

Buildings are evaluated over 110 points according to the strategies they implement under the given subcategories. They are certified under 4 different certification levels. These are; Approved (45-64 points), Good (65-79 points), Very Good (80-99 points), and Excellent (100-110 points) (Table 2.5). In Turkey, 23 residential buildings that are certified by BEST are categorized as "Approved". There have been no examples of Good, Very good, and Excellent levels of BEST certified buildings (ÇEDBİK, 2021) at the time of this study.

Table 2.5. BEST certification levels (ÇEDBİK, 2019)

	Certification Levels			
	Approved	Good	Very good	Excellent
Total credit required	45-64	65-79	80-99	100-110

A study was conducted to compare the green building rating systems of developed and developing nations (Umaroğulları et al., 2020) with BEST. The contribution of the energy criteria in Green Building Consultancy Services to each component of sustainability was discussed. The percentage of the maximum energy credits that can be gained in the total score was 33% in LEED, 42% in GRIHA, India's green building rating system, and 29% in BEST, among international green building rating systems. BEST was found to be structurally comparable to LEED, but in terms of the credit percentage and priority given to the energy criterion, it was found to be similar to BREEAM. The highest resemblance of BEST was observed with Green Building Initiative, Malaysia's green building rating system, among developing nations (Umaroğulları et al., 2020).

Deligöz and Aktan (2020) compared BREEAM (Int. 2016), LEED (v4.1), and BEST green building systems, which are the top three preferred green building rating systems applied in Turkey. The main purpose of the study was to serve as a guideline for customers in the construction industry. The histories, certification processes, evaluation methods and contents, performance criteria, energy performance classification criteria, and scoring systems of the 3 certificate programs were examined in detail. There was no subjective conclusion as to which certificate was better or worse in the study. As a result of the evaluations, it was seen that each system was designed in line with the geography and socioeconomic characteristics of relevant countries. The study also classified the evaluation criteria as energy, water, materials, and others, and scoring percentages of each green building system were calculated in these categories. As a result, it was seen that LEED gives priority to energy, BREEAM to carbon, and BEST to renewable energy categories (Deligöz & Aktan, 2020).

In another study conducted by Güler and Deniz (2020), LEED and BEST certification systems were examined with a quantitative comparison model. Several suggestions were presented for the development and improvement of BEST, as well as improving the legal infrastructure of the certification system and its brand reputation. According to the results of the research, it was speculated that BEST will certify a desired level at lower costs than LEED. Also, with the use of national certificates, it is expected that the capital will stay within the country and eventually contribute to national economy. However, the fact that the LEED certificate program is an international certificate program makes it preferable. In addition, the high reputation of the LEED certificate program is an important reason why companies prefer this certificate (Güler & Deniz, 2020).

In a thesis study carried out in Uludağ University in Turkey, opinions were received from green building consultants about the materials and resources categories of LEED, BREEAM, and BEST certification systems and the current situation in Turkey. According to the study, the material is the main and tangible factor that enables the buildings to be constructed, and the success of green building certification systems depends on the building materials, thus also the material category. The fact that the preferred green building certification systems are of foreign origin, costs of contractor companies increase. These companies have difficulties in finding certified materials in the building material category. In addition, according to the study, green building consultancy firms work with a focus on LEED approved materials; they are not accustomed to the new certification system of Turkey, BEST (Gökçen, 2020).

2.4.2 LEED (Leadership in Energy and Environmental Design) Green Building Rating System

The LEED certificate was issued by USGBC (United States Green Building Council) in 2000. It is the most widely used green building rating system in Turkey and in the world as well. LEED has been continuously improved by the Council. The most up to date version of LEED in the market is LEED v4.1. For a new construction, LEED BD+C (LEED Building Design and Construction) can be chosen for the rating process (U.S. Green Building Council, 2021)

Within the scope of LEED, buildings are evaluated under 9 main categories. These are integrative process, location and transport, sustainable sites, water efficiency, energy and atmosphere, material and resource, indoor environmental quality, innovation, and regional Priority (Table 2.6).

Table 2.6.Main categories and sub-categories and credits of the LEED

	Credits
1. Integrative Process	
1.2. Integrative Process	1
2. Location and Transportation	
2.1. Sensitive Land Protection	1
2.2. High Priority Site and Equitable Development	1-2
2.3. Surrounding Density and Diverse Uses	1-5
2.4. Access to Quality Transit	1-5
2.5. Bicycle Facilities	1
2.6. Reduced Parking Footprint	1
2.7. Electric Vehicles	1
3. Sustainable Sites	
3.1. Construction Activity Pollution Prevention	Prerequisite
3.2. Site Assessment	1
3.3. Protect or Restore Habitat	2
3.4. Open Space	1
3.5. Rainwater Management	3
3.6. Heat Island Reduction	2
3.8. Light Pollution Reduction	1
4. Water Efficiency	
4.1. Outdoor Water Use Reduction	Prerequisite
4.2. Indoor Water Use Reduction	Prerequisite
4.3. Building-Level Water Metering	Prerequisite
4.4. Outdoor Water Use Reduction	2
4.5. Indoor Water Use Reduction	6
4.6. Optimize Process Water Use	2
4.7. Water Metering	1

Table 2.6 *(cont'd)*

	Credits
5. Energy and Atmosphere	
5.1. Fundamental Commissioning and Verification	Prerequisite
5.2. Minimum Energy Performance	Prerequisite
5.3. Building-Level Energy Metering	Prerequisite
5.4. Fundamental Refrigerant Management	Prerequisite
5.5. Enhanced Commissioning	1-6
5.6. Optimize Energy Performance	1-18
5.7. Advanced Energy Metering	1
5.8. Grid Harmonization	1-2
5.9. Renewable Energy	1-5
5.10. Enhanced Refrigerant Management	1
6.Materials and Resources	
6.1. Storage and Collection of Recyclables	Prerequisite
6.2. Building Life-Cycle Impact Reduction	1-5
6..3. Environmental Product Declarations	1-2
6.4. Sourcing of Raw Materials	1-2
6.5. Material Ingredients	1-2
6.6. Construction and Demolition Waste Management	1-2
7. Indoor Environmental Quality	
7.1. Minimum Indoor Air Quality Performance	Prerequisite
7.2. Environmental Tobacco Smoke Control	Prerequisite
7.3. Enhanced Indoor Air Quality Strategies	1-2
7.4. Low-Emitting Materials	1-3
7.5. Construction Indoor Air Quality Management Plan	1
7.6. Indoor Air Quality Assessment	1-2
7.7. Thermal Comfort	1
7.8. Interior Lighting	1-2
7.9. Daylight	1-3

Table 2.6 *(cont'd)*

	Credits
7.10. Quality Views	1
7.11. Acoustic Performance	1
8.Innovation	
8.1. Innovation	1-5
8.2. LEED Accredited Professional	1
9.Regional Priority	
9.1. Regional Priority: Specific Credit	1
9.2. Regional Priority: Specific Credit	1
9.3. Regional Priority: Specific Credit	1
9.4. Regional Priority: Specific Credit	1
TOTAL	**110**

Projects are evaluated over 110 points according to the strategies they implement under the given sub-categories, and are certified with one of 4 different certification levels (Table 2.7). These levels are; certified (40-49 points), silver (50-59 points), gold (60-79 points), and platinum (80-110 points). In Turkey, 30 buildings are certified with the certified, 62 buildings with silver, 298 buildings with gold, and 58 buildings with platinum levels of LEED (U.S. Green Building Council, 2021).

Table 2.7. LEED certification levels

Certification Levels

	Certified	Silver	Gold	Platinum
Credit required	40-49	50-59	60-79	80-110

In a study conducted in 2012, the infrastructure and functioning of BREEAM and LEED rating systems were discussed and these two systems were compared. Buildings certificated with BREEAM and LEED in Turkey were examined. Suggestions for a green building rating system that can be developed for Turkey were presented (Kaya, 2012).

Within the scope of another study conducted by Görgün (2012), all criteria related to energy efficiency were discussed for LEED and BREEAM rating systems. Afterwards, the norms and standards that these criteria refer to were revealed. According to the study, in order to establish a valid evaluation system in Turkey, first of all, the infrastructure required for these rating systems must be fully prepared. For this reason, the conformity of the norms and standards referenced in the LEED and BREEAM with Turkey were evaluated. At the end of the study, BREEAM appeared to be more suited for the Turkish green certification system, but the implementation of BREEAM word by word deemed not possible. It was suggested that adaptation to Turkish standards were needed (Görgün, 2012).

New buildings that received LEED Gold level green building certification in Europe and Turkey were examined by Baştanoğlu in 2017. In the study, implementation rates of LEED certification criteria for Europe and Turkey were determined. Based on these ratios, the features that were preferred and not preferred in certified buildings were emphasized. As a result of the study, it was determined that LEED certified buildings in Turkey lagged behind LEED certified buildings in Europe, especially in terms of energy performance. Although they have the same certification levels, green buildings in Europe are more energy efficient than those in Turkey. The buildings in Turkey also fall behind the buildings in Europe in terms of reclaiming of lands, light pollution, the use of certified wood and floor coverings with low VOC content, and user vision quality. In these areas, it was seen that the regulations in Turkey and the education level in the sector were lacking. In addition, contrary to a popular belief, it was determined that applications such as renewable energy generation and green energy purchase were preferred at a very low rate in green buildings (Baştanoğlu, 2017).

Aytekin (2019) conducted a study that evaluated an existing office building in Turkey within the scope of LEED. The score of the building was calculated. The building was examined according to the necessary criteria that should be met. Suggestions were made for obtaining a LEED certificate (Aytekin, 2019).

2.5 Cost of Green Buildings

Green Buildings are generally more expensive than traditional buildings of the same size and use (Morris et al., 2007). According to a study conducted in UK, green buildings cost approximately 5-15% more than traditional buildings (Bartlett & Howard, 2000). A higher cost results due to materials, import fees, embedded R&D investments, compliance tests, documentation and consultant fees (Ofek et al., 2018). However, green buildings may also increase revenue and rental rate of a building as well (Eichholtz et al., 2010). Many studies have been conducted to understand the willingness of stakeholders to pay more for green buildings. In Sweden, people are willing to pay 2-4% more for energy efficiency and 5-8% more for water efficiency (Mandell & Wilhelmsson, 2011). In Korea, willingness to pay increases by 3-13% depending on the use of energy saving systems such as energy efficient windows, thicker walls, and ventilation systems (Kwak et al., 2010). In Australia, consumers are willing to pay 10-15% more for buildings with a sustainability certification (Judge et al., 2019). In Turkey, investors are more willing to get green certifications for their buildings mostly in big cities in order to increase their competitiveness in the market (Aktas & Ozorhon, 2015). Stakeholders such as consumers, contractors, and developers need to be convinced that these extra costs are justified (Portnov et al., 2018). Especially in developing countries such as Turkey, justification of an extra cost becomes more important to prompt the stakeholders to go green because of the currency exchange rates. Hence, cost is the most important pillar for choosing to go green in most cases.

Many studies have been carried out related to green building costs. Wide range of studies conducted was specifically on the life-cycle costing of green buildings. The common outcome of the life-cycle costing studies is that the initial cost of green buildings possesses a barrier on noticing the potential savings to be achieved (Illankoon & Lu, 2019). In 2020, another study examined 80 years of life-cycle cost of a building and showed that energy consumption accounts for 67% of the whole life-cycle cost of the building. Hence, reducing energy consumption was concluded as the most crucial factor in a green building (Gopanagoni & Velpula, 2020). Moreover, rather than the whole building life-cycle costs, systems effect on the cost were studied as well. Life-cycle costing of rainwater harvesting systems used in green buildings was calculated. It was concluded that the roof areas of high rise buildings can supply 25.7% of the water required for washing machines in buildings in their life through rainfall harvesting (Gao et al., 2014). A study carried out about the life-cycle cost of solar panels used in residential buildings in India presented a system that provides up to 54% energy cost savings in the whole life of buildings (Kale et al., 2016).

In 2002, it was shown that the green cost premium is between 0.9-21% for different levels of LEED certification (Diener et al., 2002). Two years later, Matthiessen & Morris (2004) found that there is no statistical difference between green and traditional building costs. In the study, 45 green buildings and 93 traditional buildings were examined (Matthiessen & Morris, 2004). Another study conducted by Swarr in UK, compared the costs for four case studies and found 0-7% variance in cost premiums between green buildings (Swarr, 2006). In a study conducted in 2014, as a case study one green residential building was compared with its traditional counterpart. According to the study, it was found that construction cost increased by 10.77% for the green building (Kim et al., 2014). Another study conducted by Vyas and Jha with GRIHA, green building rating system of India, showed that although the initial costs of green buildings were much higher than traditional buildings, cost premiums were 2-5% for three stars (third-best certification level of GRIHA) and 5-17% for five stars (the best certification level of GRIHA) rated projects. Their payback periods were 2.04-7.56 years for three stars and 2.37–9.14 years for five stars rated buildings (Vyas & Jha, 2018). Tatari and Kucukvar explored the relationships between cost premiums and LEED categories and built a neural network model to predict the startup costs of the green buildings based on current construction costs. Data were examined using LEED version 2.2 for 74 LEED certified buildings. Based on the preceding assumption, the additional cost premium for each certification level was collected and computed at 0.66% for certified, 2.11% for silver, 4.41% for gold, and 6.5% for platinum levels (Tatari & Kucukvar, 2011).

2.6 Cost-Based Optimization of Green Buildings

In general, mathematical optimization (or mathematical programming) is a field of applied mathematics concerned with the study of techniques for determining the maximum and minimum values of an objective function by modifying the values assigned to decision variables. Like most engineering optimization problems, variables are constrained by lower and upper boundaries that serve as external dimension limits. Constraints can be in the form of equality and inequality constraints. Depending on the variables and constraints, optimization models can be categorized as linear, non-linear, or binary. Also, regarding the aim, an optimization model can be classified as single or multi-objective. If the model minimizes or maximizes considering a single aim, it is called a single objective problem. If minimization or maximization problem considers multiple aims such as minimizing both, maximizing both, or minimizing one while maximizing the other, it is called a multi-objective model (Longo et al., 2019).

An optimization model was developed by Park in 2017. The model provided deterministic average LEED accreditation costs and the easiest approach for LEED credits to be obtained for various buildings in Korea such as a bank, a daycare center, and a factory. The optimization method helped to get the score required to obtain a LEED certification at a least cost. The study further evaluated green expenses based on several architectural systems, such as the roof, building size, compulsory energy reduction rate, and the number of storeys (Park et al., 2017). In order to discover the optimum green credits that have the minimum life cycle cost to Australian business buildings, a cost calculation methodology using the Green Star Design System in Australia has been developed. This study evaluated all the green credits while calculating life-cycle costs (Illankoon, 2018). In another study (AlAwam & Alshamrani, 2021), a stochastic model was developed for assessing the startup and green costs of different types using a Monte Carlo simulation. In addition, a risk evaluation model was established utilizing an efficient frontier technique to help contractors and decision-makers to achieve an equal balance between cost and sustainability. 200 buildings were studied by transforming their LEED scores into monetary values, considering the degree of certification, building area, and structure type (AlAwam & Alshamrani, 2021).

Until now, many articles have optimized green building rating systems on a cost basis. However, BEST has not been studied much because it is a newly published green building rating system unique to Turkey. In fact, there are no studies examining BEST with cost-based optimization. Therefore, this study would provide a contribution to the literature. In addition, LEED, which is the most preferred green building rating system in the world, was compared with BEST. Such a comparison is also not available in the literature. In addition, this study will show the systems/materials/equipment to be selected for the most cost-efficient way to obtain each BEST certification level for a reference building. There are green building optimization studies in the literature. However, these studies did not present the systems/materials/equipment used in the construction of green buildings. In this study, all the systems/materials/equipment used in the building were revealed by considering constraints and assumptions made in the study. Systems/materials/equipment that will be more advantageous in terms of initial costs and brand image for each case study will be shown.

CHAPTER 3

METHODOLOGY

The goal of this study is to propose an optimization model in order to obtain a green building certificate at the least cost based on the BEST certification system, the national green building rating system of Turkey. In addition, it is aimed to have a comparison between BEST and LEED, one of the most well-known green building rating systems in the world and in Turkey. This is done through comparing the certification level that can be obtained by LEED for the optimal systems selected for BEST via cost-based optimization. In order to conduct the study an ad-hoc optimization model is developed. Output of the model will show the approximate cost to construct a typical building in Ankara for each certification levels of BEST and LEED. Furthermore, the materials/equipment/systems suggested to be purchased will be presented for each certification levels of BEST and LEED. Additionally, water and electricity savings of each certification levels of BEST and LEED will be revealed. Afterwards, corresponding LEED levels of BEST will be determined and then compared with each other.

There are 9 main credit categories in the BEST green building certification system. These are integrated green project management, land use, water consumption, energy consumption, health and comfort, material and resource use, residential life, operation and maintenance and innovation. Moreover, there are sub-categories associated to a given credit category. In this study, sub-categories of BEST were classified as cost-dependent and cost-independent. Some sub-categories have no or insignificant monetary value such as preparing a building manual and employing an environmentally friendly contractor. There are 22 cost-dependent and 23 cost-independent sub-categories. Among the 22 cost-dependent sub-categories, 4 of them are partially cost-dependent. Cost-dependent, independent and partially dependent sub-categories are provided in Appendix A. It is assumed that all cost-independent categories were met and maximum credits were obtained. Therefore, cost-dependent sub-categories would define the further credits that can be obtained towards a desired BEST certification. This also means that the cost that will be calculated is the total cost of the materials/equipment/systems selected for cost-dependent categories by the optimization model.

Cost-dependent credits were calculated by various methods. Electricity consumption calculations were conducted in three steps. The first step is the electricity consumption calculation of building structural elements such as walls, floors, windows, and roof. For structural elements there are also 3 options. The options are the elements are coherent with the Turkish Building Code TS825 Standard (TSE) issued in 2008, coherent with a more recent study conducted in 2016 by IZODER (Isı Su Ses ve Yangın Yalıtımcıları Derneği - Heat, Water, Sound and Fire Insulation Association), and non-green elements. For instance, for the choice of walls, the choice would be amongst a TSE Standard coherent wall, an IZODER study coherent wall, or non-green wall. The optimization model chooses one of these elements. According to the TSE Standard, there are 4 climate zones in Turkey. Ankara is situated in the 3rd climate zone. On the other hand, for IZODER study, there are 6 climate zones for Turkey. Ankara is situated in the 4th coldest zone, called as Rather Cold. Measure of the heat transmission through structural elements is represented by the U-value. U-values for the structural elements were chosen according to the maximum U-value limits provided in TSE and IZODER standards for the climate zone of Ankara. The U-values, however, generally are not provided in the Turkish Market. Hence, thermal resistance values were found instead. Thermal resistance values of the layers of structural elements were summed up and the reciprocal of the summation were equal to the U-value.

For the electricity consumption calculation of the structural elements, the buildings of concern were drawn in Autodesk Revit Software. Then, the drawings were imported to Autodesk Ecotect Analysis Software for energy analyses. The software adjusted the global position and climate values for Ankara. Moreover, it calculated the solar access of the buildings. Then weather tool revealed the best orientation of the building. Then U-values of the elements were defined in the Software. Energy analyses of the buildings were conducted for each structural element. First of all, energy analysis of a base building whose all materials/equipment/systems are non-green was conducted. Afterwards, electricity savings brought by each structural element were found for the base building by running the Ecotect Analysis software for every structural element one by one. This is because energy credits in BEST were given according to the percentage savings in comparison to the base building.

Energy demands of materials/equipment/systems that consume electricity were determined by considering their power capacity. In this step, Autodesk Revit was not employed. Energy demands of the fridge, dishwasher, and washing machine, lightening inside and lightening outside were calculated with the same approach. There are 2 options for each of them. These are green and non-green options. Yearly energy demand for one unit was multiplied by the number of appliances in a building to determine the overall demand. Then, the electricity consumption of a green option was subtracted from the non-green opponent in order to find out the electricity savings from choosing the green option. Every household was assumed to have 1 fridge, 1 dishwasher, 1 washing machine, 20 indoor lightening. 10 outdoor lightening for each building. As dishwasher and washing machine consume both energy and water, they were imported to the model separately. Then, electricity savings of renewable energy systems, which are solar, wind, and solar water heater, were calculated according to the unit capacities of selected systems. The model offers the option of choosing the amount of the renewable energy systems. However, there is 10 kW installation limit for the buildings according to the Turkish Regulation on Unlicensed Electricity Production in the Electricity Market in force.

For water consumption evaluations, the calculation method used in the BEST certification was used for green (EPA WaterSense labeled) and non-green materials/equipment/systems. The total water consumption of a household is equal to the summation of water consumption in toilets, showers, kitchen taps, bathroom taps, dishwashers, the garden, and the rainwater harvesting system. According to the

BEST, water usage calculations were conducted per household. Usage frequency and intensity for these systems were provided by BEST. Water consumption in toilets was calculated by the multiplication of an effective washing volume which is a parameter specific to the toilet type purchased, usage frequency, intensity of use, and female to male ratio which was accepted as 1. Shower, kitchen and bathroom tap water consumptions were calculated by multiplying flowrate, usage frequency and intensity of use which are specific to systems purchased. For the dishwasher and washing machine, the calculation was conducted by multiplying the amount of water used for each wash, usage frequency, and the intensity of use, which are specific to the machines purchased.

Water consumption in a garden was calculated by multiplying the garden area and the amount of water used for irrigation divided by the number of households. The value of water used for irrigation is the water need of the garden and it was calculated via the method of FAO (Food and Agriculture Organization) (FAO, 2021). First, crop water need of the garden was calculated. This value is equal to the multiplication of the reference crop evapotranspiration and crop factor. The garden of the case study was assumed as 20 m^2 and it was planted with roses having the crop factor of 0.5. The reference crop evapotranspiration value depends on the location. This value is 900 mm/year and it represents the amount of water lost by evapotranspiration in a year. Afterwards, effective rainfall value of Ankara was calculated. The average rainfall value of Ankara is less than 75 mm/month (General Directorate of Meteorology of Turkey, n.d.). According to the method of FAO, since average rainfall value of Ankara is 75 mm/month, the average rainfall value was multiplied with 0.6 and subtracted by 10. The calculation gives the effective rainfall. The actual water demand of the crop then was calculated by subtracting effective rainfall from reference crop evapotranspiration value. Moreover, irrigation water demand was calculated by adding the amount of water needed to saturate the soil, percolation and seepage loses, water needed to establish a water layer and crop water need. The result was then subtracted from effective rainfall. The water need of the garden was calculated by the multiplication of the unit irrigation water need and the area of the garden. As, water calculation was applied for a household, the garden water need was divided by the number of households for a given building. The water requirement of the garden can be provided by either drip irrigation or sprinklers. The choice was made by the model. Finally, water need was divided by field application efficiency for each building.

According to the Regulation on the Amendment of the Planned Areas Zoning Regulation published on July 11th 2021, for the mechanical installation projects of the buildings to be built on parcels larger than 2000 m^2, it is obligatory to include a rainwater system in order to collect the rainwater from the roof surface in a tank by filtering, if necessary, and use it in toilet flushing in buildings. Since the floor area of the building examined in this study is 561.75 m^2, it is not within the scope of this requirement. However, it should not be forgotten that if the floor area of the building to be constructed is more than and equal to 2000m^2, the rainwater system must be chosen by the model as mandatory (T.C. Çevre Şehircilik ve İklim Değişikliği Bakanlığı, 2021). Rainwater calculation was conducted by two options; a system for toilets only and for a system for both toilets and a garden. The decision is made by the optimization model. The rainwater calculation depends on the chosen toilet system, either green toilet or non-green, as well as the chosen irrigation system for a garden, either sprinkler or drip irrigation. For instance, if a green toilet and drip irrigation was chosen by the model, rainwater calculation is equal to the water consumption of the green toilet and drip irrigation. After the calculations of water and energy consumptions, other cost-related credits were calculated according to the presence of green materials/equipment/systems.

Optimization model was solved by LINGO 18.0 optimization software. LINGO is a quick and efficient tool that makes mathematical programming problems simple to input, analyze, and solve (Zhang, 2011). It assists in finding the optimal solution to an optimization problem with well-defined constraints in the shortest time possible (Awe et al., 2020). As a result, it is commonly used in mathematical, scientific, and industrial applications. Linear programming, nonlinear programming, quadratic programming, and integer programming problems can be handled by LINGO. Users can utilize LINGO to establish programming problems by invoking a modeling language (script) and several standard mathematical functions (Zhang, 2011). LINGO scripts of the study are provided in Appendix F.

The optimization model chose among different alternatives of materials/equipment/systems to reach a given BEST certificate level. Total costs and materials/equipment/systems chosen for each scenario were attained. Afterwards, water and electricity savings of each scenario in reference to a base building were calculated. While doing that, water consumption cost has been determined by the multiplication of water saved, water consumption unit price, and number of households, as shown in the optimization model development section. Water consumption unit price of 2021 was taken from ASKI (General Directorate of Water and Sewage Administration of Ankara). For the calculation of the water consumption unit price in the years ahead, water consumption unit price average increase rate has been calculated by taking the average of the previous increase rates taken from Central Bank of Turkey. Electricity consumption cost, on the other hand, was calculated by multiplying the electricity saved and electricity consumption unit cost. Electricity saved signifies non-green building electricity consumption times the percent electricity saved from a green building. Percent electricity saved from a green building was used because in the electricity calculation recommended in BEST, the credits were distributed considering the percent electricity saved, not the amount of the electricity consumed, unlike water calculation. Electricity consumption unit price in 2021 was obtained from TEDAŞ (Türkiye Elektrik Dağıtım Anonim Şirketi - Turkish Electricity Distribution Corporation). For the following years, electricity consumption unit price average increase rate was found by again considering the average of the previous increase rates taken from Central Bank of Turkey. Water and electricity consumption unit prices were provided in Turkish Liras by aforementioned Turkish governmental organizations. The unit prices were first converted to US Dollars using the currency exchange rate of 7.35 TL/USD. Net Present Value of the savings were calculated using an US Dollars inflation rate of 1.9%. All of the costs were considered in US Dollars due to rapidly changing currency exchange rates in Turkey. The corresponding Turkish Lira value can be obtained by multiplying the costs by the current exchange rate.

3.1 Description of the Study Area

Ankara, the capital city of Turkey, was chosen as the city where the green buildings constructed. Ankara is situated in between 38^0 44' - 40^0 45' N and 30^0 49' - 33^0 52' E (Figure 3.1). In the city, the continental climate prevails. Winter temperatures are low and summer is hot. The hottest months are July and August, and the coldest month is January. In the provincial scale, the average temperature is 12.6 °C and the annual average rainfall is 413.6 mm. The highest temperature recorded in years between 1927 to 2020 was 41°C, and the lowest temperature was -24.9°C (General Directorate of Meteorology, 2021b). The number of days with frost is 60 to 117, and the number of snowy days is 30.5 per year, on average (Governorship of Ankara, 2021a). Strong winds are seen in March and April. The highest wind speed detected is 34 m/sec (General Directorate of Meteorology, 2021b).

Figure 3.1. Geographical location of Ankara

The solar energy potential map of Turkey is given in Figure 3.2. According to the map, most of the area of Ankara is located in the orange region and has a long-term average energy potential of 4.2 kWh per day and 1534 kWh/kWp per year. This value is named as specific output and refers to how much energy (kWh) is produced for every peak kW (kWp) value of the module capacity over a year (World Bank, 2021a).

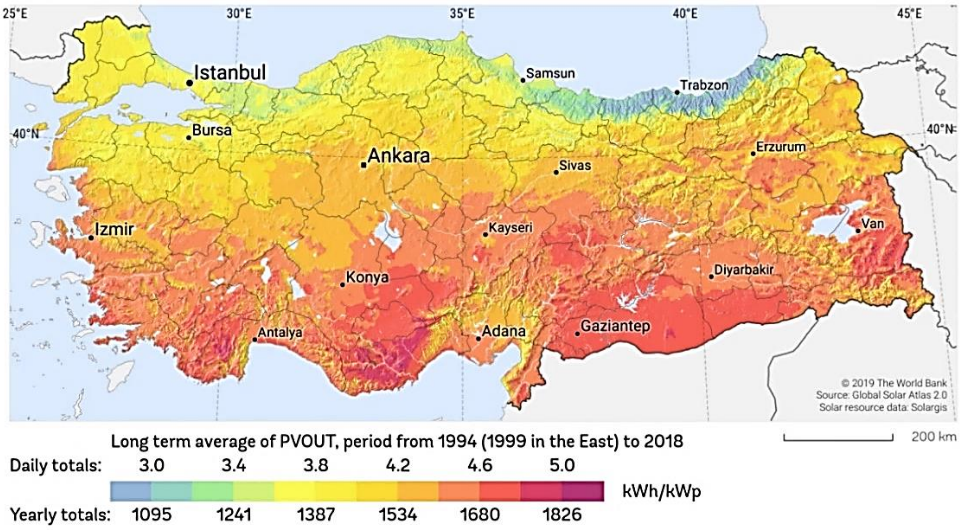

Figure 3.2. Solar power potential map of Turkey (World Bank, 2021a)

The map of wind energy potential of Turkey is given in Figure 3.3. This potential depends on the magnitudes of wind speeds observed. The higher the wind speed, the greater is the potential. According to the map, Ankara is located in green, yellow and orange regions. Wind speeds in these regions are between 3.5 m/sec and 5.5 m/sec (World Bank, 2021b).

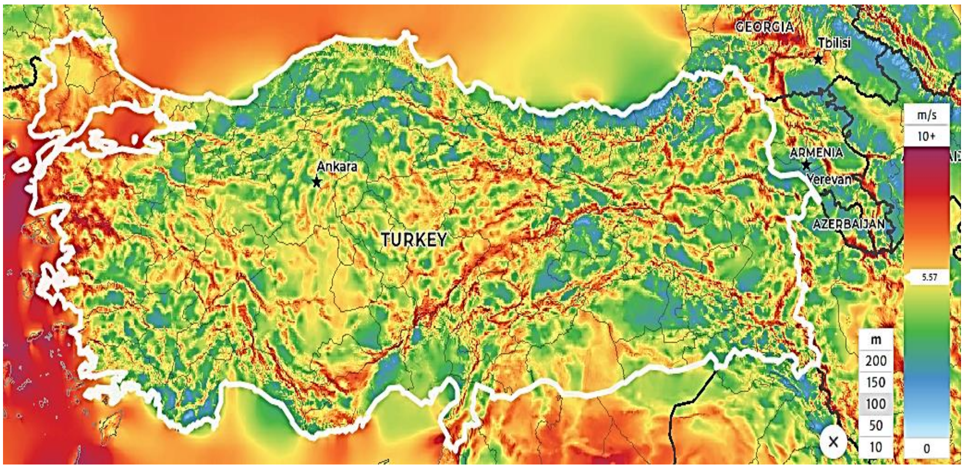

Figure 3.3. Wind power potential map of Turkey (World Bank, 2021b)

Considering the 2020 census, Ankara is the second most crowded city of Turkey with 5,663,322 people (TÜİK, 2021a). The population has been increasing for years. Population of Ankara over last 20 years is shown below.

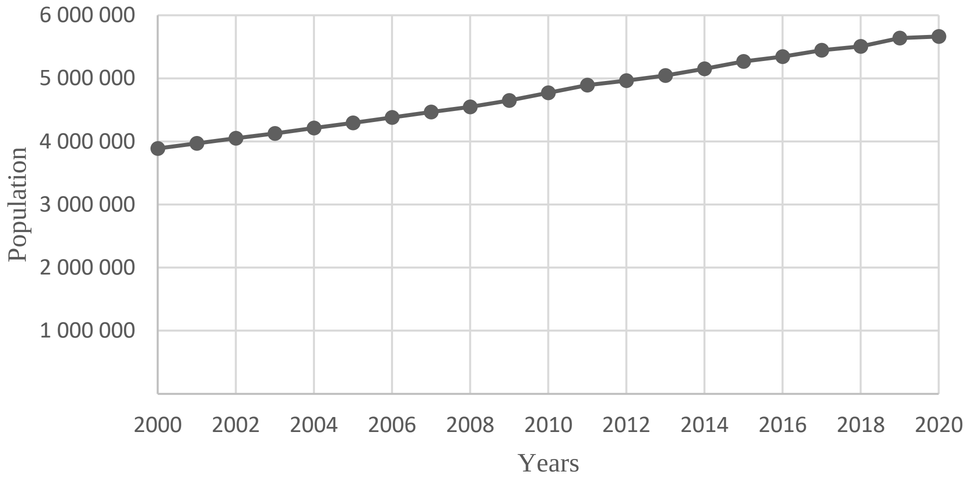

Figure 3.4. Population of Ankara over 20 years (TÜİK, 2021a)

The reason for the high population is mainly the diverse economic activities and educational opportunities. Ankara is among the provinces of Turkey with an industry-based economy. When the production activities carried out in Ankara are examined, it is seen that it has an important place in the wood-working branch throughout Turkey. Lumberjacks, furniture makers, lacquerers and upholsterers operating in this branch of production make production in more than 13,000 workplaces in Ankara's Siteler District. While there were few industrial establishments such as the beer factory established in 1925, the cement factory established in 1926, and the gunpowder factory established in Elmadağ District, the number of industrial establishments increased rapidly in recent years and gained diversity. In addition to establishments belonging to the food industry such as pasta, flour, vegetable oil, dairy products, sugar, wine, beer, cement, tractors, agricultural tools and machinery, engines, paints, bricks, tile and forest products, furniture, mineral industrial establishments producing goods and weaving have also begun to appear. The most important investments related to the defense industry were also made in Ankara. Some production activities carried out in Ankara have the feature of being the only one in Turkey in terms of their subjects. For example, serial production of gears with bearings is carried out only in Ankara. In addition, the production of dialysis machine with morphine, which is used as a pharmaceutical raw material, is also a production activity carried out only in Ankara (Governorship of Ankara, 2021b). In terms of education, there are also 21 universities in Ankara. Of them, 13 are private and 8 are public universities. In all universities, there are total of 319,406 students registered (YÖK, 2021).

3.2 Description of the Buildings and Scenarios Considered

In order to apply the optimization model, a reference building was selected by considering the buildings have been recently constructed by TOKI in Ankara (TOKI, 2021). A 4-storey building which is a typical medium-rise residential building designed and constructed by TOKI and it is considered as a reference residential building of Turkey (Dino & Meral Akgül, 2019). The building has total floor area of 2247 m^2.

4-storey and floor area of 2247 m^2 is a common building type in Turkey. Therefore, it was stated as one of the reference buildings of Turkey in the literature. WGBC encourages green building rating systems to be specific to countries. Yet, in order to get more accurate results for specific comparisons, the rating systems must be reduced to be region-specific rather than country-specific. Therefore, a city was chosen to conduct the study to obtain mainly climate-specific parameters. The case study is the capital city of Turkey, Ankara. The city is the second largest city in Turkey in terms of population. High population requires high number of buildings. Therefore, conducting this study considering Ankara was preferred. Also, when we look at the climate map of Turkey, Ankara is in the climate zone of Continental Mild Zone. This climate zone is the largest climate zone as can be seen in the Figure 3.5. Therefore, the climate is also quite representative for Turkey.

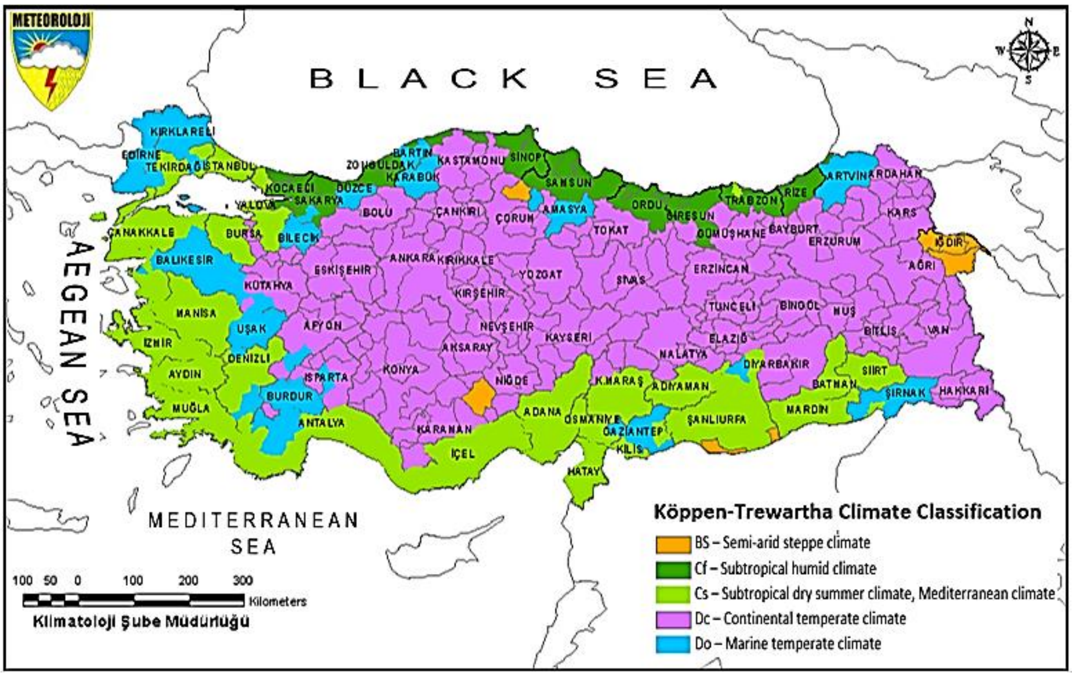

Figure 3.5. Climate of Turkey according to Köppen-Trewartha Climate Classification (General Directorate of Meteorology, 2021a)

Each floor of the reference building is occupied by 4 households. Therefore, the reference building has 16 households. According to the TUIK, average number of people in a household was 3.30 in 2020. Therefore, 3.30 was rounded up to the whole number and it was accepted that each household has 4 family members as occupants (TÜİK, 2020a). In addition to the building used as the reference base-case, buildings with higher number of storeys were considered as well. For this purpose, the new buildings built by TOKI in Ankara in recent years through urban transformation projects (TOKI, 2021) were evaluated. Based on the evaluation, 7-, 12-, and, 15-storey residential buildings were selected. For comparison, it was assumed that these buildings have the same floor plan with the reference base-building. 7-, 12-, and, 15-storey buildings have 28, 48, and 60 households, respectively, and again every household has 4 occupants.

According to the study conducted by Tunc and Al-Ageedi, when the number of storey increases, shear wall area increases as well (Tunç & Al-Ageedi, 2020). Therefore, the net floor area that is occupied by the residents decreases when floor area increases for the same floor plan. In the study it was assumed that, the floor area stays the same with the increasing number of storeys.

Four different BEST certification levels were targeted for each building. For instance, the 4-storey building can be constructed to obtain either an "Onaylı (Approved)", "İyi (Good)", "Çok İyi (Very Good)", or "Mükemmel (Excellent)" levels in BEST certification. For example, the 4-storey building can be constructed to obtain either an Approved (45-64 credits), Good (65-79 credits), Very Good (80-99 credits), and Excellent (100-110 credits) levels in BEST certification. Overall, 16 cases were considered in cost-based optimization, each having a building of different storeys (4-storey, 7-storey, 12-storey, and 15-storey) aiming to achieve a different BEST certification level (Approved, Good, Very Good, Excellent).

In order to distinguish between cases, a naming convention is used. A number is used to state the number of storey followed by a hyphened letter representing the first letter of the certification level. For instance, case `7-g` represents the case of constructing a 7-storey residential building with a `Good` certification level of BEST. The cases and corresponding titles are presented in Table 3.1.

Table 3.1. Titles of the cases studies

BEST certification level aimed	**Building height**			
	4-storey	**7-storey**	**12-storey**	**15-storey**
Approved	4-a	7-a	12-a	15-a
Good	4-g	7-g	12-g	15-g
Very good	4-vg	7-vg	12-vg	15-vg
Excellent	4-e	7-e	12-e	15-e

A summary of the basic assumptions used for the buildings considered is as follows:

4-storey residential building: This is the reference base-building which is also used for comparisons to higher storey buildings as well. The base floor area of the building is 561.75m^2 and the total building floor area is 2247 m^2. The ceiling height throughout the building is 3.0 m. There are 16 flats in total and every floor contains four separate flats of 128m^2 floor area each. There is also a hallway of 48m^2 in each floor between flats. Every flat has 4 occupants with a total of 64 residents residing in the building (Dino & Meral Akgül, 2019). The floor plan of the building is shown in Figure 3.6. Front view and corner view of the building is shown in Figure 3.7.

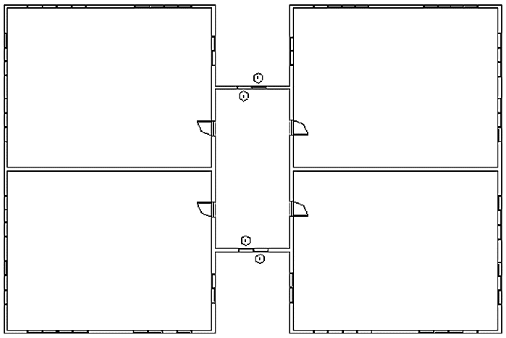

Figure 3.6. Floor plan of the 4-storey building

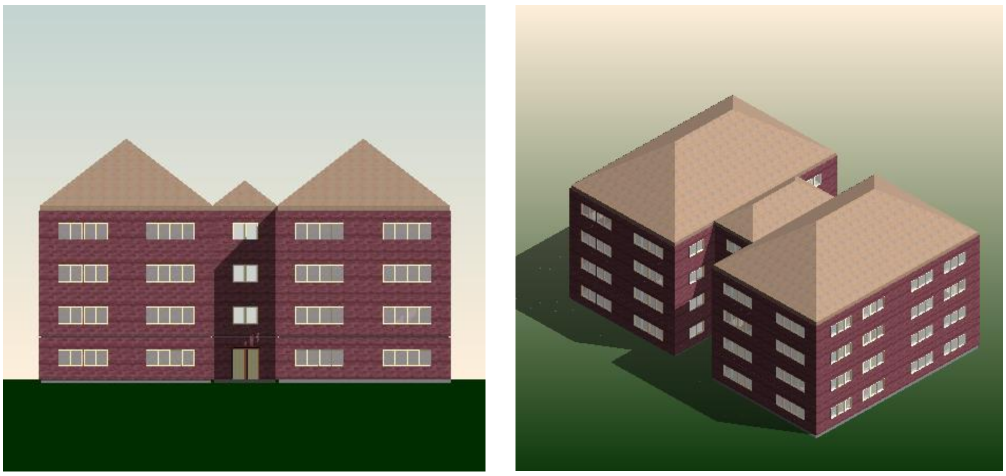

Figure 3.7. Front view (left), diagonal view (right) of the 4-storey building

7-storey residential building: The base floor area of the building is 561.75m^2 and the total building floor area is 3832.25 m^2. The ceiling height throughout the building is 3.0 m. There are 28 flats and every floor contains four separate flats of 128 m^2 floor area each. There is also a hallway of 48m^2 in each floor between flats. Every flat has 4 occupants with a total of 112 residents in the building. Front view and diagonal view of the building are shown in Figure 3.8. The floor plan is the same as the one for the reference base-building (Figure 3.6).

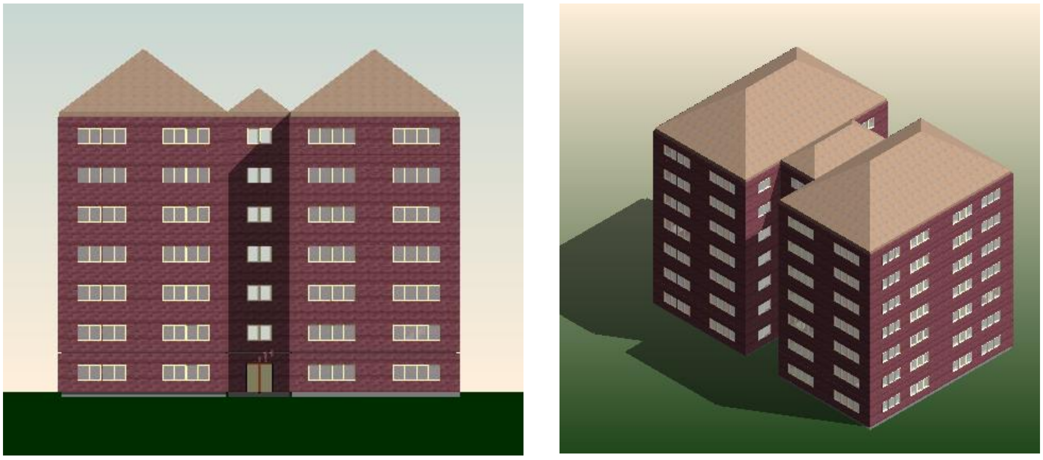

Figure 3.8. Front view (left), diagonal view (right) of the 7-storey building

12-storey residential building: The base floor area of the building is 561.75m^2 and the total building floor area is 6741 m^2. The ceiling throughout the building is 3.0m. There are 48 flats and every floor contain four separate flats of 128m^2 floor area each. There is also a hallway of 48m^2 in each floor between flats. Every flat has 4 occupants with total of 192 residents. The front view and diagonal view of the building are shown in Figure 3.9. The floor plan is the same as the one for the reference base-building (Figure 3.6).

Figure 3.9. Front view (left), diagonal view (right) of the 12-storey building

15-storey residential building: The base floor area of the building is 561.75m^2 and total building floor area is 8426.25 m^2. The ceiling throughout the building is 3.0m. There are 60 flats and every floor contain four separate flats of 128m^2 floor area. There is also a hallway of 48m^2 in each floor between flats. Every flat has 4 occupants with total of 240 residents. The front view and diagonal view of the building are shown in Figure 3.10. The floor plan is the same as the one for the reference base-building (Figure 3.6).

Figure 3.10. Front view (left), diagonal view (right) of the 15-storey building

3.3 BEST Scoring

There are 9 main credit categories in the BEST green building certification system (Table 2.4). These are integrated green project management, land use, water consumption, electricity consumption, health and comfort, material and resource use, residential life, operation and maintenance and innovation. Under these main credit categories, there are sub-categories, associated with a given main category. In this study, score sub-categories of BEST were classified as cost-dependent and cost-independent. Cost-independent sub-categories do not require an installation of a building component or requirements are already met. They do not have or have insignificant monetary value such as preparing a building manual and employing an environmentally friendly contractor. For cost-dependent sub-categories, on the other hand, total attainable credits are gained in whole or in part by installing systems, purchasing materials, and applying technologies. A number of assumptions have been made for the building considered in this study in order to earn full credits from the sub-categories that are cost-independent as will be provided below. In total, there are 22 cost-dependent and 23 cost-independent sub-categories. Among the 22 cost-dependent sub-categories, 4 of them are partially cost-dependent. These categories are shown in Appendix A.

It is assumed that all cost-independent sub-categories were met and maximum credits were obtained. Therefore, cost-dependent sub-categories would define further credits that can be obtained towards a desired BEST certification. This also means that the cost that will be calculated is the total cost of the materials/equipment/systems selected by the optimization model. The maximum total points gained from cost-independent sub-categories was 52 points. In order to achieve this sum, below assumptions were used for relevant cost-independent sub-categories. Below numbering of the sub-categories is with respect to Table 2.4. Points in parentheses represent the score attained for a given sub-category.

Prerequisite 1. Integrated Design: An electrical engineer, civil engineer, control-commissioning-acceptance specialist, mechanical engineer, architect, project manager and contractor are involved in all stages of the project. Individuals in the project team are members of relevant professional chambers and/or have at least 3 years of experience in the relevant subject. Periodic meetings are held and meeting reports are kept in order to determine and follow up the duties and responsibilities of the project team.

Sub-category 1.1. Integrated Design (2 points): In addition to the prerequisite given above, experts and members of major disciplines are included in the project team. The project team includes an environmental engineer, a lighting specialist, a landscape architect, a structural engineer, a city-regional planner, an interior architect, and an acoustics specialist.

Sub-category 1.2. Environmentally-conscious contractor (2 points): An environmental management plan has been prepared for the construction phase. Responsible staff has been appointed on-site for the implementation of the environmental management plan. The contractor firm has ISO 14001 environmental management certification, and the representative of the contractor on-site also holds the ISO 14001 Internal Auditor Certificate.

Sub-category 1.3. Construction waste reduction and waste management (3 points): The type, amount and disposal method of waste generated at the construction site have been determined. Plans including the instructions for the reuse or recycling of wastes were prepared. A representative from the main contractor group has been appointed for waste management. Construction waste is properly grouped. Furthermore, 45% of the wastes by weight or volume are recycled and/or reused. Construction waste management monthly progress table is filled regularly.

Sub-category 1.4. Noise pollution (2 points): Noise sensitive buildings within the 800 m radius around the building have been identified. There are no existing noise-sensitive areas or buildings within this radius.

Sub-category 2.1. Land settlement (3 points): A report about minimizing the damage on water resources or river beds, protecting vegetation and natural life, and reducing potential harmful effects, has been prepared by competent urban planners and landscape architects with 5 years of experience and the specified measures are implemented. The report includes the studies of analytical survey, solar and wind uptake of the land, impact on water resources and stream beds, protection of vegetation and natural life, and the structure of the land and adaptation to topography.

Sub-category 2.2 Disaster Risk (3 points): A report has been prepared on measures against disasters. Measures for disasters to cause the least damage have been specified. Past and present analysis studies have been made on the geological structure of the project site. The ratio of public open spaces, which serve as escape points for possible earthquake situations, to closed areas, has been measured. The flood level of the land has been determined. In order to prevent the building and the land from becoming an island in case of floods, the entrance of the building and the access roads of the land were built at least 6 m above the calculated flood level.

Sub-category 2.3. Density and housing structure relationship (2 points): The planning was made in accordance with the zoning status of the relevant parcel and the plan notes, and the areas outside of the building were arranged to meet the needs of urban facilities and green areas. Associations have been made with other social functions in the proximate surroundings in the region, relations of neighboring parcels and opportunities of neighboring parcels to benefit from the project area were evaluated. The effect of the equivalence value of the project on carrying capacity and ecological values according to the upper scale plans has been examined. The population density and appropriate housing typology defined in the project were evaluated.

Sub-category 2.4. Reuse of land (3 points): The area where the project is located can be defined as an area suitable for reuse. This type of area is defined as they have been used for a certain function or functions for a period and will be re-functionalized depending on the development and needs of the urban structure. In 75% of the floor area of the building, there has been housing for the last 50 years. Then the buildings were demolished before the project owners have bought the premises.

Sub-category 2.5. Proximity to urban facilities (2 points): The project is located less than 500 meters from a mosque, ATMs, a hairdresser, a restaurant, a farmers' market, a green area, a super market and a dry cleaner.

Prerequisite 2. Reducing water consumption: The amount of water consumption per household has been calculated and the value does not exceed 85m^3/year.

Prerequisite 3. Commissioning: An authorized person with sufficient competence has been appointed as the control-commissioning-acceptance process to conduct the necessary work. The authorized person works for the company that has undertaken the commitment of the building, but did not take part in the design or contracting processes of the building.

Prerequisite 4. Energy efficiency: Dynamic modeling and simulation tools were used for building energy modeling, and the energy performance-weighted improvement rate is at least 6%. The total number of hours that do not provide heating and cooling set temperatures depending on the usage schedules in the building does not exceed 300 hours/year.

Sub-category 4.2. Renewable energy (2 points): The feasibility study for renewable energy technologies at the project stage via an energy expert accepted by the authorities was prepared. The study includes the renewable energy technologies that can be handled within the scope of the project. The annual amount of energy to be obtained was examined. While examining that payback periods, land use, noise and planning methods were considered.

Sub-category 5.1. Thermal comfort (3 points): Thermal comfort analyzes were made according to the Fanger method described in the TS EN ISO 7730 standard. Using this method, it has been shown for the whole year that the following conditions are met for all regularly used spaces in the building: PPD (Predicted Percentage of dissatisfied) and PMV (Predicted Mean Vote) values meet the conditions such that PPD is less than 10% and PMV is bigger than -0.5 and but less than 0.5.

Sub-category 5.2. Visual comfort (3 points): In terms of natural lighting, at least 50% of the annual daylight lightens the living rooms and kitchens. Average horizontal illumination level (Em) of excess daylight is more than 100 lux in 95% and more than 300 lux in 50% of the working areas in the building where 0.85 m height from the floor and 0.5 m away from the walls. In terms of artificial lighting, an average horizontal illumination level of 100 lux was achieved in the living room, kitchen, study and bedrooms of the building in the working area where 0.85 m height from the floor and 0.5 m away from the walls. The color rendering index (Ra) of all lamps is more than 80.

Sub-category 5.4. Control of pollutants (2 points): When determining the interior equipment, documents of the relevant pollutant rates of materials were requested. It was presented as a suggestion in the "Building Use and Maintenance Manual" for the materials to be applied during use of the building. The pollutant content and rate were tested in accordance with the relevant standards and this rate does not exceed the limit values.

Sub-category 6.1. Environmentally friendly material use (3 points): 20 of the structural building materials used in the construction have an environmental label such as EU ECO LABEL (eco-label), EPD (environmental product declaration), NATUREPLUS, CE, Cradle to Cradle, FSC, PEFC, which are specified in relevant references.

Sub-category 6.2. Existing building elements use (0 point out of 3): The buildings were built from scratch, and no old building remains were used during construction. Therefore, the buildings cannot get points from this category.

Sub-category 6.3. Reuse of materials (1 point out of 3): This is a partially cost-dependent sub-category. 20% by-weight of the aggregate used in specified basic building elements were recycled aggregate. The aggregate was obtained from a distance of at most 50 km away from the site.

Sub-category 6.4. Local materials use (3 points): In order to reduce emissions and fuel consumption from transportation, at least 30% of the material used (in terms of cost or volume), was produced within 500 km radius or within 500 km transportation route. Furthermore, at least 10% of the materials used in terms of cost or volume are local and regional materials produced within 200 km of the project.

Sub-category 6.5. Durable materials (1 point out of 2): This is a partially cost-dependent sub-category. The warranty periods or the service life of the building elements used in building core, specified by the independent institutions, are at least 30 years, excluding the periodic maintenance purpose.

Sub-category 7.1. Universal inclusive design (2 points)**:** Arrangements have been made to ensure that all users, including those with disabilities, children and people with restricted movement due to old age or illness, can use the building comfortably such that:

- In the building, there is a special working room reserved for the doorman, technical, cleaning and maintenance staff in an area where the users can access easily.
- There is a 12 m^2 common area that receives daylight, equipped with suitable furniture, where the floor owners can gather.
- There are two benches provided by the municipality at the entrance of the building.
- There are ramps with suitable slopes, illuminated walkways, entrances and passages, and common areas.
- The elevators suitable for disabled people use.
- On the ground floor, there is a toilet and a bathroom that can be adapted for disabled use.
- There is an easily accessible room on the ground floor that can be arranged as a bedroom for people with reduced mobility.
- The places of the door, window handles and key entrances are arranged in a way that people with limited movement can use them.
- The stairs inside the building are suitable to mount a disabled platform if needed.
- There are contact surfaces at the entrance of the building for the visually impaired.

- There is a 2 m^2 storage area per a household.
- There is a 12 m^2 common area that receives daylight, equipped with suitable furniture, where the floor owners will gather.

Sub-category 7.2. Security (1 out of 2 points): This is a partially cost-independent sub-category. Pedestrian and bicycle roads are shared. This road is 3 meters wide and directly connected to the building entrance from the main road. An emergency action plan has been prepared for the building. The other 1 point can be earned if other cost related criteria specified in the certificate are applied by the optimization model. Therefore, that additional 1 point is subject to a cost-related item.

Sub-category 7.3 Sports and recreation areas (2 points): The building is located at a distance of less than 1000 meters (15 minutes walking distance) to a walking track, a bicycle track, an outdoor basketball court, an indoor sports hall, a park, a children playground, a cafe and an ornamental pool.

Sub-category 7.5 Transportation (3 points): The distance from the building entrance to the public transportation point is less than 500 meters. Public transportation services are available at least 4 times per hour.

Sub-category 7.6 Parking area (1 out of 2 points): This is a partially cost-independent sub-category. Car parks are of appropriate width. There is an electric car lot and a disabled parking lot located close to the entrance and exit of the parking area. The other 1 point can be earned if other suggestions, cost related ones, specified in the certificate are chosen by the optimization model.

Sub-category 7.7 Working from home (2 points): The building has fiber optic cable, internet, television, and telephone infrastructure. A room in every flat, assigned as a study room, has two electrical outlets, wireless data connection, telephone line, and an openable window larger than 0.5 m^2.

Sub-category 8.3 Building use and maintenance manual (1 point): A building user manual, written in a non-technical language, containing the suggested topics, has been prepared and the users were planned to be trained within the first month of operation. The building use and maintenance manual is located in places that users can easily access.

Information regarding the cost-dependent sub-categories will be given in the optimization model development section. In order to run the optimization model, 16 scenarios were generated as mentioned before. Optimal costs were found to obtain a given BEST certification. Corresponding LEED certifications were then identified for the cost-optimum materials/equipment/systems obtained for the BEST certificates. Four different BEST certification levels were targeted for each building. For instance, the 4-storey building can be constructed to obtain either an Approved, Good, Very Good, and Excellent levels in BEST certification. Methods of calculation, assumptions made, and constraints considered will be described in further detail in following sections. The framework of the study is summarized in Figure 3.11.

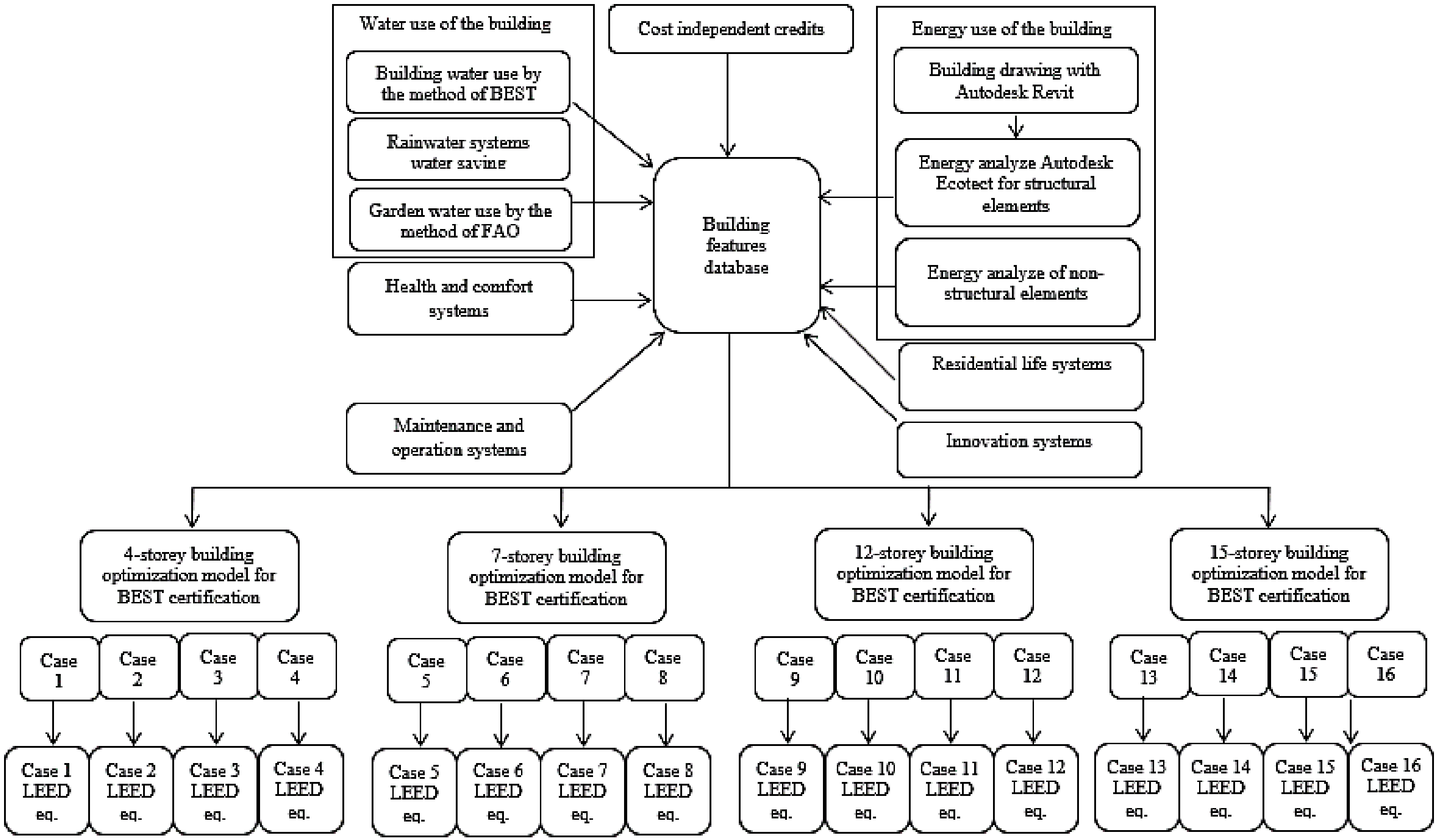

Figure 3.11. The framework of the study

3.4 Assessing LEED Certification Levels

In the final stage of the study, after obtaining the selections made by the optimization model, corresponding LEED certificate levels were determined using similar assumptions made for BEST certification and using the systems/materials/equipment selected by the model. Therefore, a comparison was made in order to reveal the similarities and differences between the BEST and LEED certificate levels that can be attained and also understand which system gives more importance to which area of the credit sub-categories. For this purpose, the outputs of the optimization model based on BEST for 16 case studies were assessed in terms of LEED scores. A new optimization model for LEED was not constructed.

When the requirements for credit sub-categories for LEED (Table 2.6) were examined, it was seen that some of the sub-categories can be classified as cost-dependent and cost-independent like in BEST. In cost-dependent sub-categories, credits are gained by installing systems/materials/equipment. Nevertheless, cost-independent categories do not require installing systems, materials or technologies, but involves activities such as preparing building manuals and working with environmentally-friendly contractor. Thereby, a number of assumptions have been made for the buildings studied in order to earn credits from the sub-categories that are independent from cost or quantifiable properly. In order to compare BEST and LEED systems, it has been acknowledged that the cost-independent credits earned in BEST were also earned in LEED. Total points gained from the cost-independent sub-categories was 32 points. It was assumed that full credits were obtained from the cost-independent sub-categories that are in line with BEST. Since the aim is to find the corresponding LEED level of the BEST certification level, cost-independent sub-categories in LEED that are not necessary to be satisfied according to the BEST are not considered. LEED and BEST credit assumptions comparison is provided in Table 3.2. The assumptions used for each sub-category in Table 2.6 are given in detail below.

Table 3.2 LEED and BEST credit assumptions comparison table

LEED sub-category	Credits can be attained	Credits assigned	Corresponding BEST sub-category
L.1.2. Integrative Process	1	1	1.1
L.2.2. Sensitive Land Protection	1	1	2.4
L.2.3. Surrounding Density and Diverse Uses	5	5	2.5
L.2.4. Access to Quality Transit	5	3	7.5
L.3.2. Site Assessment	1	1	2.1
L.3.8. Light Pollution Reduction	1	1	5.2
L.5.5. Enhanced Commissioning	6	6	4.1
L.6.3. Environmental Product Declarations	2	2	6.1
L.6.5. Material Ingredients	2	2	5.4
L.6.6. Construction and Demolition Waste Management	2	2	1.4
L.7.4. Low-Emitting Materials	3	3	5.4
L.7.8. Interior Lighting	2	2	5.2
L.7.9. Daylight	3	3	5.2

LEED Sub-category 1.2 Integrative Process (1 point): Starting from preliminary design and continuing through the design stages, opportunities were identified and used to achieve synergies between disciplines and building systems. Analyses were conducted to report the owner's project requirements (OPR), basis of design (BOD), design documentation and construction documentation.

LEED Sub-category 2.2 Sensitive Land Protection (1 point): The building was located at a land that has been previously developed.

LEED Sub-category 2.4 Surrounding Density and Diverse Uses (5 points): Since the building was granted full points from the walkable distance sub-category in BEST, full points were granted for LEED as well.

LEED Sub-category 2.4 Access to Quality Transit (3 points out of 5): The buildings were granted full points from the quality transit in BEST assuming an available transit in every 15 minutes close to the building. The minimum daily public transit services and the corresponding credits in LEED are presented in Table 3.3.

Table 3.3 Minimum daily public transit services

Weekday trips	Weekend trips	Credits
72	30	1
100	70	2
144	108	3
250	160	4
360	216	5

Since BEST does not divide the total number of bus services as weekends and weekdays, the lowest number of trips, were taken into account in the table provided by LEED. 108 trips a day means about once in 13 minutes. This number is the closest one to the equivalent in BEST. Therefore, 3 points were received in this category.

LEED Sub-category 3.2 Site Assessment (1 point): The site survey including topography, hydrology, climate, vegetation, soils and human health effects was performed and the survey demonstrates the relationships between the site features and the mentioned subjects and their influences to the project design.

LEED Sub-category 3.8 Light Pollution Reduction (1 point): The building has full points from visual comfort in BEST and it was accepted that it does not exceed the defined percentages of total lumens emitted above horizontal. Same was assumed for LEED as well.

LEED Sub-category 5.5 Enhanced Commissioning (6 points): Building enclosure commissioning and enhanced monitoring-based commissioning standards in LEED have been satisfied and also the building has granted with full points from commissioning as in the BEST as well.

LEED Sub-category 6.3 Environmental Product Declarations (2 Points): The building gained full credits from the environmentally friendly material use sub-category of BEST, which covers materials with Environmental Product Declarations. Therefore, a similar situation is present for LEED as well.

LEED Sub-category 6.5 Material Ingredients (2 Points): The buildings were awarded with full credits from the control of pollutants sub-category in BEST. Hence, it was assumed that full points are obtained in LEED from this sub-category.

LEED Sub-category 6.6 Construction and Demolition Waste Management (2 points): The building has developed and implemented a construction and demolition waste management plan and conduct regular waste prevention and diversion activities. Through them, the building generates less than 50 kg/m^2 of waste.

LEED Sub-category 7.4 Low-Emitting Materials (3 points): VOC content evaluation has been practiced and %75 of a building is constructed with materials considered as low emitting.

LEED Sub-category 7.8 Interior Lighting (2 points): The building has gained full credits from visual comfort category of BEST; therefore, it was assumed that it gains full credit from this category as well.

LEED Sub-category 7.9 Daylight (3 Points): The building has gained full credits from the visual comfort category of BEST; therefore, it was assumed that it gains full credit from this category as well.

CHAPTER 4

DEVELOPMENT OF THE OPTIMIZATION MODEL

The optimization model aims to obtain the most appropriate systems, technologies, and materials for a given BEST green building certification level with the minimum cost possible through making a selection between alternatives with different costs. The model is developed as a binary integer model and solved by the LINGO software version 18.0.

4.1 Objective Function

The mathematical representation of the objective is called as the objective function. Using the assumptions provided in the Methodology section, the objective function of the optimization model is defined as below.

$$MinZ = \sum_{i=1}^{8} C_w(i) * I_w(i) + C_{wn}(i) * I_{wn}(i) + \sum_{j=1}^{2} C_{rw}(j) * I_{rw}(j) + \sum_{k=1}^{4} C_{es,tse}(k) * I_{es,tse}(k) + C_{es,ideal}(k) * I_{es,ideal}(k) + C_{esn}(k) * I_{esn}(k) + \sum_{m=1}^{3} C_e(m) * I_e(m) + C_{en}(m) * I_{en}(m) + \sum_{t=1}^{2} C_{ew}(t) * I_{ew}(t) + C_{ewn}(t) * I_{ewn}(t) + \sum_{l=1}^{3} C_{re}(l) * A_{re}(l) * I_{re}(l) + \sum_{n=1}^{21} C_o(n) * I_o(n) \quad (1)$$

Where;

Z	Overall initial cost of the green building in consideration ($)
$C_w(i)$	Initial cost of a green system *i* that impacts the water use of a building ($)

$C_{wn}(i)$ Initial cost of a non-green system *i* that impacts the water use of a building ($)

$C_{rw}(j)$ Initial cost of a rainwater system *j* that impacts the water use of a building ($)

$C_{es,tse}(k)$ Initial cost of a green system *k* in a building structure that impacts the energy consumption of a building and is in line with TSE Standard in force published in 2006 ($)

$C_{es,ideal}(k)$ Initial cost of a green system *k* in a building structure that impacts the energy consumption of a building and in line with more up to date study published in 2016 by order of IZODER ($)

$C_{es,n}(k)$ Initial cost of a non-green system *k* in a building structure that impacts the energy consumption of a building ($)

$C_{re}(l)$ Initial cost of a renewable energy system *l* that impacts the energy consumption of a building ($)

$C_e(m)$ Initial cost of a green material *m* that impact energy consumption of a building ($)

$C_{en}(m)$ Initial cost of a non-green material *m* that impact the energy consumption of a building ($)

$C_{ew}(t)$ Initial cost of a green material *t* that impacts both energy and water consumptions of a building ($)

$C_{ewn}(t)$ Initial cost of a non-green material *t* that impacts both the energy and water consumptions of a building ($)

$C_o(n)$ Initial cost of another system *n* that does not impacts building-related calculations such as energy and water ($)

$I_w(i)$ Binary variable for choosing a green system *i* that impacts water consumption

$I_{wn}(i)$ Binary variable for choosing a non-green system *i* that impacts water consumption

$I_{rw}(j)$ Binary variable for choosing a rainwater system *j* that impacts water use

$I_{es,tse}(k)$	Binary variable for choosing a green system *k* in a building structure that impacts energy consumption and in line with TSE Standard in force that published in 2006
$I_{es,ideal}$	Binary variable for choosing a green system *k* in building structure that impacts energy consumption and in line with more up to date study published in 2016 by order of IZODER
$I_{esn}(k)$	Binary variable for choosing a non-green system *k* in building structure that impacts energy consumption of building.
$I_r(l)$	Binary variable for choosing a renewable energy system *l*
$I_e(m)$	Binary variable for choosing a green material *m* that affects energy consumption
$I_{en}(m)$	Binary variable for choosing a non-green material *m* that affects energy consumption
$I_{ew}(t)$	Binary variable for choosing a green material *t* that affects both energy and water consumption
$I_{ewn}(t)$	Binary variable for choosing a non-green material *t* that affects both energy and water consumption
$I_o(n)$	Binary variable for choosing another system *n* that does not impact building-related calculations such as energy and water
$A_r(l)$	Amount of a renewable energy system *l* to be installed

In the objective function, only the initial costs of the selected items were considered as operational costs are not relevant for obtaining a green building certificate. Yet, in results and discussion, operational savings due to reduced water and energy consumptions in comparison to non-green counterparts are discussed. The operational time for calculation of savings is taken as 10 years.

The alternatives available for materials/equipment/systems selections for the buildings of concern are provided in Table 4.1.

Table 4.1 Systems considered in the optimization model.

Symbol	Alternative
$C_w(1)$	Green toilet (2 per flat)
$C_w(2)$	Green showerhead (2 per flat)
$C_w(3)$	Green faucet for kitchen
$C_w(4)$	Green faucets in bathroom (2 per flat)
$C_w(5)$	Drip irrigation system
$C_{wn}(1)$	Non-green toilet (2 per flat)
$C_{wn}(2)$	Non-green showerheads (2 per flat)
$C_{wn}(3)$	Non-green faucet for kitchen
$C_{wn}(4)$	Non-green faucet in bathroom (2 per flat)
$C_{wn}(5)$	Sprinkler irrigation system
$C_{rw}(1)$	Rainwater systems for toilet only
$C_{rw}(2)$	Rainwater systems for toilet and garden
$C_{ew}(1)$	Green dishwasher
$C_{ew}(2)$	Green washing machines
$C_{ewn}(1)$	Non-green dishwasher
$C_{ewn}(2)$	Non-green washing machine
$C_{es,tse}(1)$	Wall for TSE Standard
$C_{es,tse}(2)$	Window for TSE Standard
$C_{es,tse}(3)$	Roof for TSE Standard
$C_{es,tse}(4)$	Floor for TSE Standard
$C_{es,ideal}(1)$	Wall for IZODER study
$C_{es,ideal}(2)$	Window for IZODER study
$C_{es,ideal}(3)$	Roof for IZODER study
$C_{es,ideal}(4)$	Floor for IZODER study
$C_{esn}(1)$	Non-green wall
$C_{esn}(2)$	Non-green widow

Table 4.1 *(cont'd)*

Symbol	**Alternative**
$C_{esn}(3)$	Non-green roof
$C_{esn}(4)$	Non-green floor
$C_e(1)$	Green fridge
$C_e(2)$	Green inside lightening (20 per flat)
$C_e(3)$	Green outside lightening (10 for the building)
$C_{en}(1)$	Non-green fridge
$C_{en}(2)$	Non-green inside lightening (20 per flat)
$C_{en}(3)$	Non-green outside lightening (10 for the building)
$C_{re}(1)$	PV panels
$C_{re}(2)$	Wind Turbine
$C_{re}(3)$	Solar water heaters
$C_o(1)$	Humidity controller for garden
$C_o(2)$	Water meters
$C_o(3)$	Green roof
$C_o(4)$	Permeable pavement (1.5mx4m pedestrian road)
$C_o(5)$	Green elevators (2 in the building)
$C_o(6)$	Hood fume (1 per flat)
$C_o(7)$	Exhaust fans (2 per flat)
$C_o(8)$	Auditory insulation to floors (in between flats)
$C_o(9)$	Auditory insulation to walls
$C_o(10)$	Linoleum floor
$C_o(11)$	Protective bands on delicate wall corners (4 in each floor)
$C_o(12)$	Kickstands on the doors (Main door only)
$C_o(13)$	Door handle slams (10 per flat)
$C_o(14)$	Fire alarm (a main controller and an alarm for each flat)

Table 4.1 *(cont'd)*

Symbol	**Alternative**
$C_o(15)$	Video door phone system for 16 flats
$C_o(16)$	Fences around waste storage area
$C_o(17)$	Piece of art
$C_o(18)$	Electric charging station (2 for the building)
$C_o(19)$	Waste separation bins
$C_o(20)$	Tree branch grinder
$C_o(21)$	Main energy meter
$C_o(22)$	Innovation
$C_o(23)$	Approved consultant
$C_o(24)$	Wastewater treatment unit

4.2 Constraints of the Optimization Model for BEST

Constraints are mathematical expressions that restrain the values that can be assigned to the decision variables by the model and provide conditions that affects the evaluation of the decision variables in order to attain the aim of the model. The constraints of the optimization model were derived for cost-dependent sub-categories as presented below.

Sub-category 3.2 Reducing water consumption: For the purpose of reducing water use, the annual amount of domestic and outdoor water use per household is calculated and evaluated. In order to do that, water consumption value of each system is multiplied with its own binary decision variable. On the other hand, installing rainwater systems help reducing the water consumption. That means the rainwater use value is subtracted from the water consumption value of the systems (Equation 2).

$$\sum_{t=1}^{2} U_{eww}(t) * I_{eww}(t) + U_{ewwn}(t) * I_{ewwn}(t) + \sum_{i=1}^{5} U_{w}(i) * I_{w}(i) + U_{wn}(i) * I_{wn}(i) - \sum_{j=1}^{2} U_{rw}(j) * I_{rw}(j) = U_{wGB} \quad (2)$$

Where;

$U_w(i)$	Water consumption of a green system *i* per one household in a year ((m^3/year)/household)
$U_{wn}(i)$	Water consumption of non-green system *i* per one household in a year ((m^3/year)/household)
$U_{eww}(t)$	Water consumption of green systems *t* that affects the consumption of both water and energy per one household in a year ((m^3/year)/household)
$U_{ewwn}(t)$	Water consumption of non-green systems *t* that affects the consumption of both water and energy per one household in a year ((m^3/year)/household)
$U_{rw}(j)$	Water consumption of rainwater system *j* per one household in a year ((m^3/year)/household)
U_{wGB}	The total water use of the building per one household in a year ((m^3/year)/household)

The quantity provided by Equation 2 is compared to the given ranges of water consumption below to determine the credits that can be obtained in sub-category 3.2 such that:

If the annual indoor and outdoor water use per household is;

- > 85 m^3/year, the building is not eligible to get points from sub-category 3.2.

$$U_{wGB} > 85 \quad \Rightarrow \; CR_w = 0 \quad (3)$$

- 70-85m^3/year, the building can guarantee 1 point from sub-category 3.2.

$$85 \geq U_{wGB} \geq 70 \quad \Rightarrow \; CR_w = 1 \quad (4)$$

- 50-70m^3/year, the building can guarantee 2 points from sub-category 3.2.

$$70 \geq U_{wGB} \geq 50 \quad \Rightarrow \; CR_w = 2 \tag{5}$$

- 40-50m^3/year, the building can guarantee 3 points from sub-category 3.2.

$$50 \geq U_{wGB} \geq 40 \quad \Rightarrow \; CR_w = 3 \tag{6}$$

- 30-40m^3/year, the building can guarantee 4 points from sub-category 3.2.

$$40 \geq U_{wGB} \geq 30 \quad \Rightarrow \; CR_w = 4 \tag{7}$$

Green and non-green alternatives for a system cannot be chosen at the same time since they represent alternatives for a particular system. For instance, a water efficient dishwasher cannot be chosen together with a traditional dishwasher. The model must choose either of them. Therefore, the relevant constraint is set as:

$$I_w(i) + I_{wn}(i) = 1 \quad \forall i \tag{8}$$

By installing a proper filter for rainwater systems for toilets only, reclaimed water can be used for irrigating the garden as well. Therefore, the model must choose one of the alternatives of rainwater systems.

$$\sum_{j=1}^{2} I_{rw}(j) = 1 \tag{9}$$

According to the certification, the building can get 2 more points if it has a rainwater system, drip irrigation and humidity controller all together.

$$\sum_{j=1}^{2} I_{rw}(j) + I_w(5) + I_o(1) = 3 \quad \Rightarrow \; CR_w = CR_w + 2 \tag{10}$$

Where;

CR_w Total credits gained from water consumption category.

<u>Sub-category 3.4 Wastewater treatment and utilization:</u> The scores in this sub-category are calculated by two different methods. If the number of residents in the

building is up to 100 (there are 64 residents in a 4-storey building), the building does not need to possess a wastewater treatment plant of its own. In this case, the way to get 2 points in this category is to get at least 4 points from the sub-category 3.2.

$$CR_w \geq 4 \qquad \Rightarrow CR_w = CR_w + 2 \tag{11}$$

According to BEST, if the number of residents in the building is more than 100 (112 residents for 7 floors, 192 residents for 12 floors, and 240 residents for 15 floors), it is not enough to get 4 or more points from the water calculation. In this case, a building-specific wastewater treatment plant should be installed. Points in this category can only be obtained in this way.

$$I_o(24) = 1 \qquad \Rightarrow CR_w = CR_w + 2 \tag{12}$$

Sub-category 3.5 Surface water flow: In order to avoid flooding in cities caused by over urbanization and unplanned urbanization in river beds, necessary measures must be taken. In this case, installing green roofs and permeable pavements in the project can reduce the impact of a building on flooding. The building can gain 2 points from this sub-category.

$$I_o(3) + I_o(4) = 2 \qquad \Rightarrow CR_w = CR_w + 2 \tag{13}$$

Sub-category 4.3. Energy efficiency**:** For the purpose of reducing energy usage in a building, energy recovery rates are calculated and evaluated. In order to do that first of all, the reference building was drawn in Autodesk Revit software. Later, the drawing was exported to the Autodesk Ecotech software and energy analysis of the building was conducted. From the Ecotech, the annual usage in the existence of green walls, green roof, green floor and green windows were calculated by running the model several times and comparing with the reference building. Energy usage of domestic appliances and indoor and outdoor lightening appliances were annualized for both green and non-green options.

Following data collection, energy recovery amounts for each system were calculated by subtracting the energy use of a green building system from the non-green building system. Each system has three alternatives. These are the systems that are in line with the TSE Standard in force since 2006, systems that are in line with a more up to date study published in 2016 by IZODER, and finally systems that are accepted as non-green. Energy recovery amounts and binary decision variables of each system were multiplied and the sum of the energy recovery amounts of the chosen systems were found. Later, renewable energy contribution was added to the energy recovery amount. This renewable energy contribution amount was calculated as the multiplication of the unit energy production, amount and the binary decision variable for each system. Summation of energy recovery amount and renewable energy contribution provided the energy recovered in the green building (see Equation 14).

$$\sum_{k=1}^{4} U_{es,tse}(k) * I_{es,tse}(k) + U_{es,ideal}(k) * I_{es,ideal}(k) + \sum_{l=1}^{3} + U_{re}(l) * I_{r}e(l) * A_{re}(l) + \sum_{m=1}^{3} U_{e}(m) * I_{e}(m) + \sum_{t=1}^{2} U_{ewe}(t) * I_{ew}(t) = U_{eGB} \quad (14)$$

Where;

$U_{es,tse}(k)$	Energy gained by choosing green system *k* in a year when compared with non-green system and is in line with TSE (kwh/year)
$U_{es,ideal}(k)$	Energy gained by using green system *k* in a year when compared with non-green system and is in line with IZODER (kwh/year)
$U_{e}(m)$	Energy gained by using green system *m* that affects the energy consumption of the building in a year (kwh/year)
$U_{ewe}(t)$	Energy gained by using green system t that affects both the energy and water consumption of the building in a year (kwh/year)
$U_{re}(l)$	Energy produced from renewable energy system *l* in a year that published in impacts the energy consumption of the building (kwh/year)
U_{eGB}	The total energy consumption of the green building in a year (kwh/year)
U_{eNGB}	The total energy use of the non-green building which has no green system in a year (kwh/year)

The energy recovery rate of a green building is the ratio of the energy recovered in the green building to the non-green building, the base building, whose all systems are accepted as non-green. Evaluation of the energy recovery rate are done by following considerations:

If the energy recovery rate is between:

- 0.13-0.19, the building can guarantee 1 point from sub-category 4.3.

$$0.19 \geq (U_{eGB}/U_{eNGB}) \geq 0.13 \Rightarrow CR_e = 1 \tag{15}$$

- 0.19-0.25, the building can guarantee 2 points from sub-category 4.3.

$$0.25 \geq (U_{eGB}/U_{eNGB}) \geq 0.19 \Rightarrow CR_e = 2 \tag{16}$$

- 0.25-0.31, the building can guarantee 3 points from sub-category 4.3.

$$0.31 \geq (U_{eGB}/U_{eNGB}) \geq 0.25 \Rightarrow CR_e = 3 \tag{17}$$

- 0.31-0.37, the building can guarantee 4 points from sub-category 4.3.

$$0.37 \geq (U_{eGB}/U_{eNGB}) \geq 0.31 \Rightarrow CR_e = 4 \tag{18}$$

- 0.37-0.43, the building can guarantee 5 points from sub-category 4.3.

$$0.43 \geq (U_{eGB}/U_{eNGB}) \geq 0.37 \Rightarrow CR_e = 5 \tag{19}$$

- 0.43-0.49, the building can guarantee 6 points from sub-category 4.3.

$$0.49 \geq (U_{eGB}/U_{eNGB}) \geq 0.43 \Rightarrow CR_e = 6 \tag{20}$$

- 0.49-0.55, the building can guarantee 7 points from sub-category 4.3.

$$0.55 \geq (U_{eGB}/U_{eNGB}) \geq 0.49 \Rightarrow CR_e = 7 \tag{21}$$

- 0.55-0.60, the building can guarantee 8 points from sub-category 4.3.

$$0.60 \geq (U_{eGB}/U_{eNGB}) \geq 0.55 \Rightarrow CR_e = 8 \tag{22}$$

- 0.60-0.65, the building can guarantee 9 points from sub-category 4.3.

$$0.65 \geq (U_{eGB}/U_{eNGB}) \geq 0.60 \;\Rightarrow\; CR_e = 9 \qquad (23)$$

- 0.65-0.70, the building can guarantee 10 points from sub-category 4.3.

$$0.70 \geq (U_{eGB}/U_{eNGB}) \geq 0.65 \;\Rightarrow CR_e = 10 \qquad (24)$$

- 0.70-0.75, the building can guarantee 11 points from sub-category 4.3.

$$0.75 \geq (U_{eGB}/U_{eNGB}) \geq 0.70 \;\Rightarrow\; CR_e = 11 \qquad (25)$$

- 0.75-0.80, the building can guarantee 12 points from sub-category 4.3.

$$0.80 \geq (U_{eGB}/U_{eNGB}) \geq 0.75 \;\Rightarrow CR_e = 12 \qquad (26)$$

- 0.80-0.85, the building can guarantee 13 points from sub-category 4.3.

$$0.85 \geq (U_{eGB}/U_{eNGB}) \geq 0.80 \;\Rightarrow\; CR_e = 13 \qquad (27)$$

- 0.85-0.90, the building can guarantee 14 points from sub-category 4.3.

$$0.90 \geq (U_{eGB}/U_{eNGB}) \geq 0.85 \;\Rightarrow CR_e = 14 \qquad (28)$$

- 0.95-1.00, the building can guarantee 15 points from sub-category 4.3.

$$1.00 \geq (U_{eGB}/U_{eNGB}) \geq 0.90 \;\Rightarrow\; CR_e = 15 \qquad (29)$$

- Less than 0.13, the building cannot be eligible to get any points from sub-category 4.3.

$$0.13 \geq (U_{eGB}/U_{eNGB}) \Rightarrow\; CR_e = 0 \qquad (30)$$

Where;

CR_e Total credits gained from energy use category excluding renewable energy use.

Green and non-green alternatives of each system cannot be chosen at the same time since they represent alternatives for one particular application. For instance, walls that are in line with the TSE Standard cannot be chosen together with non-green walls, and the ones that are in line with the current study published in 2016. The model must choose one in between three alternatives for each system.

$$I_{es,tse}(k) + I_{es,ideal}(k) + I_{esn}(k) = 1 \quad (31)$$

$$I_{ew}(t) + I_{ewn}(t) = 1 \quad (32)$$

$$I_{e}(m) + I_{en}(m) = 1 \quad (33)$$

According to the current regulations that are in force in Turkey, total installed capacity of renewable energy sources cannot exceed 10 KW. Therefore, the maximum amounts were determined for PV panels (Are(1)) and wind turbines (Are(2)). On the other hand, for solar water heater (Are(3)) the capacity should not exceed the water consumption of the whole building in the situation of choosing the equipment all non-green.

$$0 \leq A_{re}(3) \leq 4 \text{ for a 4-storey building} \quad (34)$$

$$0 \leq A_{re}(3) \leq 7 \text{ for a 7-storey building} \quad (35)$$

$$0 \leq A_{re}(3) \leq 11 \text{ for a 12-storey building} \quad (36)$$

$$0 \leq A_{re}(3) \leq 14 \text{ for a 15-storey building} \quad (37)$$

$$\sum_{l=1}^{2} U_{re}(l) * I_{re}(l) * A_{re}(l) \leq 10000 \quad (38)$$

Where;

$A_{re}(l)$ Amount of renewable energy system *l* to be installed

Renewable energy amount for each system must be identified as integer in order to the prevent model from choosing part of a system.

$$A_{re}(l) \in \mathbb{Z} \quad \forall l \quad (39)$$

Sub-category 4.4 Use of renewable energy**:** It is required to meet a certain predicted rate of the annual final energy consumption through the renewable energy systems installed on the building or on its land. This is determined through building energy modeling and necessary calculations. Evaluation of the energy recovery rate is made by the following considerations:

If the percentage of the building energy consumption covered by the renewable energy system is in between:

- 2-5%, the building can gain 1 point from this section.

$$0.05 \geq \sum_{l=1}^{3}\left[\frac{U_{re}(l)*I_{re}(l)*A_{re}(l)}{U_{eNGB}-U_{eGB}}\right] \geq 0.02 \quad \Rightarrow \; CR_r = 1 \tag{40}$$

- 5-10%, the building can gain 2 points from this section.

$$0.1 \geq \sum_{l=1}^{3}\left[\frac{U_{re}(l)*I_{re}(l)*A_{re}(l)}{U_{eNGB}-U_{eGB}}\right] \geq 0.05 \quad \Rightarrow \; CR_r = 2 \tag{41}$$

- 10-20%, the building can gain 3 points from this section.

$$0.2 \geq \sum_{l=1}^{3}\left[\frac{U_{re}(l)*I_{re}(l)*A_{re}(l)}{U_{eNGB}-U_{eGB}}\right] \geq 0.1 \quad \Rightarrow CR_r = 3 \tag{42}$$

- 20-30%, the building can gain 4 points from this section.

$$0.3 \geq \sum_{l=1}^{3}\left[\frac{U_{re}(l)*I_{re}(l)*A_{re}(l)}{U_{eNGB}-U_{eGB}}\right] \geq 0.2 \quad \Rightarrow \; CR_r = 4 \tag{43}$$

- 30-100%, the building can gain 5 points from this section.

$$1.0 \geq \sum_{l=1}^{3}\left[\frac{U_{re}(l)*I_{re}(l)*A_{re}(l)}{U_{eNGB}-U_{eGB}}\right] \geq 0.3 \quad \Rightarrow \; CR_r = 5 \tag{44}$$

Sub-category 4.5 Outdoor lighting: The building can earn 1 point by choosing outdoor lighting of the building from options that generate its own energy through integrated photovoltaic solar panels.

$$I_e(3) = 1 \Rightarrow CR_e = CR_e + 1 \tag{45}$$

Sub-category 4.6 Energy efficient domestic appliances: The building can gain 1 point by preferring domestic appliances in the building that are considered as energy efficient.

$$\sum_{t=1}^{2} I_{ew}(t) + I_{ew}(1) = 3 \Rightarrow CR_e = CR_e + 1 \tag{46}$$

Sub-category 4.7 Elevators: The building can gain 1 point from elevators that are considered as energy efficient.

$$I_o(5) = 1 \quad \Rightarrow CR_e = CR_e + 2 \tag{47}$$

Sub-category 5.3 Fresh air**:** In buildings larger than 2,000 m^2, in case of insufficient natural exhaustion in the toilet, bathroom and kitchen, hoods in kitchens and exhaust fans in bathrooms and toilets should be used for exhaust purposes. Therefore, the use of hoods in the kitchen and exhaust fans in the bathroom together will provide the building 1 point from this sub-category.

$$\sum_{n=6}^{7} I_o(n) = 2 \Rightarrow CR_h = 3 \tag{48}$$

Where;

CR_h Total credits gained from health and comfort category.

Sub-category 5.5 Auditory comfort**:** The building can gain 3 points if auditory insulation is achieved through insulation on walls and floors to reduce the loud noise coming from outside and between flats.

$$\sum_{n=8}^{9} I_o(n) = 2 \Rightarrow CR_h = CR_h + 3 \tag{49}$$

Sub-category 6.3 Reuse of materials: It is desired that materials containing renewable or recycled raw materials are used at least by 2.5% of the primary structure used in construction in terms of cost and volume. In this case linoleum floor coverings is preferred. Thereby, if the building has linoleum floor coverings, it can gain 2 points.

$$I_o(10) = 1 \Rightarrow CR_m = CR_m + 2 \tag{50}$$

Where;

CR_m Total credits gained from materials category.

Sub-category 6.5. Durable materials: It is required to use durable materials in buildings. In order to protect common areas (entrance halls, corridors, stairs, indoor car parks, etc.) from the corrosive effects due to intensive use, protective bands on walls which are not resistant to impact, kickstands on doors, and door handle slams to protect the walls that are closer than 10 cm to the door must be installed. If all of those measures are taken, the building can get 1 point from this section.

$$\sum_{n=11}^{13} I_o(n) = 3 \Rightarrow CR_m = CR_m + 1 \tag{51}$$

Sub-category 7.2 Security: This sub-category aims to ensure that the pedestrian roads and building entrances in the building premises are safe for all users. Assessment is made according to the measures taken to ensure security within the building premises. If efficient outdoor lightning, an emergency alert system, video door phone system, locked fences around the waste storage area are present all together; the building can gain 1 point from this sub-category.

$$I_e(3) + \sum_{n=14}^{16} I_o(n) = 4 \Rightarrow CR_l = 1 \tag{52}$$

Where;

CR_l Total credits gained from life category

Sub-category 7.4 Art: It is desired to provide a life intertwined with art. An original work of art (other than reproductions) such as a painting or sculpture should be exhibited in a space indoors in the building where everyone can see (entrance, hall, etc.). Hence, the building can earn 1 point from this section.

$$I_o(17) = 1 \Rightarrow CR_l = CR_l + 1 \tag{53}$$

Sub-category 7.6 Parking area: In case of the presence of an electric vehicle charging station in the car parking lot, the building can earn 1 point.

$$I_o(18) = 1 \Rightarrow CR_l = CR_l + 1 \tag{54}$$

Sub-category 8.1 Waste reallocation and user access**:** Wastes generated in the building should be separated according to their types. Separate containers placed outside the building can bring the building 2 points from this section.

$$I_o(19) = 1 \Rightarrow CR_a = 2 \tag{55}$$

Where;

CR_a	Total credits gained from operation and maintenance category.

Sub-category 8.2 Waste technologies: Waste technologies or equipment should be used to recover the generated wastes in the building premises or to send them to waste recycling facilities. In order to gain 1 point from this sub-category, first the building must have gained 2 points from the sub-category 8.1 and then possess a tree branch grinder in the building garden.

$$(I_o(19) + I_o(20) = 2) \Rightarrow CR_a = CR_a + 1 \tag{56}$$

Sub-category 8.4 Tracking of consumption values**:** A system should be established to monitor the energy consumption both on monthly and annual bases. Consumption values obtained from the main meters and sub-meters should be equal to each other. Buildings with these systems are entitled to 1 point from this sub-category.

$$I_o(21) + I_o(2) = 2 \Rightarrow CR_a = CR_a + 2 \tag{57}$$

Sub-category 9.1 Innovation**:** It is favored to install systems or conduct practices that are sustainable in terms of technology, design features, management methods, and apply strategies different than the ones defined in the certification system that can make a difference in the building water use, energy use, health and comfort or material and resource use. Buildings having these kinds of practices or systems can earn 1 point from this sub-category.

$$I_o(22) = 1 \Rightarrow CR_{in} = 1 \quad (58)$$

Where;

CR_{in} Total credits gained from innovation category

Sub-category 9.2 Approved consultant**:** 1 point can be obtained if there is at least one approved consultant in the team from the beginning to the end of the project.

$$I_o(23) = 1 \Rightarrow CR_{in} = CR_{in} + 1 \quad (59)$$

As well as the constraints relevant to cost-dependent sub-categories that are applied to all cases, there are specific constraints relevant to the level of the BEST certificate. As mentioned before there are 16 case studies. These are designed to present what choices the model has made for each certification level for different building heights and whether the building storeys and higher number of apartments would create significant difference in results. It is aimed to show all stakeholders which choices are the most optimum in terms of cost in order to achieve each level of certification for each type of building. Moreover, the model is inclined to choose the cheapest alternatives which are mostly non-green systems, since the aim of the optimization model is to minimize the cost of the whole building. Therefore, additional constraints are applied to lead the optimization model to stay between certain credit ranges to achieve a given certification level.

Additional constraint for Cases 4-a, 7-a, 12-a, and 15-a: This constraint is used for the `Approved` level of the BEST certificate. Total credits must be between 45 and 64. For each building (4-, 7-, 12- and 15-storey), there is one case for Approved level. Meaning that there are 4 cases in total where this constraint applies.

$$64 \geq 39 + CR_w + CR_e + CR_r + CR_h + CR_m + CR_l + CR_a + CR_{in} \geq 45 \quad (60)$$

Additional constraint for Cases 4-g, 7-g, 12-g, and 15-g: This constraint is used for the `Good` level of BEST certificate. Total credits must be in between 65 and 79.

For each building (4-, 7-, 12- and 15-storey), there is one case for Good level. Meaning that there are 4 cases in total where this constraint applies.

$$79 \geq 39 + CR_w + CR_e + CR_r + CR_h + CR_m + CR_y + CR_a + CR_{in} \geq 65 \quad (61)$$

<u>Additional constraint for Cases 4-vg, 7-vg, 12-vg and 15-vg:</u> This constraint is used for the `Very Good` level of the BEST certificate. Total credits must be in between 80 and 99. For each building (4-, 7-, 12- and 15-storey), there is one case for Very Good level. Meaning that there are 4 cases in total where this constraint applies.

$$99 \geq 39 + CR_w + CR_e + CR_r + CR_h + CR_m + CR_y + CR_a + CR_{in} \geq 80 \quad (62)$$

<u>Additional constraint for Cases 4-e, 7-e, 12-e and 15-e:</u> This constraint is used for the `Excellent` level of BEST certificate. Total credits must be in between 100 and 110. For each building (4-, 7-, 12- and 15-storey), there is one case for Excellent level. Meaning that there are 4 cases in total where this constraint applies.

$$110 \geq 39 + CR_w + CR_e + CR_r + CR_h + CR_m + CR_y + CR_a + CR_{in} \geq 100 \quad (63)$$

<u>Binary decision variable declaration</u> Binary variables must be declared in the optimization model such that they can only get 0 or 1. Thereby, the model can assign 0 to the systems that it decides not to choose and assign 1 to the ones it chooses.

Binary variables declarations are defined as;

$$I_w(i), I_{wn}(i), I_{rw}(j), I_{es,tse}(k),\ I_{es,ideal}(k), I_{esn}(k),\ I_e(m),\ I_{en}(m),\ I_{re}(l), I_o(n), I_{ew}(t), I_{ewn}(t) \in \{0,1\} \quad \forall i\ \forall j\ \forall k\ \forall m\ \forall l\ \forall n\ \forall t \quad (64)$$

4.3 Constraints for LEED Certification Credits

<u>LEED Sub-category 2.7 Electric Vehicles (1 point):</u> If the model has chosen to buy 2 electric vehicle charging stations, it can get 1 point from LEED certificate as well.

LEED Sub-category 3.5 Rainwater Management (1 point): If the model has chosen to apply rainwater collection systems on the roof which covers approximately 80% of the area of the building site, the building can get 1 point from LEED certificate as well.

LEED Sub-category 3.6 Heat Island Reduction (2 points): According to this credit if the model has chosen to install a green roof, it can gain 2 credits from this sub-section.

LEED Sub-category 4.1 Outdoor Water Use Reduction (1-2 points): The garden of the building has already planted with low water requiring plants such as roses with a Kc value of 0.5. Therefore, in addition, if the model has chosen drip irrigation (1 point) and rainwater use for a garden (1 point), it can fulfil the requirement for the reduction of water consumption from this section.

LEED Sub-category 4.2 Indoor Water Use Reduction (1-6 points): Amount of water use was calculated by BEST and the calculation includes both indoor and outdoor water consumption. Having regard to the result of the model, water reduction of only the indoor water use was calculated and credits were given considering the percent drop off. The credits given for the percentage reduction achieved are provided in Table 4.2.

Table 4.2. Credits for percentage reduction of water use

Percentage Reduction	**Credits**
25%	1
30%	2
35%	3
40%	4
45%	5
50%	6

LEED Sub-category 4.7 Water Metering (1 point): Based on whether water meters have been installed in a building, the building can get this point from LEED.

LEED Sub-category 5.6 Optimize Energy Performance (1-18 points): In LEED, energy credits are given considering two parameters. Up to 9 points can be gained by unit (percentage) improvement in energy performance by considering cost. While calculating the energy according to the BEST, the decrease in energy was calculated by using kwh unit. This unit, which can also be expressed as an electricity usage unit, will also indicate the change in cost. Therefore, the percentage of decrease in energy use achieved in BEST is equivalent to this score in LEED. The credits given for the percentage reduction achieved are provided in Table 4.3.

Table 4.3. Credits for percentage reduction of energy cost

Percentage Reduction	**Credits**
5%	1
10%	2
15%	3
20%	4
25%	5
30%	6
35%	7
40%	8
45%	9

Another 9 points can be gained by GHG emission percentage reduction in LEED. The calculation of GHG emission can be done by following formula.

$$mTCO2e = units\ of\ electricity\ consumed\ (kwh) * mTCO2e\ per\ kwh \tag{65}$$

Where;

mTCO2e: Metric tons of carbon dioxide equivalent *mTCO2e per kwh*: Average annual emissions intensity

Since average annual emissions intensity is constant during the calculations, the result of GHG emissions depends on the units of electricity consumed (kwh). Therefore, the percent reduction in the electricity use considered in above was used in this section of the energy credits calculation as well. The credits given for the percentage reduction achieved are provided in Table 4.4.

Table 4.4. Credits for percentage reduction of GHG emissions

Percentage Reduction	**Credits**
5%	1
10%	2
15%	3
20%	4
25%	5
30%	6
35%	7
40%	8
45%	9

<u>LEED Sub-category 5.7 Advanced Energy Metering (1 point):</u> If the building is equipped with energy metering equipment, the building can gain a point from LEED.

<u>LEED Sub-category 5.9 Renewable Energy (1-5 points</u>**):** In the renewable energy category, wind turbine, solar panel and solar water heater options were presented to the model for use in the building. If these options are selected, they will be installed onsite and will only meet the energy requirement of the building in concern. The percentage of energy in the building covered by renewable energy and the credit gained corresponding to this percentage are given in Table 4.5.

Table 4.5. Credits for percentage reduction of energy by renewable energy production

Percentage Reduction	Credits
2%	1
5%	2
10%	3
15%	4
20%	5

LEED Sub-category 5.10 Enhanced Refrigerant Management (1 point): The ozone depletion potential of the cooling systems (such as air conditioners) used in the building is zero. Besides, if the green fridge is chosen by the model, the building can get credit from this category.

LEED Sub-category 7.3 Enhanced Indoor Air Quality Strategies (1 point): Indoor air quality strategies have been applied in the building such as natural ventilation systems and operable windows. Additionally, if hood fumes are used in the kitchens and exhaust fans are used in the bathrooms, the building can get credit from this category.

LEED Sub-category 7.11 Acoustic Performance (1 point): Whether sound insulation materials are installed on walls and floors, the building can get points from acoustic performance.

LEED Sub-category 8.1 Innovation (1 point): If an innovative solution that has not mentioned in the LEED has implemented on the building, the building can get points from this section.

LEED Sub-category 8.2 Accredited Professional (1 point): If the model deems it appropriate to hire an approved consultant, it will also get credits from LEED in this category.

LEED Sub-category 9.1 Regional Priority (1-3 points): If the model has satisfied the following criteria, it can gain one credit for each.

- If it gets minimum of 2 points from Renewable Energy category
- If it gets minimum of 2 points from Rainwater Management category
- If it gets minimum of 8 points from Optimize Energy Performance category

4.4 Data Collection and Cost Calculation for Determination of Credits in the Optimization Model

Data inputs to the optimization model relevant to energy, water, and renewable energy related credits were calculated within the study. Remaining data inputs were gathered directly via market research. Calculation of total cost, on the other hand, was conducted considering the number of storeys and the selected items for each building. Cost unit was United States Dollars (USD), in order not to be affected by the current exchange rates. Details are provided below.

4.4.1 Energy Demand Analyzes

In order to calculate the energy consumption credits, energy analyzes needed to be performed according to the article 4.1 of BEST. As mentioned before, 4-, 7-, 12-, and 15-storey buildings of concern were drawn by Revit Software individually. The drawings were then imported to the Ecotect Analysis Software (Figure 4.1).

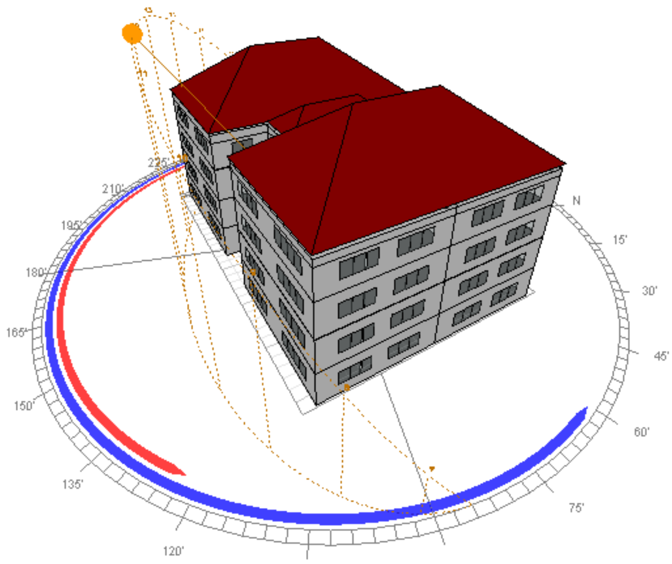

Figure 4.1. Imported drawing of 4-storey house into Ecotect

Global position and climate values were adjusted according to Ankara. Solar access analyses were conducted in order to calculate the sun light falling onto a given building for a whole year (Figure 4.2). Then, the weather tool was employed in order to find out the best orientation of the building for best irradiation impact. It was calculated that the best orientation of the building must be 17.5^{o} offset from the south (162.5^{o}) in Ankara (Figure 4.3).

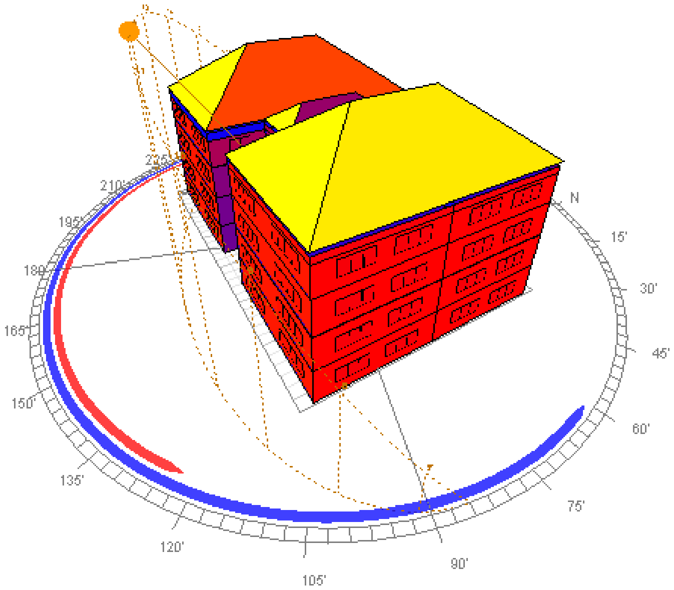

Figure 4.2. Result of solar access analyses of the 4-storey building

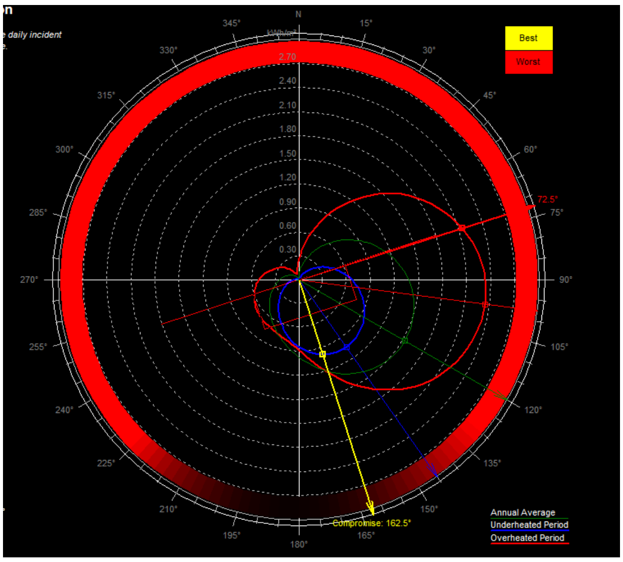

Figure 4.3. Modeling of the best orientation of the building

For all rooms and halls, there is one thermal zone. This thermal zone has the following properties: both heating and cooling systems prevail, lightening level is 300 lux (ÇEDBİK, 2019), number of occupants is 4 with sedentary activity, thermal range is between 19.4 - 27.8°C (ASHRAE, 2020), and there is 24 hours of occupation in a day. Using the software, impacts of walls, windows, roofs, and floors on the energy calculation were examined.

According to the TSE Standard issued in 2008 (IZODER, 2016), Turkey is divided into 4 climate regions. Ankara is situated in the 3rd climate zone (Figure 4.4). Yet, as the standard was issued in 2008, a more recent study was taken into consideration. Hence, the study conducted by IZODER was taken into consideration. This study was conducted in 2016, 8 years after the TSE standard was in enforcement, and prepared according to the European Energy Performance of Buildings Directive by considering cost-optimality. Therefore, the values provided by IZODER are deemed as “ideal” values. IZODER categorized climate regions of Turkey into 6 and Ankara is situated in the region named as “Rather Cold” (Figure 4.5) (IZODER, 2016).

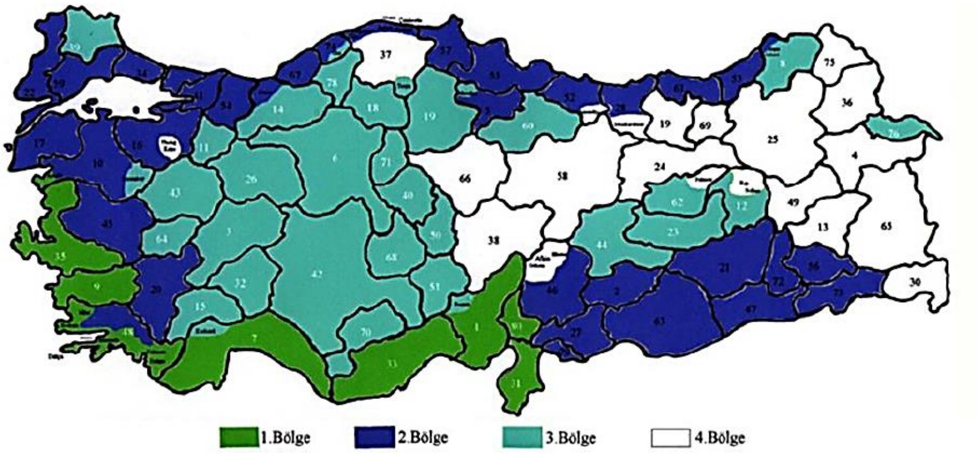

Figure 4.4. Climate regions of Turkey according to the TS825 standard

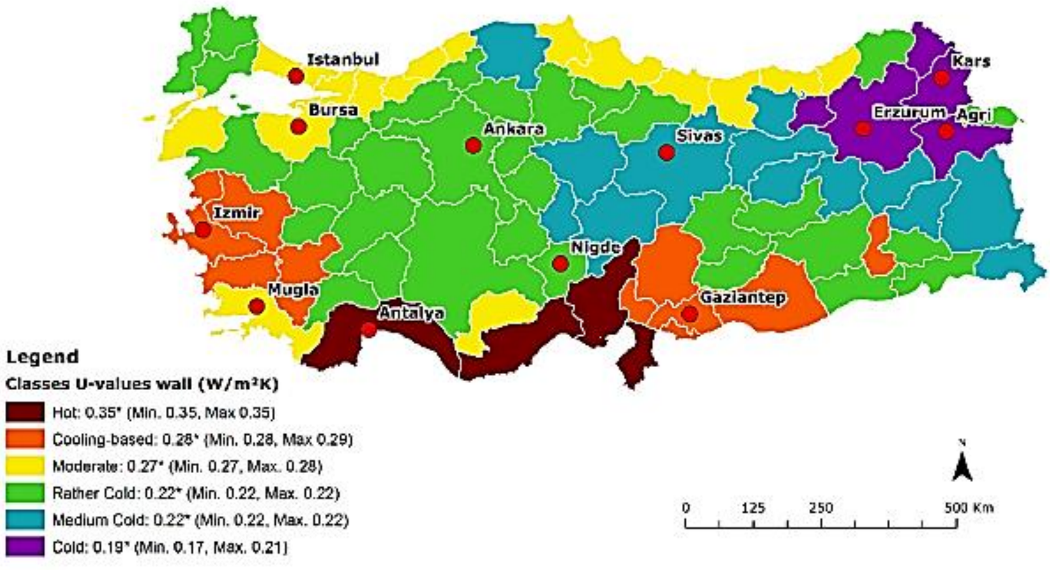

Figure 4.5. Climate regions of Turkey according to the IZODER study (2016)

Insulation needs can be indicated by the `U-value`. U-value is a measure of the heat transmission through a material. Lower U-values indicate better insulating features. Considering the climate zones, TSE and IZODER designated the required U-values for walls, windows, roofs, and floors. U-values of TSE and IZODER are provided in Table 4.6.

Table 4.6. U-values for walls, windows, roofs and floors for TSE and IZODER standards

	U-values (W/m^2*K)			
	Walls	**Windows**	**Roofs**	**Floors**
TSE	0.5	2.4	0.3	0.45
IZODER	0.22	1.10	0.16	0.32

The U-values of walls, windows, roofs and floors were calculated having regard to the limits provided in Table 4.6. Necessary calculations were conducted considering the materials available on the market. The U-value for a sum of materials can be found by conducting calculations based on thermal resistance values (m^2.K/W), since U-values cannot be summed up. Therefore, the thermal resistances of structural elements were summed and the reciprocate of the sum led to the U-value of concern. This calculation method is followed to determine the TSE U-values. Below the U-values for walls, windows, roofs, and floors based on the TSE approved, IZODER approved, and non-green materials are shown.

<u>Walls:</u> For the calculation of TSE U-values, internal resistance (Ri) and external resistance (Re) values are provided by TSE. The reciprocals of the total thermal resistances were found and written as the U-values of walls of different materials. Table 4.7, Table 4.8, and Table 4.9 show the U-values for TSE approved, IZODER approved, and non-green walls, respectively.

Table 4.7. Calculation of U-value of the TSE approved wall

	Ri	Stone wool	Channeled Brick	Plaster	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.13	1.563	0.211	0.020	0.040	1.963	**0.509**

Table 4.8. Calculation of U-value of the IZODER approved wall

	Ri	Stone wool	Gas concrete	Plaster	Thermal wall paint	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.13	2.50	0.802	0.111	0.087	0.04	3.67	**0.272**

Table 4.9. Calculation of U-value of the non-green wall

	Ri	Plaster	Clay brick	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.130	0.001	0.0357	0.040	0.207	**4.838**

Windows: U-values for window frame and glass were taken into consideration. Table 4.10, Table 4.11, and Table 4.12 give the U-values for TSE approved, IZODER approved, and non-green windows, respectively.

Table 4.10. Calculation of U-value of the TSE approved window

	Window frame	Isıcam 16mm Argon	**Overall**
U value (W/m2.K)	1	1	**1**

Table 4.11. Calculation of U-value of the IZODER approved window

	Window frame	Isıcam S+3 36cm Argon	**Overall**
U value (W/m2.K)	0.7	0.7	**0.7**

Table 4.12. Calculation of U-value of the non-green window

	Window frame	4mm single glass	**Overall**
U value (W/m2.K)	5.42	5.42	**5.42**

Roofs: Internal resistance (Ri) and external resistance (Re) values are provided by TSE. Moreover, for the calculation reciprocal of total thermal resistances were multiplied by 0.8 and U-values were achieved. Table 4.13, Table 4.14, and Table 4.15 provide the U-values for TSE approved, IZODER approved, and non-green roofs, respectively.

Table 4.13. Calculation of U-value of the TSE approved roof

	Ri	Stone wool	Concrete	Plaster	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.130	2.500	0.255	0.02	0.08	2.985	**0.268**

Table 4.14. Calculation of U-value of the IZODER approved roof

	Ri	Stone wool	Concrete	Plaster	Thermal paint	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.13	4.375	0.255	0.111	0.0869	0.08	5.038	**0.159**

Table 4.15. Calculation of U-value of the non-green roof

	Ri	Concrete	Plaster	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.13	0.0625	0.01	0.08	0.283	**2.832**

Floors: For the calculation of the U-value, the reciprocal of total thermal resistances were multiplied with 0.5. Table 4.16, Table 4.17, and Table 4.18 provide the U-values for TSE approved, IZODER approved, and non-green floors, respectively.

Table 4.16. Calculation of U-value of the TSE approved floor

	Ri	Stone wool	Concrete	Cement finish	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.130	0.688	0.213	0.02	0.08	1.130	**0.442**

Table 4.17. Calculation of U-value of the IZODER approved floor

	Ri	Stone wool	Concrete	Cement finish	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.13	1.125	0.213	0.02	0.08	1.568	**0.319**

Table 4.18. Calculation of U-value of the non-green floor

	Ri	Concrete	Cement finish	Re	Total	**U-value**
Thermal Resistance (m2.K/W)	0.13	0.0313	0.0072	0.08	0.248	**2.013**

In order to constitute a base scenario and comparisons between different cases, home appliances that consume electricity were examined as well. The green and non-green home appliances and their yearly energy consumption are provided in Table 4.19, Table 20, Table 4.21, Table 4.22, and Table 4.23. In calculations, the energy demand for one item is multiplied with the total number of units used in the whole building.

Table 4.19. Energy demand of non-green home appliances

		Fridge	Dish-washer	Washing machine	Indoor lights	Out-door lights	**Total**
Energy demand for a single unit (kwh/yr)		349	290	152	216	216	-
4-storey building	Number of units	16	16	16	320	10	-
	Total energy demand (kwh/yr)	5584	4640	2432	69120	2160	**83936**
5-storey building	Number of units	28	28	28	560	10	-
	Total energy demand (kwh/yr)	9772	8120	4256	120960	2160	**145268**
7-storey building	Number of units	28	28	28	560	10	-
	Total energy demand (kwh/yr)	9772	8120	4256	120960	2160	**145268**

Table 4.19 *(cont'd)*

		Fridge	Dish-washer	Washing machine	Indoor lights	Out-door lights	**Total**
15-storey building	Number of units	48	48	48	960	10	**-**
	Total energy demand (kwh/yr)	16752	13920	7296	207360	2160	**247488**

Table 4.20. Energy demand of green home appliances for 4-storey building

	Fridge	Dish-washer	Washing machine	Lights inside	Lights outside	**Total**
Energy demand for one (kwh/year)	203	262	84	31	31	**-**
Amount	16	16	16	320	10	**-**
Energy demand (kwh/year)	3680	3792	1040	9792	306	**20980**

Table 4.21. Energy demand of green home appliances for 7-storey building

	Fridge	Dish-washer	Washing machine	Lights inside	Lights outside	**Total**
Energy demand for one (kwh/year)	203	262	841	31	31	**-**
Amount	28	28	28	560	10	**-**
Energy demand (kwh/year)	6440	6636	1820	17136	306	**33438**

Table 4.22. Energy demand of green home appliances for 12-storey building

	Fridge	Dish-washer	Washing machine	Lights inside	Lights outside	**Total**
Energy demand for one (kwh/year)	203	262	841	31	31	-
Amount	48	48	48	960	10	-
Energy demand (kwh/year)	11040	11376	3120	29376	306	**56318**

Table 4.23. Energy demand of green home appliances for 15-storey building

	Fridge	Dish-washer	Washing machine	Lights inside	Lights outside	**Total**
Energy demand for one (kwh/year)	203	262	841	31	31	-
Amount	60	60	60	1200	10	-
Energy demand (kwh/year)	13800	14220	3900	36720	306	**70046**

U-values provided above were inserted into the Ecotect Software. First of all, yearly thermal loads needed for non-green structural elements were calculated for each building by Ecotect. The sum of the non-green structural elements and non-green appliances constituted the base scenario. Base scenario energy demand values for all buildings are provided in Table 4.24.

Table 4.24. Base scenario demand values for all buildings

	4-storey	**7-storey**	**12-storey**	**15-storey**
Non-green structural elements energy demand (kwh/year)	17651	22422	31472	36690
Non-green appliances energy demand (kwh/year)	83936	145268	247488	308820

Table 4.24 *(cont'd)*

	4-storey	7-storey	12-storey	15-storey
Base scenario total energy demand (kwh/year)	101587	167690	278960	345509

Yearly thermal loads needs were calculated for TSE Standard and IZODER study as well. The difference between the needs of each element was noted down as the energy savings since, in BEST certification system, energy credits are given regarding to how much a building saves energy compared to the base scenario. For instance, the difference between the yearly thermal loads of a non-green wall and a TSE approved wall will provide the energy saving that can be gained by preferring the TSE approved wall instead of the non-green wall. Calculations are made accordingly. Savings that can be gained by green building structures approved by TSE and IZODER over non-green structures are provided in 4.25.

Table 4.25. Savings that can be gained by green building structures approved by TSE and IZODER over non-green structures

	Savings from items approved by TSE ($)	Savings from items approved by IZODER ($)
4-storey		
Wall	8109	8438
Window	2144	2287
Roof	3069	3196
Floor	28	31
7-storey		
Wall	12448	12908
Window	3475	3703
Roof	3018	3140
Floor	93	100

Table 4.25 *(cont'd)*

	Savings from items approved by TSE ($)	**Savings from items approved by IZODER ($)**
12-storey		
Wall	19738	20428
Window	5856	6239
Roof	3049	3176
Floor	166	176
15-storey		
Wall	24117	24947
Window	7289	7765
Roof	3026	3152
Floor	210	227

Energy savings gained from home appliances were calculated with the same logic with calculation of savings from building structures (Table 4.26).

Table 4.26. Savings that can be gained from green home appliances

	4-storey ($)	**7-storey ($)**	**12-storey ($)**	**15-storey ($)**
Green fridge savings	1904	3332	5712	7140
Green dishwasher savings	848	1484	2544	3180
Green washing machine savings	1392	2436	4176	5220
Green inside lightening savings (60w)	59328	103824	177984	222480
Green outside lightening savings (60w)	1854	1854	1854	1854

Savings from renewable energy systems were calculated with the same logic with calculation of savings from the use of different building structures. Credits were given according to the sub-category 4.2 of BEST. Nevertheless, the optimization model chose which systems/materials/equipment would be selected to obtain a given BEST certificate. However, while making this choice, the sum of energy generation capacities of solar panels and wind turbines must not exceed 10 kW. This value is the maximum energy value that can be produced in buildings in accordance with Turkish Regulations in force. For the solar heater system, the total capacity in the calculation should not exceed the non-green water consumption for each building. Considering this capacity, a maximum number of 4 solar heaters for a 4-storey building, 7 for a 7-storey building, 11 for a 12-storey and 14 for a 15-storey building cannot be exceeded. Savings that can be gained by renewable energy systems are provided in Table 4.27.

Table 4.27. Savings that can be gained by renewable energy systems

Systems	**Energy savings (kwh/year)**
Solar panels (300W each)	370
Wind turbines (1kW each)	2000
Solar water heater (200lt storage tank each)	2425

4.4.2 Water Demand Analyzes

Water calculations were conducted according to the method provided in article 3.1 of BEST. In this method, when calculating the domestic water consumption, the water used in toilets, showers, sinks, and kitchen faucets, dishwashers, washing machines and the amount of water used in garden irrigation were examined. Unlike the energy calculation which calculates the energy savings for whole building, water calculation was conducted by calculating the water demand not the savings. Moreover, energy calculation was performed for the total energy used in the building but water calculation is performed by considering only a household. The method is explained further in detail below. The abbreviations were used as in the BEST certification manual.

First, water uses of toilets, showers, sinks and kitchen faucets, dishwashers, washing machines, and irrigation were calculated one by one considering the method in the BEST. Then, water recovered were subtracted from the total water use. The total water use is equal to water used indoors and water used outdoors. Usage frequency and intensity of use of equipment are provided in Table 4.28.

$$\text{Water use} = \text{Total water used} - \text{Water recovered} \tag{66}$$

$$\text{Total water used} = \text{Water used indoors} + \text{Water used outdoors} \tag{67}$$

Table 4.28. Usage frequency and intensity of use of equipment (ÇEDBİK, 2019)

Equipment	**Usage frequency (UF) (1/(person*day))**	**Intensity of Use (IU) (Usage percentage and duration of capacity)**
Toilet (Man)	4	1
Toilet (Woman)	4	1
Showerhead	0.03	5.60
Tap (Bathroom)	4	0.25
Tap (Kitchen)	1	0.44
Dishwasher	0.04	12
Washing machine	1	0.69

<u>Toilets:</u> Water use in toilets for one flat was calculated as:

$$\sum \frac{(Full\ washing\ volume * 1) + (Half\ washing\ volume * 2)}{3} \tag{68}$$

$$Wtoilet = EF * UF * IU * MFR \tag{69}$$

Where;

Wtoilet: Yearly water use by toilets (m^3/year)

EF: Effective washing volume (L)

UF: Usage frequency (1 / person * day)

IU: Intensity of use (percentage of use and duration of capacity)

MFR: Female to male ratio (%), (accepted as 50% each)

Showers: Water use for showers in one flat was calculated by

$$Wshower = FR * UF * IU \tag{70}$$

Where;

Wshower: Yearly water use by showers (m^3/year)

FR: Flowrate (L/min);

Tap (kitchen) Water use by kitchen taps for one flat was calculated as;

$$Wtap, kitchen = FR * UF * IU \tag{71}$$

Where;

Wtap,kitchen: Yearly water use by taps in kitchen (m^3/year)

Tap (bathroom): Water use by bathroom taps for one flat was calculated as

$$Wtap, bathroom = FR * UF * IU \tag{72}$$

Where;

Wtap,kitchen: Yearly water use by taps in bathroom (m^3/year)

Dishwasher: Water use by dishwashers for one flat was calculated as below.

$$Wdishwasher = LPC * UF * IU \qquad (73)$$

Where;

Wdishwasher: Yearly water use by dishwasher (m^3/year)

LPC: The amount of water (L) used for each washing of the dishwasher

Washing machine: Water use by washing machines for one flat was calculated as:

$$Wwashing\ machine = LKG * UF * IU \qquad (74)$$

Where;

Wwashing machine: Yearly water use by washing machine (m^3/year)

LKG: The amount of water (L) used for each washing of the washing machine

Since the calculations were performed for only one household, calculations are valid for all buildings. The results of the calculations conducted accordingly are provided in Table 4.29 and Table 4.30.

Table 4.29. Results of water consumption values for non-green equipment

	Toilet	Shower	Bathroom Tap	Kitchen Tap	Dish-washer	Washing machine
EF	6.057	-	-	-	-	-
UF	4	0.030	4	1	0.040	1
IU	1	5.600	0.250	0.440	12	0.690
MFR	1	-	-	-	-	-
FR	6.057	9.464	9	6.814	-	-

Table 4.29 *(cont'd)*

	Toilet	**Shower**	**Bathroom Tap**	**Kitchen Tap**	**Dish-washer**	**Washing machine**
WU	-	-	-	-	13	50.995
C	24.227	1.590	6.814	2.998	6.240	35.187
Capita	4	4	4	4	4	4
TWU	35.371	2.321	9.948	4.377	9.110	51.373
Total						**112.501**

Table 4.30. Results of water consumption values for green equipment

	Toilet	**Shower**	**Bathroom Tap**	**Kitchen Tap**	**Dish-washer**	**Washing machine**
EF	3.030	-	-	-	-	-
UF	4	0.030	4	1	0.040	1
IU	1	5.600	0.250	0.440	12	0.690
MFR	1	-	-	-	-	-
FR	3	3.785	3.785	3.785	-	-
WU	-	-	-	-	6.500	26.422
C	12.120	0.636	3.785	1.665	3.120	18.231
Capita	4	4	4	4	4	4
TWU	17.695	0.928	5.526	2.431	4.555	26.618

Garden: Water use in the garden was calculated as below;

$$Wgarden = \frac{A * IR}{Number\ of\ household\ (number\ of\ flat)} \qquad (75)$$

Where;

Wgarden: Yearly water use by washing machine (m^3/year)

A: Garden area to be irrigated (m^2);

IR: The amount of water used for garden irrigation (Liter / m^2 * year);

The amount of water used for irrigation is calculated with the method suggested by FAO. The method is explained below.

$$ETcrop = ETo * Kc \qquad (76)$$

$$IN = ETcrop + SAT + PERC + WL - Pe \qquad (77)$$

$$Pe = 0.8 * P - 25\ \ if\ P > 75\ mm/month \qquad (78)$$

$$Pe = 0.6 * P - 10\ \ if\ P \leq 75\ mm/month \qquad (79)$$

$$PE = ETcrop - Pe \qquad (80)$$

$$Water\ need\ of\ the\ garden = IN * Area \qquad (81)$$

Where;

ETcrop: Crop water needs (mm)

ETo: Reference crop evapotranspiration (mm)

Kc: Crop factor

IN: Irrigation water need (mm)

ETcrop: Amount of crop water needs (mm)

SAT: Amount of water needed to saturate the soil (mm)

PERC: Amount of percolation and seepage loses (mm)

WL: Amount of water needed to establish a water layer (mm)

Pe: Effective rainfall (mm)

Gardens of the all buildings were accepted to be of same size, which is 20 m^2 and the garden was planted with plants having a Kc value of 0.5, such as roses. Eto value for Ankara is 900 mm (General Directorate of Meteorology of Turkey, 2021).

$$ETcrop = 900\frac{mm}{year} * 0.5 = 450\frac{mm}{year} \tag{82}$$

$$Pe = 0.6 * 413.6\frac{mm}{month} - 10 = 238.16 \ \ since\ P\ < 75\ mm/month \tag{83}$$

$$PE = 450 - 223.46 = 226.54 \tag{84}$$

$$IN = 450\frac{mm}{year} + 200\frac{mm}{year} + 2190\frac{mm}{year} + 100\frac{mm}{year} - 226.54\frac{mm}{year} = 2716.54\frac{mm}{year} = 2.717\frac{m}{year} \tag{85}$$

$$Water\ need\ = 2.717\frac{m}{year} * 20\ m2 = 54.33\ m^3 \tag{86}$$

$$Water\ need\ \ for\ one\ household\ for\ 4 - storey = \frac{54.33\ m^3}{16\ households} = \ 3.396 m^3/household \tag{87}$$

$$Water\ need\ \ for\ one\ household\ for\ 7 - storey = \frac{54.33\ m^3}{28\ households} = \ 1.940 m^3/household \tag{88}$$

$$Water\ need\ \ for\ one\ household\ for\ 12 - storey = \frac{54.33\ m^3}{48\ households} = \ 1.132 m^3/household \tag{89}$$

$$Water\ need\ \ for\ one\ household\ for\ 15-storey=\frac{54.33\ m^3}{60\ households} \tag{90}$$

$$=\ 0.906m^3/household$$

Where;

P: Monthly average rainfall (mm/month)

PE: Actual water need of the crop (mm)

The irrigation of a garden was accomplished by either drip irrigation or sprinklers. The choice was given to the model. The field application efficiency was 0.75 for a sprinkler and 0.9 for drip irrigation. Therefore, the actual irrigation water need was calculated as below.

$$Actual\ water\ need=Water\ need\ /Field\ application\ efficiency \tag{91}$$

<u>Sprinkler</u>

$$Actual\ water\ need\ for\ 4-storey=\frac{3.396m^3}{0.75}=4.528\ \ m^3 \tag{92}$$

$$Actual\ water\ need\ for\ 7-storey=\frac{1.940m^3}{0.75}=2.587\ m^3 \tag{93}$$

$$Actual\ water\ need\ for\ 12-storey=\frac{1.132m^3}{0.75}=1.509\ m^3 \tag{94}$$

$$Actual\ water\ need\ for\ 15-storey=\frac{0.906m^3}{0.75}=1.207\ m^3 \tag{95}$$

<u>Drip irrigation</u>

$$Actual\ water\ need\ for\ 4-storey=\frac{3.396m^3}{0.9}=3.773\ m^3 \tag{96}$$

$$Actual\ water\ need\ for\ 7-storey=\frac{1.940m^3}{0.9}=2.156\ m^3 \tag{97}$$

$$Actual\ water\ need\ for\ 12-storey = \frac{1.132m^3}{0.9} = 1.258\ m^3 \quad (98)$$

$$Actual\ water\ need\ for\ 15-storey = \frac{0.906m^3}{0.9} = 1.006\ m^3 \quad (99)$$

Rainwater calculation

Rainwater systems were used either in toilets only, or in both toilets and garden irrigation. Therefore, the capacities of the systems were calculated according to the choices made by the optimization model. In other saying, for toilets, if the model has chosen the green toilet, then the rainwater system capacity will be equal to the water need of the green toilet. Moreover, if the model has chosen the sprinkler for irrigating the garden, then the rainwater system capacity will be set to meet the sprinkler capacity. Since, water need calculations are made for a household; calculation for the toilet water need is the same for all buildings. Nevertheless, the total water requirement of gardens was divided into the number of households in the building in order to find the water consumption per household. Therefore, garden water need varies between buildings of concern. The calculations are given in detail in below.

$$Rainwater\ for\ only\ toilets =$$

$$17.695\ \frac{m^3}{year} * \ I_w(1) + 35.371 \frac{m^3}{year} * I_{wn}(1) \quad (100)$$

$$Rainwater\ for\ garden\ for\ 4-storey =$$

$$3.773 \frac{m^3}{year} * I_w(5) + 4.528 \frac{m^3}{year} * I_{wn}(5) \quad (101)$$

$$Rainwater\ for\ \ garden\ for\ 7-storey =$$

$$2.156 \frac{m^3}{year} * I_w(5) + 2.587 \frac{m^3}{year} * I_{wn}(5) \quad (102)$$

$$Rainwater\ for\ garden\ for\ 12-storey = \quad (103)$$

$$1.258 \frac{m^3}{year} * I_w(5) + 1.509 \frac{m^3}{year} * I_{wn}(5)$$

$$Rainwater\ for\ garden\ for\ 15 - storey =$$

$$1.006 \frac{m^3}{year} * I_w(5) + 1.207 \frac{m^3}{year} * I_{wn}(5) \quad (104)$$

4.4.3 Savings Due to Reduced Water and Energy Consumptions

Green systems/materials/equipment can contribute to water and electricity savings for buildings. In order to evaluate these potential savings, first savings for the optimum solutions for all cases were found. Then corresponding monetary savings in Net Present Value (NPV) were calculated over a management period of 10 years using a US Dollar inflation rate of 1.9% which is average of the inflation rates of the last 5 years (Federal Reserve Bank of St. Louis, 2021). Whether the initial costs can be compensated for by electricity and water savings after 10 years were evaluated for the optimum solutions for each certification level. Equations and unit prices used are provided below:

$$Uws = Uwn - Uwgb \quad (105)$$

$$Cwc = Uws * Cwu * Nh \quad (106)$$

Where;

Uws	Water saved (m^3/year)
Uwn	Non-green building water consumption (m^3/year)
$Uwgb$	Green building water consumption (m^3/year)
Cwc	Water consumption cost ($/$m^3$)
Cwu	Water consumption unit cost ($/$m^3$)

Nh Number of households

$$Ues = Uen - Ue \tag{107}$$

$$Cec = Ues * Ceu * Nh \tag{108}$$

Where;

Ues Electricity saved (kwh/year)

Uen Non-green building electricity consumption (kwh/year)

Ue Green building electricity consumption (kwh/year)

Cec Electricity consumption cost ($/kwh)

Ceu Electricity consumption unit cost ($/kwh)

Nh Number of households

$$NPV = Rt \,/\, (1 + inf)^t \tag{109}$$

Where;

Rt: Savings in a particular year ($)

inf: Inflation rate

t: Duration with respect to current day (year)

Water unit cost in 2021 was 3.60 TL/m^3 and water consumption unit cost average increase rate has been 6.863% (Türkiye Cumhuriyet Merkez Bankası, 2021). Water consumption unit cost with the increase of water price increase rate is calculated and the corresponding unit prices in US Dollars are presented in Table 4.31.

Table 4.31. Estimations for the water consumption unit prices over the years

Year	Water consumption unit price ($)
2021	0.49
2022	0.52
2023	0.56
2024	0.60
2025	0.64
2026	0.68
2027	0.73
2028	0.78
2029	0.83
2030	0.89
2031	0.95

Electricity consumption unit price in 2021 was 0.6508 TL/kwh (TEDAŞ, 2021) and the increase rate in the average electricity consumption unit price has been 11.229% (Türkiye Cumhuriyet Merkez Bankası, 2021). Using this rate, the electricity consumption unit price over 10 years were estimated as given in Table 4.32.

Table 4.32. Estimated electricity consumption unit prices over the years

Year	Electricity consumption unit price ($)
2021	0.09
2022	0.10
2023	0.11
2024	0.12
2025	0.14

Table 4.32 *(cont'd)*

Year	**Electricity consumption unit price ($)**
2026	0.15
2027	0.17
2028	0.19
2029	0.21
2030	0.23
2031	0.26

4.4.4 Other Materials

The materials that do not affect the energy and water use were categorized in this section. Their costs were considered by the model if they were chosen by the model. The costs of all materials, systems and services were calculated for each building type as provided in Appendix B.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Model Optimization Results and Discussion

61 binary variables, 3 integer variables, and 98 model parameters were entered into the optimization model for each case study, and using these, the most appropriate choices were made by the model according to the objective function, assumptions and constraints. The model was conditioned to obtain the given certificates with the minimum costs. It should not be forgotten that these prices are not to transform an existing building to green, but to build a building from scratch, and were calculated based on the average costs defined to the model. Costs are in the unit of USD. The prices of all systems were entered in the model in US Dollars. The reason for this is the rapidly changing exchange rate in Turkey. The Turkish lira value can be obtained by multiplying the costs according to the current exchange rate. According to the results of the model, the minimum costs to achieve a given certain certification levels of BEST are provided in Table 5.1.

Table 5.1 Minimum initial costs of the cases in USD

	Initial costs of the cases ($)			
	4-storey	7-storey	12-storey	15-storey
Approved	87,667	144,473	239,153	295,954
Good	88,337	145,302	240,422	297,487
Very good	325,387	524,682	849,327	1,043,524
Excellent	216,774	330,913	509,963	618,186

When the minimum initial costs given in Table 5.1 are examined, it is seen that the price generally increases as the level increases, but this situation differs at the Very Good level. This is the level with the highest initial cost among all. The reason for this is the choices made by the model to achieve the predefined credit range to reach the Very Good level. It may be the case that the model may give other results if it is not restricted with this credit range. In addition, it has been observed that as the number of floors of the building increase, costs also increase. In this case, it makes sense considering the amount of material used. Looking at the Approved and Good levels, it was seen that about $1000 was spent between two scenarios for each building. Therefore, preferring Good over Approved is considered as a better act when one takes the potentially positive effect on brand name into account.

The initial costs of green-buildings that have given BEST certificate levels are compared to their non-green versions. The reason for this analysis is that only the costs of the systems rated for a BEST certification level are considered in the optimization model. There are materials and systems that are not credited by BEST, but necessary for the construction of a building. The prices of such materials and systems are not included. In addition, it is assumed that some credits are earned automatically as cost-independent and cost-insignificant subcategories. In other words, the costs given so far are actually the costs required to obtain a green building compared to a base non-green building considering credited elements in BEST, not to build a building from scratch. Therefore, in order to assess the overall increase in construction of a green building compared to a non-green counterpart, the overall construction costs are determined. by assuming that all systems are selected as non-green, the prices of all non-green systems were added up. Non-green building costs are provided in Table 5.2 and percentage increase in costs to make the building green with respect to non-green building are given in Table 5.3.

Table 5.2 Non green building costs

Number of storey	Non-green building cost ($)
4-storey	84,122
7-storey	138,268
12-storey	228,518
15-storey	282,659

Table 5.3 Percentage increases in costs with respect to non-green buildings

Level of certification	Increase in cost (%)			
	4-storey	7-storey	12-storey	15-storey
Approved	4.2	4.5	4.7	4.7
Good	5.0	5.1	5.2	5.2
Very good	286.8	279.5	271.7	269.2
Excellent	157.7	139.3	123.2	118.7

As it can be seen from the above tables, percentage increases in overall construction costs for building with Approved and Good levels were less than 15%. This increase can be deemed as bearable for people and they may be willing to pay more in order to purchase a green building/flat at given levels. However, for the buildings that can gain Very Good and Excellent levels of certification, initial costs are significantly higher. Therefore, the initial investment may become infeasible for buyers as well as the contractors.

The binary variables were assigned by the model as 1 if the systems/materials/equipment in question were selected, and 0 if not. Integer variables were used only in the selection of the number of renewable energy systems. Systems selected are provided below. The values assigned to the binary decision variables by the optimal solution are shown in detail in Appendix C.

Table 5.4 Selected systems by the optimization model for 4-storey building

	Selected systems
Approved	Rainwater system for toilet only
Good	Drip irrigation, efficient indoor lightning, humidity controller, water meters
Very Good	Green kitchen tap, green showerhead, rainwater systems for toilet and bathroom, drip irrigation system, humidity controller, water meters, green roof, water-permeable pavement, efficient elevator, exhaust fan, hood fume, soundproofing on floors, auditory insulation on walls, linoleum flooring, protective tapes on sensitive wall corners, kick guards on doors, door handle slams, fire alarms, video intercom systems, fences around landfill, artwork, electric vehicle charging station, waste separation bins, tree branch grinder, energy meter, innovation, approved consultant.
Excellent	Drip irrigation system, rainwater system for toilet and bathroom, efficient dishwasher, efficient washing machine, efficient refrigerator, efficient indoor lighting, efficient outdoor lighting, solar panels, solar water heater, humidity controller, water meters, green roof, water permeable pavement, efficient elevator, exhaust fan, hood fume, linoleum flooring, protective tapes on sensitive wall corners, kick guards on doors, door handle slams, fire alarms, video door phone systems, fences around waste storage area, artwork, electric vehicle charging station, waste separation bins, tree branch grinder, energy meter, approved consultant

Table 5.5 Selected systems by the model for 7-, 12- and 15-storey buildings

	Selected systems
Approved	Rainwater system for toilet only
Good	Drip irrigation, efficient indoor lightning, humidity controller, water meters
Very Good	Green kitchen tap, green showerhead, rainwater systems for toilet and bathroom, drip irrigation system, humidity controller, water meters, green roof, water-permeable pavement, efficient elevator, exhaust fan, hood fume, auditory insulation on floors, auditory insulation on walls , linoleum flooring, protective tapes on sensitive wall corners, kick guards on doors, door handle slams, fire alarms, video phone systems, fences around waste storage area, artwork, electric vehicle charging station, waste separation bins, tree branch grinder, energy meter, shower water recycling system, approved consultant, wastewater treatment unit
Excellent	Drip irrigation system, rainwater system for toilet and bathroom, efficient dishwasher, efficient washing machine, efficient refrigerator, efficient indoor lighting, efficient outdoor lighting, solar panels, solar water heater, humidity controller, water meters, green roof, water permeable pavement, efficient elevator, exhaust fan, hood fume, linoleum flooring, protective tapes on sensitive wall corners, kick guards on doors, door handle slams, fire alarms, video door phone systems, fences around waste storage area, artwork, electric vehicle charging station, waste separation bins, tree branch grinder, energy meter, approved consultant, wastewater treatment unit

Table 5.6 Amount of the renewable energy systems selected by the model

Level of certification	Solar panel	Wind turbine	Solar water heater
4-storey - Excellent	17	0	4
7-storey - Excellent	12	0	7
12-storey - Excellent	12	0	11
15-storey - Excellent	7	0	17

Considering the results, it was concluded that the selection of systems was not affected by the number of storeys. All of the buildings were equipped with the same systems. However, since 4-storey building does not need the wastewater treatment unit to be able to get the aforementioned water credits, the building was not equipped with the wastewater treatment unit but 7-, 12- and 15-storey buildings are.

According to the results, it was seen that only Excellent levels of the buildings were equipped with renewable energy systems. Amount of the systems does not follow any pattern. The model has chosen different number of systems for each building. However, wind turbine was not deemed suitable for any building or any level by the model. Moreover, it was sufficient to select only one system (use of rainwater system for toilet) at the Approved certification level, as it is accepted that all green systems with immeasurable cost already provided in the building. At the Good level, it was found sufficient to select 4 systems (drip irrigation system, efficient indoor lighting, humidity controller, water meters). However, the number of systems selected for Very good and Excellent certification levels increased rapidly, reaching 28 and 30 for 4-storey, 29 and 31 for 7-, 12- and 15-storey buildings, respectively. Although more systems were selected at the Excellent level than the Very Good level, it was observed that the Very Good level was more expensive. This is because the model was constrained to stay within the credit range defined for the Very Good level. For example, the model did not choose any system that would reduce electricity consumption at the Very Good level as choosing these systems would lead to high credit gain. Although earning credits may actually appear to be a positive outcome, a credit range for Very Good has already been defined in the model as a constraint and the model is forced to remain within this range. Therefore, the model chose systems that bring less credit and are relatively more expensive in order not to exceed the Very Good credit range. Green fridge, green washing machine and green dishwasher were selected to increase the energy score to reach the level of Excellent. If these systems were preferred at the Very Good level, the credit range that the model aims to reach will be exceeded. Instead of these, it has been determined by the model that auditory insulation should be made on all walls and floors and the shower water recycling system to be installed. This is a situation caused by the constraints used in the optimization model. If the model was not constrained by certification level constraints, it could have made a better choice. But it was necessary to put these constraints in order to see the initial costs to achieve a certain certification score range and the materials/systems selected to achieve a given certification level. As it is understood from this approach, actually getting the Excellent level certificate is more feasible than getting the Very Good certificate in terms of both brand image, initial cost, and savings.

The Sensitivity Analysis is a method for determining the influence of uncertainties in one or more input parameters on results. This analysis is valuable because it improves or decreases model prediction capability by investigating the model response to changes in inputs qualitatively and/or quantitatively, or by comprehending the phenomena researched via the analysis of parameter interactions (Pichery, 2014). In this regard, a sensitivity analysis was conducted in order to see if changing the unit costs of the systems effect the model results or not. For the analysis, the optimization model was solved for 5% and 10% increase and decrease in the costs of each system considered in the model. The results showed that even in the comparison of -10% and 10% change in unit costs, the choice of materials/systems to obtain a given BEST certification level does not change. The model constantly chooses the same systems. Therefore, as same systems are chosen, initial costs were changed in parallel to the given cost changes.

Savings can be earned from the reduction in water and electricity for 10 years are calculated. Net Present Value (NPV) of the savings for 10 years are calculated as well. The calculations are given in Appendix D in detail. Results of the calculations provided in below.

4-storey building

The NPV of annual change in savings from water in for 4-storey building for 10 years are shown in Figure 5.1. NPV of annual change in savings from electricity in for 4-storey building for 10 years are shown in Figure 5.2.

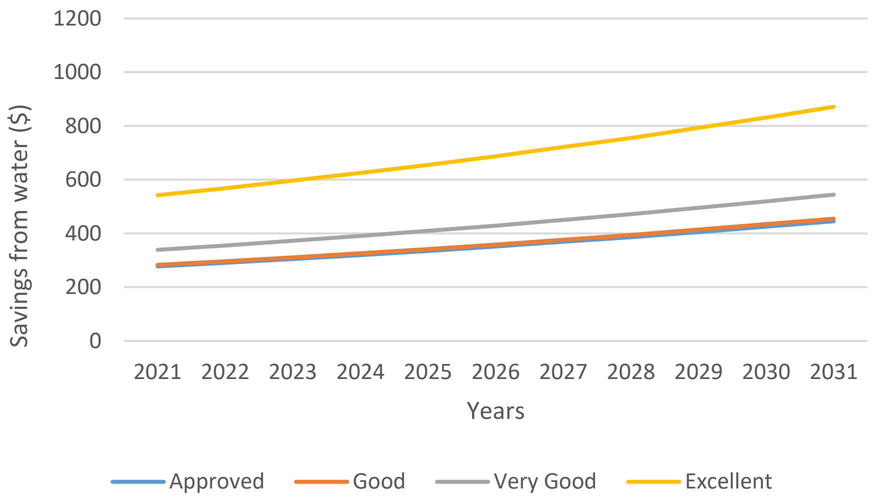

Figure 5.1. NPV of annual change in savings from water for 4-storey building for 10 years with respect to non-green building

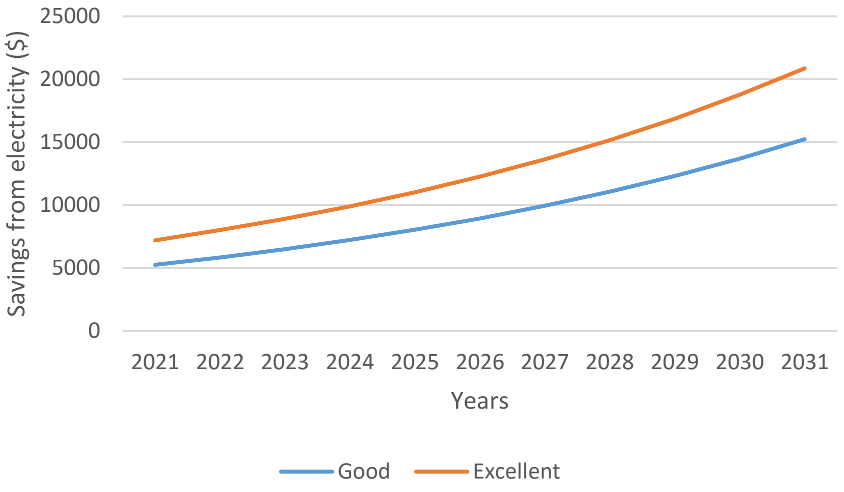

Figure 5.2. NPV of annual change in savings from electricity for 4-storey building for 10 years with respect to non-green building

7-storey building

NPV of annual change in savings from water in for 7-storey building for 10 years are shown in Figure 5.3. NPV of annual change in savings from electricity in for 7-storey building for 10 years are shown in Table 5.6.

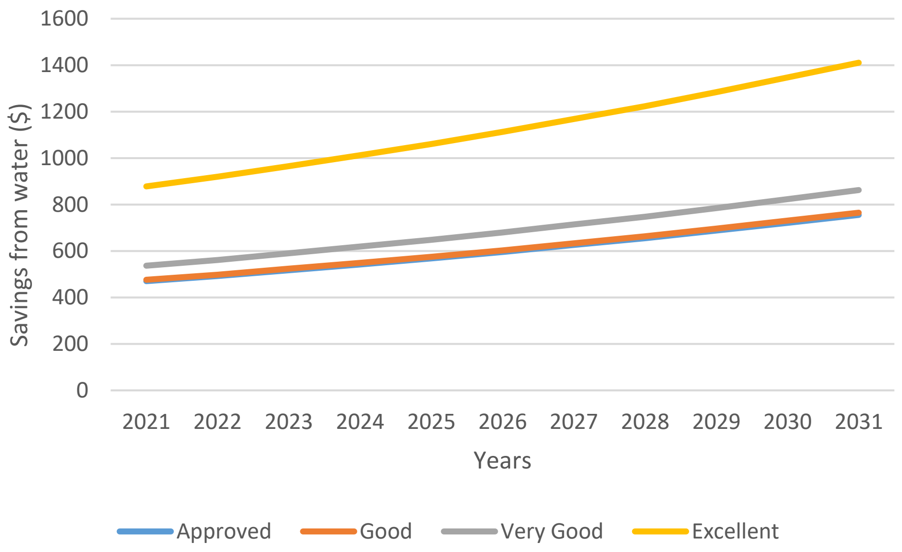

Figure 5.3. NPV of annual change in savings from water for 7-storey building for 10 years with respect to non-green building

Figure 5.4. Annual change in savings from electricity for 7-storey building for 10 years with respect to non-green building

12-storey building

NPV of annual change in savings from water in for 12-storey building for 10 years are shown in Figure 5.5. NPV of annual change in savings from electricity in for 12-storey building for 10 years are shown in Figure 5.6.

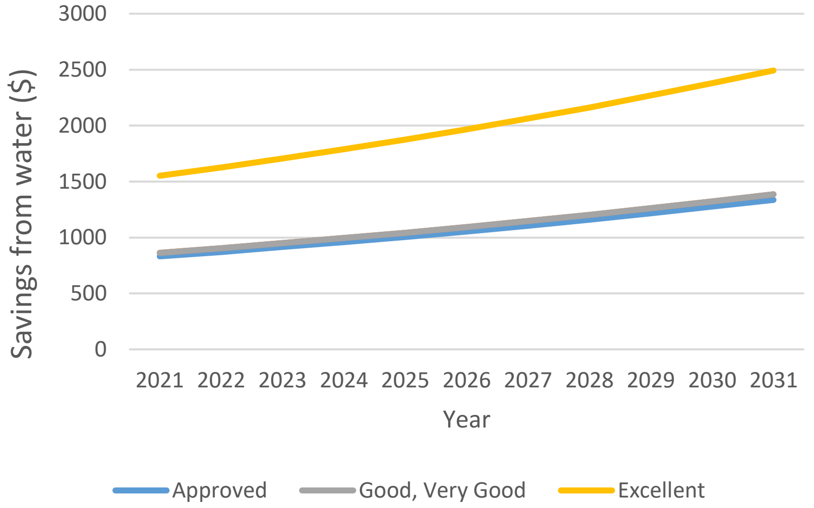

Figure 5.5. Annual change in savings from water for 12-storey building for 10 years with respect to non-green building

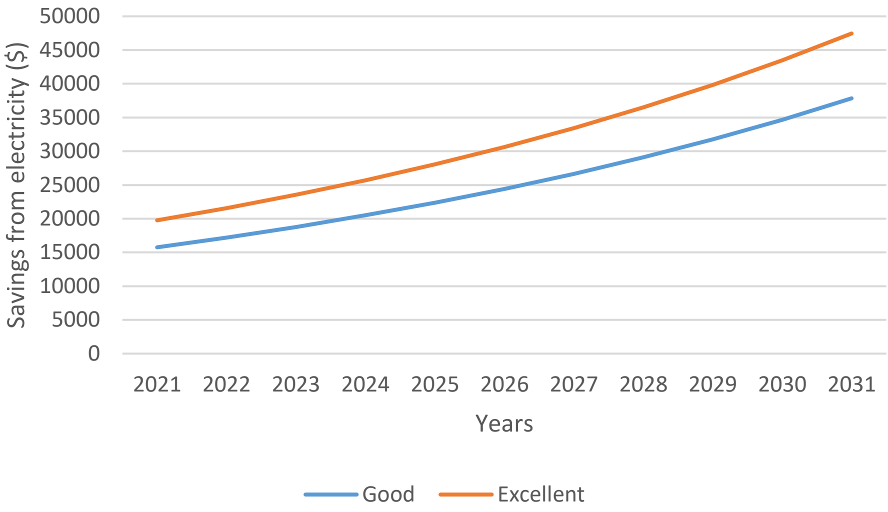

Figure 5.6. Annual change in savings from electricity for 12-storey building for 10 years with respect to non-green building

<u>15-storey building</u>

NPV of annual change in savings from water in for 15-storey building for 10 years are shown in Figure 5.7 and NPV of annual change in savings from electricity in for 15-storey building for 10 years are shown in Figure 5.8.

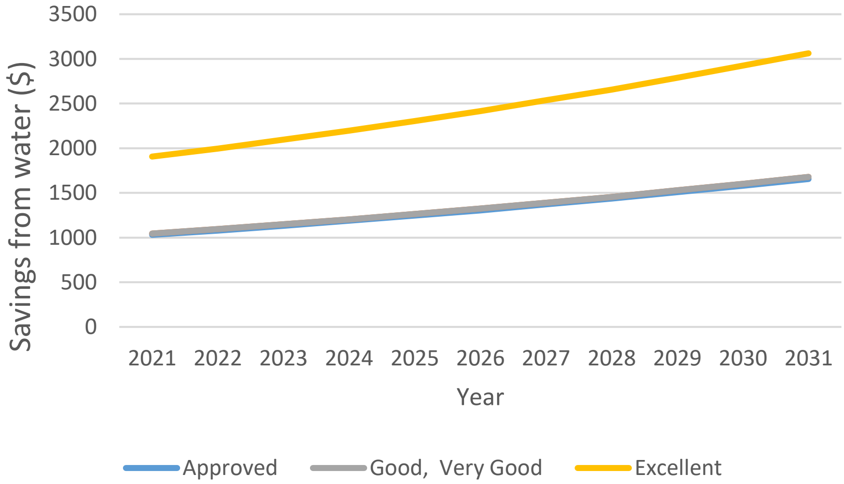

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Figure 5.7. Annual change in savings from water for 15-storey for 10 years with respect to non-green building

Figure 5.8. Annual change in savings from electricity for 15-storey building for a household for 10 years with respect to non-green building

Money will be saved in 10 years from electricity and water expenditures for whole building and per household for all cases are presented in the Table 5.7.

Table 5.7. NPV of savings from electricity and water consumption of each building type for each certification level with respect to non-green building in 10 years

NPV of savings from electricity and water ($)

	4-storey	7-storey	12-storey	15-storey
Approved	3908	6631	11,724	14,530
Good	97,012	169,466	291,219	363,616
Very Good	4777	7569	12,165	14,739
Excellent	135,072	222,722	371,792	460,270

Before the optimization model was run, it was expected that the money saved would increase as the certificate level improved. However, this expectation deteriorated at the Very Good certification level for each building as can be seen in Table 5.7. It was observed that this certification level saved almost the same amount as the Approved level, which is the lowest level of certification. Except for the Very Good level, it was seen that as certification levels increased, savings also increased. As a result, it is clear that the system that brings the most savings is the highest level of BEST, Excellent. The reason why the Very Good level resulted unexpectedly is that the model can reach the minimum initial cost for this level without selecting green systems in the energy category. This choice lowered the initial cost; on the other hand, it also reduced the savings obtained in 10 years due to lack of green energy systems. Another saying is that while the choices at this level are more profitable for the contractor initially, the savings on money for residents would be lower than expected. Moreover, the environmental impact would be higher due to lack of savings in energy consumption. The Approved level is more feasible than the Very Good level, considering the initial costs. However, the contractor should be aware that high level of green building certificate might be more desirable by the buyers during the sale of the green buildings due to lower utility costs for residents.

Subtracting the NPV of energy and water savings from the initial cost of each building shows whether savings compensates for the initial cost of a building. NPV of this difference for building attaining a given certification level are shown in Table 5.8, Table 5.9, Table 5.10 and Table 5.11 for 4-storey, 7-storey. for 12-storey, and 15-storey buildings, respectively.

Table 5.8 NPV of the difference between the initial cost and savings for the 4-storey building for each certification level

Difference in NPV ($)

	Approved	Good	Very Good	Excellent
Initial cost	87,667	88,337	325,387	216,774
Savings	3908	97,012	4777	135,072
Overall	**83,759**	**-8675**	**320,610**	**81,702**

Table 5.9 NPV of the difference between the initial cost and savings for the 7-storey building for each certification level

Difference in NPV ($)				
	Approved	Good	Very Good	Excellent
Initial cost	144,473	145,302	524,682	330,913
Savings	6631	169,466	7569	222,722
Overall	**137,842**	**-24,164**	**517,113**	**108,191**

Table 5.10 NPV of the difference between the initial cost and savings for the 12-storey building for each certification level

Difference in NPV ($)				
	Approved	Good	Very Good	Excellent
Initial cost	239,153	240,422	84,9327	509,963
Savings	11,724	291,219	12,165	371,792
Overall	**227,429**	**-50,797**	**837,162**	**138,171**

Table 5.11 NPV of the difference between the initial cost and savings for the 15-storey building for each certification level

Difference in NPV ($)				
	Approved	Good	Very Good	Excellent
Initial cost	295,954	297,487	1,043,524	618,186
Savings	14,530	363,616	14,739	460,270
Overall	**281,424**	**-66,129**	**1,028,785**	**157,916**

Looking at the results, the best overall cost for certification levels is ranked as Good, Excellent, Approved and Very Good. After 10 years in all building types, only the initial cost for the Good level was compensated and started to bring profit. It has been observed that this profit increased as the number of storeys of the buildings increased. When we compare the Good level, which is the best level in terms of overall cost, with the Very Good level, which is the worst in terms of overall cost, it is seen that there is a difference of approximately $330.000, $550.000, $880.000 and $1.097.000 for 4-, 7-, 12-, and 15-storey buildings, respectively. These differences indicate that the Very Good level is infeasible. Also, Very Good level is not feasible in terms of savings. While constructing a building, the contractors may also want to sell a building at the highest possible price. One of the most important factors in selling a building is the savings that the building will bring to residents. If a contractor can guarantee that they will save large amounts of money when selling the flats in the building, they can sell the flats for a higher price than its counterpart in a non-green building.

5.2 LEED Certification Levels Assessment

The corresponding scores and certification levels of 16 scenarios for which BEST certification scores were calculated before were found in the LEED certification system. Thus, it has been shown which level of LEED certificate each scenario can get. For water calculation, crediting was done according to the water consumption value per a household in BEST. However, in LEED, percentage of reduction in water consumption was considered while assigning credits. Thus, the reduction percentages were calculated for water. On the other hand, electricity credits were given using the same logic as in BEST. Therefore, the percentages of electricity reduction were directly taken from BEST results. The percentages of water use reduction and energy use reduction used in the LEED score calculations for all cases are shown in Figure 5.9 and Figure 5.10, respectively. Calculations are provided in Appendix E in detail. Moreover, the corresponding LEED certification levels of each case are presented in Table 5.12

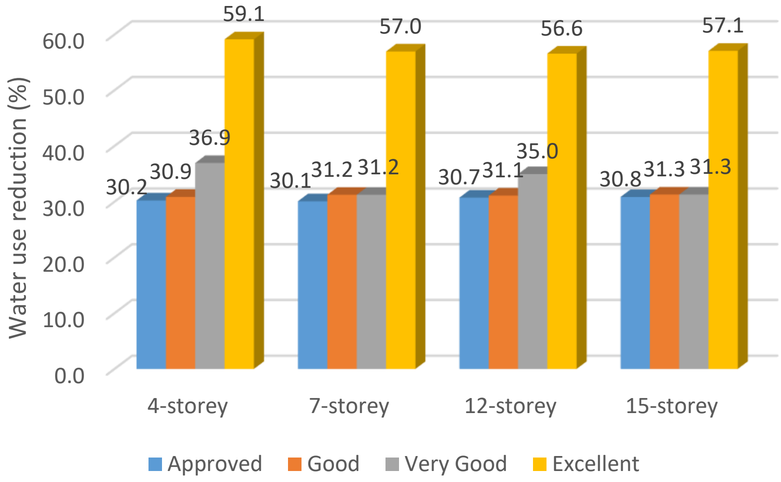

Figure 5.9. Water use reduction used in the LEED scores for each building

Figure 5.10. Energy use reduction used in the LEED scores for each building

Eser Holding building is the first LEED Platinum certified building of Turkey. The building is located in Ankara. In this building, the domestic water usage was reduced by 59%. In order to reach this result, a rainwater plan was prepared to improve water usage efficiency, and the waste water load given to the network was reduced. Rainwater falling on the land is collected and used for landscape irrigation. Water use has been minimized through the placement of double-stage reservoirs, waterless urinals, gray-water treatment system, flow-adjustable taps and rainwater collection systems. In this study, a similar result was obtained such that 60% water reduction was attained. In Eser Holding building, savings of up to 40% has been achieved in energy consumption compared to a normal building that can be built in the same area. In order to reach this energy saving, 2% of the total energy is met from renewable energy, the entire interior lighting system of the building is automatically controlled with motion and light sensors, and the light intensity is adjusted (Öncül, 2012). Savings in energy consumption by up to 40% is in line with the savings obtained in this study for Approved, Good and Very Good levels which range in 30.1 % to 36.9%. Also, there are many “Net Zero Energy Building” around the World. The buildings have net zero energy consumption, which equals to 100% energy reduction. As an example, to them, Messequartier (Graz, Austria), De Duurzame Wijk (Belgium Flsmish Region), University Research Centre of Technical University of Sofia (Sofia, Bulgaria), and Multifamily building Lenišće East (Koprivnica, Crotia) etc. According to this study, Excellent level has 80% reduction in energy (Erhorn & Erhorn-Kluttig, 2014). Therefore, it seems possible to acquire such energy reductions as observed in this study as well.

The water use reduction percentage value reached the highest value at Excellent level in all buildings with approximately 60%. In all buildings, the water use reduction percentage varies between 30% and 37% at Approved, Good and Very Good levels. This indicates that water use reduction at the Excellent level almost doubles when compared to other levels. This will also increase the savings achieved. With climate change, it is predicted that water resources will decrease significantly. Likewise, it is predicted that our country will be in class of water-poor countries in the coming years. From this point of view, the Excellent level is seen as the best option compared to other levels. On the other hand, the initial costs of each certification level can be crucial as well. If the initial cost is overcharged to increase the savings, the initial investment may become infeasible for buyers as well as the contractors.

For the electricity use reduction percentage, the Excellent level was also the highest for each building type at 80%. Then, electricity use reduction percentage at Good level increased by 58.4%, 61.9%, 63.8% and 64.4% for 4-, 7-, 12-, and 15-storeys, respectively. At Approved and Very Good levels, no system was selected for BEST that would affect electricity consumption. The reason for this is that systems that reduced electricity consumption were not preferred by the model at these certification levels due to their higher costs. Therefore, considering electricity consumption, it would be more appropriate to choose Excellent level. This will be a suitable choice both in terms of using resources efficiently and in terms of selling a flat more easily as it brings high savings to residents. On the other hand, again the initial costs of each certification level should be assessed as well. If initial cost is overcharged to increase the savings, the initial investment for the building will not be logical.

It is important for a building to save a significant amount of electricity and water in many ways. One of the motivations is the protection of our natural resources. The world population, which is increasing day by day, exceeds the rate of renewal of natural resources. Therefore, it is of great importance to protect our existing resources and it will become even more important in the future with the increase in temperatures due to climate change. If we are to have a future, we must move rapidly to cut emissions to levels consistent with the Paris Agreement. Only a combined effort by regulators, contractors, and residents can affect the essential transformation in a timely manner.

Green Deal, which claims to provide the groundwork for a new growth strategy, would make Europe the first climate-neutral continent by 2050. Plans to adopt laws to target emissions and enhance building efficiency will put the sector under pressure to address its most major source of greenhouse gas emissions. The goal of the agreement for a circular economy would certainly promote increased energy efficiency in building design. As a result of the study, it is seen that a significant amount of energy reduction can be achieved by green buildings. Therefore, constructing green buildings rather than traditional ones will be a big step towards meeting the requirements of both the Green Deal and the Paris Agreement.

Sustainability is the prevention of natural resource depletion in order to preserve ecological balance. Therefore, it is very important not to quickly deplete natural resources. If the resource consumption is higher than the resource recovery rate of the World, it means that all our natural resources will be depleted over time. Water savings of green building in the study shows that up to 60% water can be saved. This will reduce the rate of consumption of natural resources and help us to leave a more livable world for future generations.

On the other hand, saving natural resources and preventing the climate change is of course a driving force for building green, but for contractors' and residents' monetary benefits of the green buildings are crucial as well. Green buildings consume less water and electricity than traditional buildings and therefore this reduces the bills. This makes green buildings more attractive to be purchased.

Table 5.12. Corresponding LEED certification levels for each case study

	Approved	**Good**	**Very Good**	**Excellent**
4-storey building	- 35 Points	Silver 55 Points	Silver 50 Points	Gold 77 Points
7-storey building	- 35 Points	Silver 55 Points	Silver 50 Points	Gold 77 Points

Table 5.12 *(cont'd)*

	Approved	**Good**	**Very Good**	**Excellent**
12-storey building	- 35 Points	Silver 55 Points	Certified 49 Points	Gold 77 Points
15-storey building	- 35 Points	Silver 55 Points	Certified 49 Points	Gold 77 Points

As seen in Table 5.12, the Approved level of BEST certification could not achieve any level in LEED certificate with 35 points. It needs a minimum of 5 more points to get the Certified level of LEED. The Good level of BEST certification has achieved the LEED Silver level with 55 points in each building. These two levels are the 3rd best level in BEST and LEED, and they are equivalent. The Very Good level was awarded in 4-storey and 7-storey buildings at the LEED Silver level, and in 12-storey and 15-storey buildings at the LEED Certified level. There is only 1 point difference between them and the reason for this credit is that the water reduction in 4-storey and 7-storey buildings can get 3 points from the LEED, while the 12-storey and 15-storey buildings can get only 2 points. This 1-point difference has led to a difference in the level of certification. The BEST Excellent level was awarded with LEED Gold with 77 points for each building. LEED Gold is the 2nd best certificate for LEED, while BEST Excellent is the best certificate of BEST. When we consider the LEED levels, getting the good certificate seems to be the most feasible choice, as in the price comparison. It is because; it was able to get the Silver level, which is the equivalent level in LEED. Very Good level scenarios could not get their LEED equivalent Gold level certificate for any building, and even received Certified level which is the lowest level in LEED for 12- and 15-storey buildings. The Excellent level of BEST certification, on the other hand, was also unable to obtain the Platinum level, which is its LEED equivalent.

No case was able to earn the Platinum level, which is the best certification level LEED offers. But it should not be forgotten that the model was developed by considering the BEST certification requirements. Therefore, these results do not mean that LEED Platinum cannot be earned with the initial costs found. It is because; some categories in BEST cannot get points in LEED. Some of these include the presence of a work of art in the building and working from home. In addition, some categories that can be considered as cost-dependent in the LEED certificate are not credited in BEST, so they are not valid in case studies and these scores could not be obtained by LEED. Therefore, in this comparison, it is only shown which of the LEED certificates the buildings that has already awarded by BEST can get.

Deligöz and Aktan (2020) compared LEED, BREEAM and BEST. According to the results, LEED gives higher priority to energy credits with about 35% of total credits. BEST, on the other hand, gives less priority to energy credits about 25% of the total credits. Results of this thesis show that, Good level of BEST can get 8 credits and Excellent level of BEST can get 22 points out of 26. On the other hand, Good level gets 17 and Excellent level can get 22 credits out of 40 from LEED. Since, systems that consume less energy are expensive than other systems, the model can make selections to gain a given certification level without buying these systems. However, LEED value energy category more than BEST, therefore, a cost optimization model based on BEST may lead a low level of LEED certifications (Deligöz & Aktan, 2020).

With the BEST rating system developed for our country, it is foreseen that green building certification can be made at lower costs compared to LEED certification. As shown in the study, the cost to obtain BEST certificate is expected to be lower than LEED due to its compliance with the conditions in Turkey and the lower purchase fees due to exchange rates. It has also been observed that lower LEED levels correspond to a given BEST level. As also stated by Güler and Deniz (2020), obtaining similar levels of LEED certificates and acquiring extra systems for that purpose will increase the cost of green building certification.

CHAPTER 6

CONCLUSION

With the growing population, the need for new buildings is growing. In 2020, 2942 buildings were granted construction permits in Ankara (TÜİK, 2020b). In 2021 between January and June, only in 6 months, 2344 building construction permits were granted (TÜİK, 2021b). Considering the effects of buildings on carbon dioxide emissions, electricity and water consumptions, the fact that these newly built buildings are green buildings is of great importance in terms of combating climate change and protecting natural resources. Given that incentives for building green would be stronger in Turkey. The incentives can encourage the contractors to build green buildings and also the residents to buy green buildings as well.

Being aware that green buildings can make a significant difference in decreasing the effects of climate change and protecting natural resources, this study aimed to compare LEED and BEST green building rating systems employing a cost-based optimization by LINGO optimization tool. The study also proposed a guideline to all stakeholders while choosing green building elements in order to grant BEST and corresponding LEED green building certificates in Turkey at the least cost.

Results of the study showed that, Good and Excellent levels of BEST is sufficient to encourage the buyer to spend more money on the green buildings considering savings to residents in 10 years. Savings in subject expedite selling of the flat and encourage buyers to agree with paying more for the green building. Moreover, Good level brings high savings per household and is cheaper than the Excellent level. Hence, it is concluded that the most feasible level of certification is the Good level. Then, the Excellent scenario becomes the next best because of the high savings it brings. The worst choice is on the other hand is decided as the Very Good level. It has the highest initial cost and also brings low savings. All and all, contractors should be aware of that possessing a higher certification level is also important for brand image which can escalate the selling price of a flat.

In the results, corresponding LEED levels of each BEST certification was shown as well. Any level of BEST was not be able to get Platinum level of LEED but Certified, Silver and Gold levels were achieved. Since, the model was developed by considering the BEST certification requirements, these results do not necessarily mean Platinum level cannot equal to the any BEST level. This result only shows which BEST certification level can be granted with which LEED certification level. The requirements of these two certification systems differs from each other, therefore results do not show, which certification system is better or stricter. One should not forget about the fees of BEST and LEED as well. LEED is more expensive to get when compared with BEST. Moreover, it is easier to achieve credits from BEST for a building in Turkey, as the BEST is developed for Turkey's very own characteristics. On the other hand, LEED is the most accepted green building rating system in the world unlike BEST published in 2019.

The maximum water saving can be achieved at the Excellent level with approximately 60% in all buildings. The amount of water saving varies between 30% and 37% at other levels which is approximately half of Excellent level water savings. Systems that save water have been selected at all certification levels by the model. This is because water-saving systems are relatively inexpensive than electricity saving systems. On the other hand, the maximum electricity savings can be achieved at the Excellent level with 80%. Then, about 60% electricity can be saved at the Good level. Electricity savings cannot be achieved at other levels. However, initial costs of each certification level should be assessed. If a very high initial cost is selected to decrease the operational costs via less water and energy consumption, the initial investment cost of the building may not be feasible.

It should be noted that the results of this study is based on hypothetical case studies and several assumptions have been made in order to be able to get quantifiable results. Yet, as the 4-storey case is represented as the reference building of Turkey, the results obtained at the end of this study may be deemed as representative for a common buildings in Turkey. However, every building constructed in Turkey does not fully need to be alligned with the results obtained in this study. There may be better options for other building types. Furthermore, the initial costs of each materials/equipment/systems aforehand may change. Therefore, over the years, model's choices may differ. Alltogether, these notes should be taken into account before a building is constructed.

There are a few points that should be taken into consideration by the contractors who want to choose between LEED and BEST. First of all, the difference between BEST and LEED certificate fees should be taken into account. Considering the exchange rates, it is known that the LEED certification fee is 2 to 3 times more than the BEST certification fee which alters with type of the building. However, BEST published in 2019 is a very new green building rating system comparing with LEED published in 2000. LEED is the most known and accepted green building rating system in the world. Therefore, it is predicted that a LEED certified building will be more accepted than a BEST certified building. However, it is easier to get points from this certificate for a building to be built in Turkey, as the BEST certificate is developed only for Turkey, based on Turkey's characteristics. Also, local green building rating systems are encouraged by WGBC.

In this study, some issues related to BEST rating system have been realized. Some subcategories in the BEST rating system do not particularly serve the goal of combating climate change. One of these subcategories is art. Although supporting the use of original work of art should be promoted, it has no effect in reducing carbon dioxide emissions, energy and water consumptions. Moreover, presence of sports areas, security, and working from home subcategories are important factors for improving the quality of life in building. However, they should not be awarded with credits since again they cannot be considered as mitigation alternatives to combat the impacts of climate change. Also, materials used in construction must have an environmental label in order to receive points in the subcategory of use of environmentally friendly materials. Following the market research conducted within the scope of this study, it was seen that it is difficult to find materials with those labels in Turkey. Instead, it would be more appropriate to provide the names of the environmentally friendly construction materials in the guide, and choice of those materials or alternatives should bring the green-building credits. Another issue is related to waste water treatment subcategory. Many cities in Turkey have wastewater treatment plants and sewage infrastructure. The operation of these facilities requires constant control that should be carried out by professionals. With the existing treatment plants in cities, wastewater will be treated anyway. In addition, the installation of a building-specific treatment system is costly, assuming wastewater originating from a building is of domestic characteristics and does not require specific pre-treatment before discharged into domestic sewage collection system. In order to get the related score from BEST, buildings with 100 or more residents must install a treatment system. But, using the existing treatment plants will be more feasible in terms of both cost and operating convenience. If there is no wastewater treatment plant in a city where the building will be built, it would be more appropriate to include that subcategory to get credits. If there is, credits should be gained directly. Moreover, it should be ensured that the certificated buildings are followed up at certain intervals and the certificates of the buildings that do not continue to comply with the rules should be revoked.

In the future, case studies in 7 Region of Turkey should be conducted in order to get more accurate results since every region has distinctive climatic conditions, different cultures and traditions, and may have diverse building types and ages. Furthermore, buildings with different types should be studied as well. With those studies, contractors will have wide range of choices and they can find the most proper example for their building. Also, features of BEST and its effects on climate change should be studied more. BEST is a very young green building rating system and needs further advancements. Moreover, BEST should be compared with BREEAM, which is another popular green building rating system in the world, with cost optimization. Advantages and disadvantages of employing the two rating systems should be emphasized. Furthermore, in future studies, this study can be extended to different climatic regions and even for each city of Turkey. In this way, more generic results can be obtained and the most feasible systems can be selected for each city. Being aware of the fact that green buildings can decrease the stress on environment with respect to climate change, the importance given to green buildings should increase in Turkey, given the share of the construction sector in the economy and development. Water and energy resources, which will become even more important in the coming years, will suffice for many more years with the increase in number of green buildings. It was shown that even in less than 10 years a green building investment can be compensated as in the Good level of BEST certification. It has also been seen that green buildings are more feasible than traditional buildings in terms of their contribution to the environment.

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APPENDICES

A. BEST Scoring Sub-Categories' Cost Dependency

Table A. 1. Cost dependency of BEST scoring

BEST scoring sub-categories	Cost-dependent	Partially cost-dependent	Cost-independent
1. Integrated green project management			
Prerequisite 1. Integrated design			√
1.1. Integrated design			√
1.2. Environmentally-conscious contractor			√
1.3. Construction waste reduction and waste management			√
1.4. Noise pollution			√
2. Land use			
2.1. Land settlement			√
2.2. Disaster risk			√
2.3. Density and housing structure relationship			√
2.4. Reuse of land			√
2.5. Proximity to urban facilities			√
3. Water consumption			
Prerequisite 2. Reducing water consumption			√
3.1. Reducing water consumption	√		
3.2. Preventing water losses	√		
3.3. Wastewater treatment and utilization	√		
3.4. Surface water flow	√		
4. Energy consumption			
Prerequisite 3. Commissioning			√
Prerequisite 4. Energy efficiency			√
4.1. Energy efficiency	√		
4.2. Use of renewable energy	√		
4.3. Outdoor lighting	√		
4.4. Energy efficient white appliances	√		
4.5. Elevators	√		

Table A.1 *(cont'd)*

BEST scoring sub-categories	Cost-dependent	Partially cost-dependent	Cost-independent
5. Health and comfort			
5.1. Thermal comfort			√
5.2. Visual comfort			√
5.3. Fresh air	√		
5.4. Control of pollutants	√		
5.5. Auditory comfort	√		
6. Material and resource use			
6.1. Environmentally friendly materials use			√
6.2. Existing building elements use			√
6.3. Reuse of materials	√	√	
6.4. Local materials use			√
6.5. Durable materials	√	√	
7. Residential life			
7.1. Universal inclusive design			√
7.2. Security	√	√	
7.3. Sports and recreation areas			√
7.4. Art	√		
7.5. Transportation			√
7.6. Parking area	√	√	
7.7. Working from home			√
8. Operation and Maintenance			
8.1. Waste reallocation and user access	√		
8.2. Waste technologies	√		
8.3. Building use and maintenance manual			√
8.4. Tracking of consumption values	√		
9. Innovation			
9.1. Innovation	√		
9.2. Approved consultant			
TOTAL			

B. Initial Costs of The Systems

Table B. 1 Total initial costs of green and non-green equipment that consume water

	Name	Unit cost ($)	Cost ($)			
			4-storey	7-storey	12-storey	15-storey
$C_w(1)$	Green toilet (2 in a flat)	305	9760	17080	29280	36600
$C_{wn}(1)$	Non-green toilet (2 in a flat)	135	4320	7560	12960	16200
$C_w(2)$	Green showerhead (2 in a flat)	95	3040	5320	9120	11400
$C_{wn}(2)$	Non-green showerheads (2 in a flat)	20	640	1120	1920	2400
$C_w(3)$	Green faucet for kitchen	285	4560	7980	13680	17100
$C_{wn}(3)$	Non-green faucet for kitchen	45	720	1260	2160	2700
$C_w(4)$	Green faucets in bathroom (2 in a flat)	70	2240	3920	6720	8400
$C_{wn}(4)$	Non-green faucet in bathroom (2 in a flat)	40	1280	2240	3840	4800
$C_w(5)$	Drip irrigation system	35	35	35	35	35
$C_{wn}(5)$	Sprinkler irrigation system	4	4	4	4	4
$C_{rw}(1)$	Rainwater systems for toilet only	-	3545	6205	10635	13295
$C_{rw}(2)$	Rainwater systems for toilet and garden	-	4210	7370	12635	15795
$C_{ew}(1)$	Green dishwasher	1025	16400	28700	49200	61500
$C_{ewn}(1)$	Non-green dishwasher	250	4000	7000	12000	15000
$C_{ew}(2)$	Green washing machines	850	13600	23800	40800	51000
$C_{ewn}(2)$	Non-green washing machine	395	6320	11060	18960	23700

Table B. 2 Initial costs of building structure materials

	Name		Unit cost ($)	Cost ($)			
				4-storey	7-storey	12-storey	15-storey
$C_{tse}(1)$	Wall for TSE Standard	Brick (30 pieces/m^2)	0.095	51980	90960	155930	194900
		Plaster (1cm thick/m^2)	10				
		Isolation material (1 m^2)	17				
		Total:	**27/m^2**				
$C_{ideal}(1)$	Wall for IZODER study	Brick (30 pieces/m^2)	0.75	96200	168350	288600	360750
		Plaster (1cm thick/m^2)	1.65				
		Isolation material (1 m^2)	17				
		Thermal paint (1mm/m^2)	4				
		Total	**50/m^2**				
$C_{sen}(1)$	Non-green wall	Brick (55 pieces/m^2)	0.055	9325	16320	27980	34970
		Plaster (1cm thick/m^2)	10				
		Total:	**4.85/m^2**				
$C_{tse}(2)$	Window for TSE Standard		165	14760	25830	44280	55350
$C_{ideal}(2)$	Window for IZODER study		205	18360	32130	55080	68850
$C_{sen}(2)$	Non-green widow		135	12240	21420	36720	45900

Table B.2 *(cont'd)*

Name		Unit cost ($)	Cost ($)	Cost ($) 4-storey	7-storey	12-storey	15-storey
$C_{tse}(3)$	Roof for TSE Standard	Concrete (1cm/m^2)	3	32120	32120	32120	32120
		Isolation material (1 m^2)	17				
		Plaster (1cm thick/m^2)	10				
		Total:	**65**				
$C_{ideal}(3)$	Roof for IZODER study	Concrete (1cm/m^2)	3	42155	42155	42155	42155
		Isolation material (1 m^2)	17				
		Plaster (1cm thick/m^2)	1.65				
		Thermal paint (1cm/m^2)	4				
		Total:	**80**				
$C_{sen}(3)$	Non-green roof	Concrete (1cm/m^2)	1.15	11675	11675	11675	11675
		Plaster (1cm thick/m^2)	1.65				
		Total:	**22**				
$C_{tse}(4)$	Floor for TSE Standard	Concrete (1cm/m^2)	3	92645	162125	277930	347410
		Isolation material (1 m^2)	17				
		Cement finish (1cm/m^2)	7				
		Total:	**45**				

Table B.2 *(cont'd)*

	Name	Unit cost ($)	Cost ($)	Cost ($) 4-storey	7-storey	12-storey	15-storey
$C_{ideal}(4)$	Floor for IZODER study	Concrete (1cm/m^2)	3	94195	164840	282585	353230
		Isolation material (1 m^2)	17				
		Cement finish (1cm/m^2)	7				
		Total:	**45**				
$C_{sen}(4)$	Non-green floor	Concrete (1cm/m^2)	1.15	26660	46655	79985	99980
		Isolation material (1 m^2)	17				
		Cement finish (1cm/m^2)	7				
		Total:	**12.5**				

Table B. 3 Initial costs of green and non-green equipment consume electricity

	Name	Unit cost ($)	Cost ($) 4-storey	7-storey	12-storey	15-storey
$C_e(1)$	Green fridge	780	12480	21840	37440	46800
$C_{en}(1)$	Non-green fridge	405	6480	11340	19440	24300
$C_e(2)$	Green inside lightening (20 per flat)	1.5	480	840	1440	1800
$C_{en}(2)$	Non-green inside lightening (20 per flat)	0.65	208	364	624	780
$C_e(3)$	Green outside lightening (10 for the building)	155	1550	1550	1550	1550
$C_{en}(3)$	Non-green outside lightening (10 for the building)	25	250	250	250	250

Table B. 4 Initial cost of renewable energy systems

	Name	Unit cost ($)	Cost ($)			
			4-storey	7-storey	12-storey	15-storey
$C_r(1)$	PV panels	115	Number of renewable energy systems are determined by the model			
$C_r(2)$	Wind Turbine	1075				
$C_r(3)$	Solar water heaters	475				

Table B. 5 Initial costs of materials, systems and equipment that do not consume water and electricity

	Name	Unit cost ($)	Cost ($)			
			4-storey	7-storey	12-storey	15-storey
$C_o(1)$	Humidity controller for garden	175	175	175	175	175
$C_o(2)$	Water meters	12	192	336	576	720
$C_o(3)$	Green roof	8.35/m^2	2190	2190	2190	2190
$C_o(4)$	Permeable pavement (For 1.5mx4m pedestrian road)	1.65/m^2	9.8	9.8	9.8	9.8
$C_o(5)$	Green elevators (2 in the building)	28000	56000	56000	56000	56000
$C_o(6)$	Hood fume (1 per flat)	205	3280	5740	9840	12300
$C_o(7)$	Exhaust fans (2 per flat)	15	480	840	1440	1800
$C_o(8)$	Auditory insulation to floors (in between flats)	25/m^2	47450	83050	142370	177965
$C_o(9)$	Auditory insulation to walls	12.5/m^2	58330	102080	174995	218745

Table B.5 *(cont'd)*

	Name	Unit cost ($)	Cost ($)			
			4-storey	7-storey	12-storey	15-storey
$C_o(10)$	Linoleum floor	12.25/m^2	25665	44915	76995	96245
$C_o(11)$	Protective bands on delicate wall corners (4 in each floor)	2/m	64	112	192	240
$C_o(12)$	Kickstands on the main door	6.8	6.8	6.8	6.8	6.8
$C_o(13)$	Door handle slams (10 for each flat)	1 /10pieces	16	28	48	60
$C_o(14)$	Fire alarm (a main controller and an alarm for each flat)	445 / 19.5 /alarm	765	1325	2285	3485
$C_o(15)$	Video door phone system for 16 flats	995	995	1740	2985	3730
$C_o(16)$	Fences around waste storage area	310	310	310	310	310
$C_o(17)$	Piece of art	2040	2040	2040	2040	2040
$C_o(18)$	Electric charging station (2 for the building)	910	1820	1820	1820	1820
$C_o(19)$	Waste separation bins	340	340	340	340	340
$C_o(20)$	Tree branch grinder	1150	1150	1150	1150	1150
$C_o(21)$	Main energy meter	505	505	505	505	505
$C_o(22)$	Innovation	1905	30480	53340	91440	114300
$C_o(23)$	Approved consultant	-	1300	2280	3910	4880
$C_o(24)$	Wastewater treatment unit	-	-	13125	22500	28125

C. Selected Systems by The Model

Table C. 1 Selection of the systems affecting water consumption for 4-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_w(1)$	0	0	0	0
$I_w(2)$	0	0	1	0
$I_w(3)$	0	0	0	0
$I_w(4)$	0	0	1	0
$I_w(5)$	0	1	1	1
$I_{wn}(1)$	1	1	1	1
$I_{wn}(2)$	1	1	0	1
$I_{wn}(3)$	1	1	1	1
$I_{wn}(4)$	1	1	0	1
$I_{wn}(5)$	1	0	0	0
$I_{rw}(1)$	1	1	0	0
$I_{rw}(2)$	0	0	1	1
$I_{ew}(1)$	0	0	0	1
$I_{ew}(2)$	0	0	0	1
$I_{ewn}(1)$	1	1	1	0
$I_{ewn}(2)$	1	1	1	0

Table C. 2 Selection of the systems affecting energy consumption for 4-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_{es,tse}(1)$	0	0	0	0
$I_{es,tse}(2)$	0	0	0	0
$I_{es,tse}(3)$	0	0	0	0
$I_{es,tse}(4)$	0	0	0	0
$I_{es,ideal}\ (1)$	0	0	0	0
$I_{es,ideal}\ (2)$	0	0	0	0
$I_{es,ideal}\ (3)$	0	0	0	0
$I_{es,ideal}\ (4)$	0	0	0	0
$I_{esn}(1)$	1	1	1	1
$I_{esn}(2)$	1	1	1	1
$I_{esn}(3)$	1	1	1	1
$I_{esn}(4)$	1	1	1	1
$I_e(1)$	0	0	0	1
$I_e(2)$	0	1	0	1
$I_e(3)$	0	0	0	1
$I_{en}(1)$	1	1	1	0

Table C. 3 Selection of the systems that are not affecting neither water nor energy consumption for 4-storey building

	Approved	Good	Very Good	Excellent
$I_o(1)$	0	1	1	1
$I_o(2)$	0	1	1	1
$I_o(3)$	0	0	1	1
$I_o(4)$	0	0	1	1
$I_o(5)$	0	0	1	1
$I_o(6)$	0	0	1	1
$I_o(7)$	0	0	1	1
$I_o(8)$	0	0	1	0
$I_o(9)$	0	0	1	0
$I_o(10)$	0	0	1	1
$I_o(11)$	0	0	1	1
$I_o(12)$	0	0	1	1
$I_o(13)$	0	0	1	1
$I_o(14)$	0	0	1	1
$I_o(15)$	0	0	1	1
$I_o(16)$	0	0	1	1
$I_o(17)$	0	0	1	1
$I_o(18)$	0	0	1	1
$I_o(19)$	0	0	1	1
$I_o(20)$	0	0	1	1
$I_o(21)$	0	0	1	1
$I_o(22)$	0	0	1	0
$I_o(23)$	0	0	1	1

Table C. 4 Selection of the systems affecting water consumption for 7-storey building

	Approved	Good	Very Good	Excellent
$I_w(1)$	0	0	0	0
$I_w(2)$	0	0	0	0
$I_w(3)$	0	0	1	0
$I_w(4)$	0	0	0	0
$I_w(5)$	0	1	1	1
$I_{wn}(1)$	1	1	1	1
$I_{wn}(2)$	1	1	1	1
$I_{wn}(3)$	1	1	0	1
$I_{wn}(4)$	1	1	1	1

Table C.4 *(cont'd)*

	Approved	**Good**	**Very Good**	**Excellent**
$I_{wn}(5)$	1	0	0	0
$I_{rw}(1)$	1	1	1	1
$I_{rw}(2)$	0	0	0	0
$I_{ew}(1)$	0	0	0	1
$I_{ew}(2)$	0	0	0	1
$I_{ewn}(1)$	1	1	1	0
$I_{ewn}(2)$	1	1	1	0

Table C. 5 Selection of the systems affecting energy consumption for 7-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_{es,tse}(1)$	0	0	0	0
$I_{es,tse}(2)$	0	0	0	0
$I_{es,tse}(3)$	0	0	0	0
$I_{es,tse}(4)$	0	0	0	0
$I_{es,ideal}(1)$	0	0	0	0
$I_{es,ideal}(2)$	0	0	0	0
$I_{es,ideal}(3)$	0	0	0	0
$I_{es,ideal}(4)$	0	0	0	0
$I_{esn}(1)$	1	1	1	1
$I_{esn}(2)$	1	1	1	1
$I_{esn}(3)$	1	1	1	1
$I_{esn}(4)$	1	1	1	1
$I_{e}(1)$	0	0	0	1
$I_{e}(2)$	0	1	0	1
$I_{e}(3)$	0	0	0	1
$I_{en}(1)$	1	1	1	0
$I_{en}(2)$	1	0	1	0
$I_{en}(3)$	1	1	1	0
$I_{re}(1)$	0	0	0	1
$I_{re}(2)$	0	0	0	0
$I_{re}(3)$	0	0	0	1
$A_{re}(1)$	0	0	0	12
$A_{re}(2)$	0	0	0	0
$A_{re}(3)$	0	0	0	7

Table C. 6 Selection of the systems that are not affecting neither water nor energy consumption for 7-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_o(1)$	0	1	1	1
$I_o(2)$	0	0	1	1
$I_o(3)$	0	0	1	1
$I_o(4)$	0	0	1	1
$I_o(5)$	0	0	1	1
$I_o(6)$	0	0	1	1
$I_o(7)$	0	0	1	1
$I_o(8)$	0	0	1	0
$I_o(9)$	0	0	1	0
$I_o(10)$	0	0	1	1
$I_o(11)$	0	1	1	1
$I_o(12)$	0	1	1	1
$I_o(13)$	0	1	1	1
$I_o(14)$	0	0	1	1
$I_o(15)$	0	0	1	1
$I_o(16)$	0	0	1	1
$I_o(17)$	0	0	1	1
$I_o(18)$	0	0	1	1
$I_o(19)$	0	0	1	1
$I_o(20)$	0	0	1	1
$I_o(21)$	0	0	1	1
$I_o(22)$	0	0	1	0
$I_o(23)$	0	0	1	1
$I_o(24)$	0	0	1	1

Table C. 7 Selection of the systems affecting water consumption for 12-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_w(1)$	0	0	1	0
$I_w(2)$	0	0	0	0
$I_w(3)$	0	0	0	0
$I_w(4)$	0	0	0	0
$I_w(5)$	0	1	1	1
$I_{wn}(1)$	1	1	0	1
$I_{wn}(2)$	1	1	1	1
$I_{wn}(3)$	1	1	1	1
$I_{wn}(4)$	1	1	1	1
$I_{wn}(5)$	1	0	0	0
$I_{rw}(1)$	1	1	1	1

Table C.7 *(cont'd)*

	Approved	**Good**	**Very Good**	**Excellent**
$I_{rw}(2)$	0	0	0	0
$I_{ew}(1)$	0	0	0	1
$I_{ew}(2)$	0	0	0	1
$I_{ewn}(1)$	1	1	1	0
$I_{ewn}(2)$	1	1	1	0

Table C. 8 Selection of the systems affecting energy consumption for 12-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_{es,tse}(1)$	0	0	0	0
$I_{es,tse}(2)$	0	0	0	0
$I_{es,tse}(3)$	0	0	0	0
$I_{es,tse}(4)$	0	0	0	0
$I_{es,ideal}$ (1)	0	0	0	0
$I_{es,ideal}$ (2)	0	0	0	0
$I_{es,ideal}$ (3)	0	0	0	0
$I_{es,ideal}$ (4)	0	0	0	0
$I_{esn}(1)$	1	1	1	1
$I_{esn}(2)$	1	1	1	1
$I_{esn}(3)$	1	1	1	1
$I_{esn}(4)$	1	1	1	1
$I_e(1)$	0	0	0	1
$I_e(2)$	0	1	0	1
$I_e(3)$	0	0	0	1
$I_{en}(1)$	1	1	1	0
$I_{en}(2)$	1	0	1	0
$I_{en}(3)$	1	1	1	0
$I_{re}(1)$	0	0	0	1
$I_{re}(2)$	0	0	0	0
$I_{re}(3)$	0	0	0	1
$A_{re}(1)$	0	0	0	12
$A_{re}(2)$	0	0	0	0
$A_{re}(3)$	0	0	0	11

Table C. 9 Selection of the systems that are not affecting neither water or energy consumption for 12-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_o(1)$	0	1	1	1
$I_o(2)$	0	0	1	1
$I_o(3)$	0	0	1	1
$I_o(4)$	0	0	1	1
$I_o(5)$	0	0	1	1
$I_o(6)$	0	0	1	1
$I_o(7)$	0	0	1	1
$I_o(8)$	0	0	1	0
$I_o(9)$	0	0	1	0
$I_o(10)$	0	0	1	1
$I_o(11)$	0	1	1	1
$I_o(12)$	0	1	1	1
$I_o(13)$	0	1	1	1
$I_o(14)$	0	0	1	1
$I_o(15)$	0	0	1	1
$I_o(16)$	0	0	1	1
$I_o(17)$	0	0	1	1
$I_o(18)$	0	0	1	1
$I_o(19)$	0	0	1	1
$I_o(20)$	0	0	1	1
$I_o(21)$	0	0	1	1
$I_o(22)$	0	0	1	0
$I_o(23)$	0	0	1	1
$I_o(24)$	0	0	1	1

Table C. 10 Selection of the systems affecting water consumption for 15-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_w(1)$	0	0	1	0
$I_w(2)$	0	0	0	0
$I_w(3)$	0	0	0	0
$I_w(4)$	0	0	0	0
$I_w(5)$	0	1	1	1
$I_{wn}(1)$	1	1	0	1
$I_{wn}(2)$	1	1	1	1
$I_{wn}(3)$	1	1	1	1
$I_{wn}(4)$	1	1	1	1
$I_{wn}(5)$	1	0	0	0
$I_{rw}(1)$	1	1	1	1

Table C.10 *(cont'd)*

	Approved	**Good**	**Very Good**	**Excellent**
$I_{rw}(2)$	0	0	0	0
$I_{ew}(1)$	0	0	0	1
$I_{ew}(2)$	0	0	0	1
$I_{ewn}(1)$	1	1	1	0
$I_{ewn}(2)$	1	1	1	0

Table C. 11 Selection of the systems affecting energy consumption for 15-storey building

	Approved	**Good**	**Very Good**	**Excellent**
$I_{es,tse}(1)$	0	0	0	0
$I_{es,tse}(2)$	0	0	0	0
$I_{es,tse}(3)$	0	0	0	0
$I_{es,tse}(4)$	0	0	0	0
$I_{es,ideal}$ (1)	0	0	0	0
$I_{es,ideal}$ (2)	0	0	0	0
$I_{es,ideal}$ (3)	0	0	0	0
$I_{es,ideal}$ (4)	0	0	0	0
$I_{esn}(1)$	1	1	1	1
$I_{esn}(2)$	1	1	1	1
$I_{esn}(3)$	1	1	1	1
$I_{esn}(4)$	1	1	1	1
$I_e(1)$	0	0	0	1
$I_e(2)$	0	1	0	1
$I_e(3)$	0	0	0	1
$I_{en}(1)$	1	1	1	0
$I_{en}(2)$	1	0	1	0
$I_{en}(3)$	1	1	1	0
$I_{re}(1)$	0	0	0	1
$I_{re}(2)$	0	0	0	0
$I_{re}(3)$	0	0	0	1
$A_{re}(1)$	0	0	0	7
$A_{re}(2)$	0	0	0	0
$A_{re}(3)$	0	0	0	14

Table C. 12 Selection of the systems that are not affecting neither water nor energy consumption for 15-storey building

	Approved	Good	Very Good	Excellent
$I_o(1)$	0	1	1	1
$I_o(2)$	0	0	1	1
$I_o(3)$	0	0	1	1
$I_o(4)$	0	0	1	1
$I_o(5)$	0	0	1	1
$I_o(6)$	0	0	1	1
$I_o(7)$	0	0	1	1
$I_o(8)$	0	0	1	0
$I_o(9)$	0	0	1	0
$I_o(10)$	0	0	1	1
$I_o(11)$	0	1	1	1
$I_o(12)$	0	1	1	1
$I_o(13)$	0	1	1	1
$I_o(14)$	0	0	1	1
$I_o(15)$	0	0	1	1
$I_o(16)$	0	0	1	1
$I_o(17)$	0	0	1	1
$I_o(18)$	0	0	1	1
$I_o(19)$	0	0	1	1
$I_o(20)$	0	0	1	1
$I_o(21)$	0	0	1	1
$I_o(22)$	0	0	1	0
$I_o(23)$	0	0	1	1
$I_o(24)$	0	0	1	1

D. Calculation of Water and Electricity Savings for BEST

4-storey:

- **Approved**

Water consumption of a household = 81.657 m^3/year

Percent electricity saved in building = 0

Percent renewable energy correspond to the total electricity consumption = 0

$$\text{Water saved} = 117.029\ m^3/\text{year} - 81.657\ m^3/\text{year} = 35.372\ m^3/\text{year} \quad (110)$$

- **Good**

Water consumption of a household = 80.900 m^3/year

Percent electricity saved in building = 58.4%

Percent renewable energy correspond to the total electricity consumption = 0

$$\text{Water saved} = 117.029\ m^3/\text{year} - 80.9\ m^3/\text{year} = 36.129\ m^3/\text{year} \quad (111)$$

$$\text{Electricity saved} = 101586.716\ \text{kwh/year} * 0.584 = 59326.642\ \text{kwh/year} \quad (112)$$

- **Very Good**

Water consumption of a household = 73.790 m^3/year

Percent electricity saved in building = 0

Percent renewable energy correspond to the total electricity consumption = 0

$$\text{Water saved} = 117.029\ m^3/\text{year} - 73.790\ m^3/\text{year} = 43.239\ m^3/\text{year} \quad (113)$$

- **Excellent**

Water consumption of a household = 47.819 m^3/year

Percent electricity saved in building = 80%

Percent renewable energy correspond to the total electricity consumption = 78.8%

Water saved = 117.029 m^3/year - 47.819 m^3/year = 69.21 m^3/year (114)

Electricity saved = 101586.7 kwh/year *0.8 = 81269.36 kwh/year (115)

<u>7-storey:</u>

- **Approved**

Water consumption of a household = 79.716 m^3/year

Percent electricity saved in building = 0

Percent energy electricity correspond to the total electricity consumption = 0

Water saved = 114.01 m^3/year - 79.716 m^3/year = 34.294 m^3/year (116)

- **Good**

Water consumption of a household = 79.285 m^3/year

Percent electricity saved in building = 61.9%

Percent renewable energy correspond to the total electricity consumption = 0

Water saved = 114.01 m^3/year - 79.285 m^3/year = 34.725 m^3/year (117)

Electricity saved = 167690.002 kwh/year *0.619 = 103800.112 kwh/year (118)

- **Very Good**

Water consumption of a household = 74.863 m^3/year

Percent electricity saved in building = 0

Percent renewable energy correspond to the total electricity consumption = 0

Water saved = 114.01 m^3/year - 74.863 m^3/year = 39.147 m^3/year (119)

- **Excellent**

Water consumption of a household = 49.975 m^3/year

Percent electricity saved in building = 80%

Percent renewable energy correspond to the total energy consumption = 55.9%

Water saved = 114.01 m^3/year - 49.975 m^3/year = 64.035 m^3/year (120)

Electricity saved = 167690.002 kwh/year *0.8 = 134152.002 kwh/year (121)

<u>12-storey:</u>

- **Approved**

Water consumption of a household = 78.638 m^3/year

Percent electricity saved in building = 0

Percent renewable energy correspond to the total energy consumption = 0

Water saved = 115.088 m^3/year - 79.716 m^3/year = 35.372 m^3/year (122)

- **Good**

Water consumption of a household = 78.387 m^3/year

Percent electricity saved in building = 63.8%

Percent renewable energy correspond to the total energy consumption = 0

Water saved = 115.088 m^3/year - 78.387 m^3/year = 36.701 m^3/year (123)

Electricity saved = 278959.602 kwh/year *0.638 = 177976.2 kwh/year (124)

- **Very Good**

Water consumption of a household = 78.387 m^3/year

Percent electricity saved in building = 0

Percent renewable energy correspond to the total energy consumption = 0

Water saved = 115.088 m^3/year - 78.387 m^3/year = 36.701 m^3/year (125)

- **Excellent**

Water consumption of a household = 49.077 m^3/year

Percent electricity saved in building = 80%

Percent renewable energy correspond to the total energy consumption = 64.2%

Water saved = 115.088 m^3/year - 49.077 m^3/year = 66.011 m^3/year (126)

Electricity saved = 278959.602 kwh/year *0.8 = 223167.7 kwh/year (127)

<u>15-storey:</u>

- **Approved**

Water consumption of a household = 78.336 m^3/year

Percent electricity saved in building = 0

Percent renewable energy correspond to the total energy consumption = 0

Water saved = 113.708 m^3/year - 78.638 m^3/year = 35.07 m^3/year (128)

- **Good**

Water consumption of a household = 78.135 m^3/year

Percent electricity saved in building = 64.4%

Percent renewable energy correspond to the total energy consumption = 0

Water saved = 113.708 m^3/year - 78.135 m^3/year = 35.573 m^3/year (129)

Electricity saved = 345509.048 kwh/year *0.644 = 222507.796 kwh/year (130)

- **Very Good**

Water consumption of a household = 78.135 m^3/year

Percent electricity saved in building = 0

Percent renewable energy correspond to the total energy consumption = 0

Water saved = 113.708 m^3/year - 78.135 m^3/year = 35.573 m^3year (131)

- **Excellent**

Water consumption of a household = 48.825 m^3/year

Percent electricity saved in building = 80%

Percent renewable energy correspond to the total energy consumption = 52.9%

Water saved = 113.708 m^3/year - 48.825 m^3/year = 64.883 m^3/year (132)

Electricity saved = 345509.048 kwh/year *0.8 = 276407.2 kwh/year (133)

Table D. 1 NPV of savings from water for 4-storey building with respect to non-green building

Year	NPV of savings from water ($)			
	Approved	**Good**	**Very Good**	**Excellent**
2021	277	283	339	542
2022	290	296	355	568
2023	305	311	373	596
2024	319	326	391	625
2025	335	342	409	655
2026	351	359	429	687
2027	369	377	451	721
2028	386	394	472	755
2029	405	414	496	793
2030	425	434	520	832
2031	445	455	544	871
Overall	**3908**	**3992**	**4777**	**7647**

Table D. 2 NPV of savings from electricity for 4-storey building for a household with respect to non-green building

Year	Electricity consumption savings ($)	
	Good	**Excellent**
2021	5253	7196
2022	5734	7855
2023	6259	8574
2024	6832	9359
2025	7458	10216

Table D.2 *(cont'd)*

Years	Electricity consumption savings ($)	
	Good	Excellent
2026	8140	11151
2027	8886	12173
2028	9699	13287
2029	10587	14503
2030	11556	15831
2031	12615	17280
Overall	**93020**	**127425**

Table D. 3 NPV of savings from electricity for 7-storey building for a household with respect to non-green building

Year	Saving from water ($)			
	Approved	Good	Very Good	Excellent
2021	470	476	537	878
2022	492	499	562	919
2023	517	524	590	966
2024	542	549	619	1012
2025	568	575	649	1061
2026	596	603	680	1112
2027	625	633	714	1168
2028	655	663	748	1223
2029	688	696	785	1284
2030	721	730	823	1347
2031	755	765	862	1411
Overall	**6631**	**6714**	**7569**	**12381**

Table D. 4 NPV of savings from electricity for 7-storey building with respect to non-green building

Year	NPV of electricity consumption saving ($)	
	Good	Excellent
2021	9191	11878
2022	10033	12966
2023	10951	14154
2024	11954	15449
2025	13048	16864
2026	14242	18407
2027	15547	20093

Table D.4 *(cont'd)*

Year	NPV of electricity consumption saving ($)	
	Good	**Excellent**
2028	16971	21933
2029	18524	23940
2030	20219	26132
2031	22071	28525
Overall	**162751**	**210341**

Table D. 5 NPV of savings from water for 12-storey building with respect to non-green building

Year	NPV of water consumption savings ($)			
	Approved	**Good**	**Very Good**	**Excellent**
2021	832	863	863	1552
2022	871	903	903	1625
2023	914	949	949	1706
2024	958	994	994	1789
2025	1005	1043	1043	1875
2026	1053	1093	1093	1966
2027	1106	1147	1147	2064
2028	1158	1202	1202	2161
2029	1216	1262	1262	2269
2030	1275	1323	1323	2380
2031	1336	1386	1386	2493
Overall	**11724**	**12165**	**12165**	**21880**

Table D. 6 NPV of savings from electricity for 12-storey building with respect to non-green building

Year	NPV of electricity consumption saving ($)	
	Good	**Excellent**
2021	15759	19760
2022	17202	21570
2023	18777	23545
2024	20496	25700
2025	22373	28054
2026	24420	30621

Table D.6 *(cont'd)*

Years	NPV of electricity consumption saving ($)	
	Good	**Excellent**
2027	26657	33426
2028	29098	36486
2029	31761	39826
2030	34668	43471
2031	37843	47452
Overall	**279055**	**349912**

Table D. 7 NPV of savings from water for 15-storey building with respect to non-green building

Year	NPV of water consumption savings ($)			
	Approved	**Good**	**Very Good**	**Excellent**
2021	1031	1045	1045	1907
2022	1079	1094	1094	1996
2023	1133	1149	1149	2096
2024	1188	1205	1205	2198
2025	1245	1263	1263	2304
2026	1305	1324	1324	2415
2027	1371	1390	1390	2536
2028	1435	1456	1456	2656
2029	1507	1529	1529	2788
2030	1581	1603	1603	2924
2031	1655	1679	1679	3063
Overall	**14530**	**14739**	**14739**	**26883**

Table D. 8 NPV of savings from electricity for 15-storey building for a household with respect to non-green building

Year	NPV of electricity consumption saving ($)	
	Good	**Excellent**
2021	19702	24474
2022	21506	26716
2023	23475	29162
2024	25624	31831
2025	27971	34747
2026	30530	37925

Table D.8 *(cont'd)*

Year	**NPV of electricity consumption saving ($)**	
	Good	**Excellent**
2027	33327	41400
2028	36378	45191
2029	39708	49327
2030	43343	53842
2031	47312	58773
Overall	**348877**	**433388**

E. Calculation of Water and Electricity Savings for LEED

4-storey

Water use of a household for non-green building= 117.029 m^3/year

$$\text{Water use reduction percentage for Approved} = (1 - (81.657\ m^3/year\ /\ 117.029\ m^3/year)) * 100 = 30.2\% \quad (134)$$

$$\text{Water use reduction percentage for Good} = (1 - (80.902\ m^3/year\ /\ 117.029\ m^3/year)) *100 = 30.9\% \quad (135)$$

$$\text{Water use reduction percentage for Very Good} = (1 - (73.790\ m^3/year\ /\ 117.029\ m^3/year)) *100 = 37\% \quad (136)$$

$$\text{Water use reduction percentage for Excellent} = (1 - (47.819\ m^3/year\ /\ 117.029\ m^3/year)) *100 = 59.1\% \quad (137)$$

Electricity use reduction percentage for Approved = 0

Electricity use reduction percentage for Good = 58.4%

Electricity use reduction percentage for Very Good = 0

Electricity use reduction percentage for Excellent = 80%

7-storey

Water use of a household for non-green building= 115.088 m^3/year

$$\text{Water use reduction percentage for Approved level} = (1 - (79.716\ m^3/year\ /\ 115.088\ m^3/year)) *100 = 30.7\% \quad (138)$$

$$\text{Water use reduction for Good level} = (1 - (79.285\ m^3/year\ /\ 115.088\ m^3/year)) *100 = 31.1\% \quad (139)$$

$$\text{Water use reduction for Very Good level} = (1 - (74.863\ m^3/year\ /\ 115.088\ m^3/year)) *100 = 35\% \quad (140)$$

Water use reduction for Excellent level = (1 – (49.975 m^3/year / 115.088 m^3/year)) *100 =56.6% (141)

Electricity use reduction percentage for Approved level = 0

Electricity use reduction percentage for Good level = 61.9%

Electricity use reduction percentage for Very Good level = 0

Electricity use reduction percentage for Excellent level = 80%

12-storey

Water use of a household for non-green building= 114.01 m^3/year

Water use reduction percentage for Approved level = (1 – (78.638 m^3/year / 114.01 m^3/year)) *100 =31% (142)

Water use reduction percentage for Good level = (1 – (78.387 m^3/year / 114.01 m^3/year)) *100 =31.2% (143)

Water use reduction percentage for Very Good level = (1 – (78.387 m^3/year / 114.01 m^3/year)) *100 =31.2% (144)

Water use reduction percentage for Excellent level = (1 – (49.077 m^3/year / 114.01 m^3/year)) *100 =56.6% (145)

Electricity use reduction percentage for Approved level = 0

Electricity use reduction percentage for Good level = 63.8%

Electricity use reduction percentage for Very Good level = 0

Electricity use reduction percentage for Excellent level = 80%

15-storey:

Water use of a household for non-green building= 113.708 m^3/year

Water use reduction percentage for Approved level = (1 – (78.336 m^3/year / 113.708 m^3/year)) *100 =31.1% (146)

Water use reduction percentage for Good level = (1 – (78.135 m^3/year / 113.708 m^3/year)) *100=31.3% (147)

Water use reduction percentage for Very Good level = (1 – (78.135 m^3/year / 113.708 m^3/year)) *100 =31.3% (148)

Water use reduction percentage for Excellent level = (1 – (49.077 m^3/year / 113.708 m^3/year)) *100 =57.1% (149)

Electricity use reduction percentage for Approved level = 0

Electricity use reduction percentage for Good level = 64.4%

Electricity use reduction percentage for Very Good level = 0

Electricity use reduction percentage for Excellent level = 80%

F. LINGO Script of The Model

<u>4-storey - Approved level:</u>

```
Model:
Sets:
POINTW: WLVL, WCREDIT, ZA, CRww, UwGBI;
POINTE: ELVL, ECREDIT, ZB, CRee, UEI;
POINTRN: RNLVL, RNCREDIT, ZC, CRrr, UrGBI ;
others/1..23/;
water/1..5/;
stenergy/1..4/;
energy/1..3/;
renewable/1..3/;
rainwater/1..2/;
waterenergy/1..2/;
group1(others):
Co, Io;
group2(water):
Cw,Iw,Cwn,Iwn,Uw,Uwn;
group3(energy):
Cen,Ien,Ce,Ie,Ue;
group4(stenergy):
Cestse,Iestse,Cesideal,Iesideal,Cesn,Iesn,Uestse,Uesideal;
group5(renewable):
Cre,Are,Ire,Ure;
group6(rainwater):
Crw,Irw,Urw;
group7(waterenergy):
Cew,Cewn,Iew,Iewn,Ueww,Uewwn,Uewe;
Endsets
Data:
Uw=17.695 0.928 5.526 2.431 3.773; !capacity;
Uwn=35.371 2.321 9.948 4.377 4.528;
Uewe=848 1392 ;
Ueww=4.555 26.618 ;
Uewwn=9.110 51.373;
Cew= 16400 13600;
Cewn=4000 6320 ;
Uestse=8109 2144 3069 28;
Uesideal=8438 2287 3196 31;
Ue=1904 59328 1854;
Ure=370 2000 2425;
Cw=9760 3140 4560 2240 35 ;
```

```
Cwn=4320 640 720 1280 4;
Crw= 3545 4210;
Co= 175 192 2190 9.8 56000 3280 480 47450 58330 25665 64 6.8 16 765 995 310
2040 1820 340 1150 505  30480 1300;
Cestse= 51980 14760 32120 92645;
Cesideal= 96200 18360 42155 94195;
Cesn= 9325 12240 11675 26660;
Ce=12480 480 1550;
Cen=6480 208 250;
Cre= 115 1075 475;

 WLVL, WCREDIT= !in order to show if the parameter between the WLVL give
them specified the WCREDIT;
 10000     0
    85     1
    70     2
    50     3
    40     4
    30     4;

  ELVL, ECREDIT= !in order to show if the parameter between the ELVL give them
specified the ECREDIT;
     0     0
   0.13     1
   0.19     2
   0.25     3
   0.31     4
   0.37     5
   0.43     6
   0.49     7
   0.55     8
   0.60     9
   0.65     10
   0.70     11
   0.75     12
   0.80     13
   0.85     14
   0.90     15
   1.00     15;

 RNLVL, RNCREDIT= !in order to show if the parameter between the RNLVL give
them specified the RNCREDIT;
     0     0
   0.02     1
   0.05     2
```

```
   0.1    3
   0.2    4
   0.3    5
   1.0    5;

Enddata
W = @SUM(water(i):Cw(i)*Iw(i)+Cwn(i)*Iwn(i));
DW= @SUM(waterenergy (t):Iew(t)*Cew(t)+Iewn(t)*Cewn(t));
GW= @SUM(rainwater(j):Crw(j)*Irw(j));
STEN= @SUM(stenergy(k): Cestse(k)*Iestse(k)+Cesideal(k)*Iesideal(k)+
Cesn(k)*Iesn(k));
EN= @SUM (energy (m): Cen(m)*Ien(m)+Ce(m)*Ie(m));
OTH= @SUM(others(n): Co(n)*Io(n));
RN= @SUM(renewable(l): Cre(l)*Are(l)*Ire(l));
MIN= DW+W+GW+STEN+EN+OTH+RN; !minimizing the summations above;

@FOR(stenergy(k): @BIN(Iestse(k))); !defines binary variables;
@FOR(stenergy(k): @BIN(Iesn(k)));
@FOR(stenergy(k): @BIN(Iesideal(k)));
@FOR(energy(m): @BIN(Iesn(m)));
@FOR(energy(m): @BIN(Ie(m)));
@FOR(waterenergy (t): @BIN(Iew(t)));
@FOR(waterenergy (t): @BIN(Iewn(t)));
@FOR(renewable(l): @BIN(Ire(l)));
@FOR(renewable(l): @GIN(Are(l))); !defines an integer and we want LINGO to
choose;

@FOR(water(i): @BIN(Iw(i)));
@FOR(water(i): @BIN(Iwn(i)));
@FOR(others(n): @BIN(Io(n)));
@FOR(rainwater(j): @BIN(Irw(j)));
@FOR(waterenergy (t): Iew(t)+Iewn(t)=1);
@FOR(water (i): Iw(i)+Iwn(i)=1); !to choose one of them only;
Are(1) <= 33; !the integers must be within these ranges;
Are(1) >= 0;
Are(2) <= 5;
Are(2) >= 0;
Are(3) <= 4;
Are(3) >= 0;
(Are(1)*Ure(1)*Ire(1)+ Are(2)*Ure(2)*Ire(2))<= 10000;
 !this calculation shouldnt exceed 10000;
 !to choose one of them only;
Urw(1)= 17.695*Iw(1)+ 35.371*Iwn(1); !This value is either 25.648 if Iw(1) is
preferred above, or 35.371 if Iwn(1) is preferred by the model;
```

```
Urw(2)= 3.773* Iw(5) + 4.528 * Iwn(5)+ Urw(1); !This value is either 3.773+Urw(1)
if Iw(7) is preferred above, or 4.528 if Iwn(7)+Urw(1) is preferred by the model;
(Irw(1)+Irw(2))=1;
A=@SUM(water(i): Uw(i)*Iw(i)+Uwn(i)*Iwn(i));
B=@SUM(waterenergy (t): Ueww(t)*Iew(t)+Uewwn(t)*Iewn(t));
C= Urw(1)*Irw(1)+Urw(2)*Irw(2);
UwGB= A+B-C;
UwGB <= 85;
@FOR( POINTW( x) | x #LT# @SIZE( POINTW):
  @BIN( ZA( x));
    UwGBI( x) <=  WLVL( x)*ZA(x);
    UwGBI( x) >  WLVL( x+1 )*ZA(x);
    CRww(x) = WCREDIT( x)*ZA(x);
      );

@SUM( POINTW( x) | x #LT# @SIZE( POINTW):  ZA( x)) = 1; !choose only one
range;
CRw1 =   @SUM( POINTW( x) | x #LT# @SIZE( POINTW):  CRww( x)); ! For
the FOR loop above, calculated CRww is equal to CRw1;
UwGB   = @SUM( POINTW( x) | x #LT# @SIZE( POINTW): UwGBI( x));

CRw2= @IF((Iw(5)+Irw(1)+Irw(2)+Io(1)) #EQ# 3 ,2,0);
CRw3= @IF(C #EQ# 4,2,0); !if total of Crws are greater and equal to 4 than crw6 is
2 else zero;
CRw4= @IF(Io(2) #EQ# 1,2,0); !if Io(2) is 1 (if it is chosen by the model) than crw7
is 2 else 0;
CRw5= @IF ((Io(3)+Io(4)) #EQ# 2,2,0);
@FOR(stenergy(k): (Iestse(k)+Iesideal(k)+Iesn(k))=1); !For every k, choose
exactly one of them);
@FOR(energy(m): (Ie(m)+Ien(m))=1);
D= @SUM( stenergy(k): Uestse(k)*Iestse(k)+ Uesideal(k)*Iesideal(k));
E= @SUM ( energy (m): Ue(m)*Ie(m));
F=@SUM ( waterenergy (t): Uewe(t)*Iew(t));
G= @SUM(renewable(l): Ure(l)*Are(l)*Ire(l));
UeGB= D+E+F+G;
UeNGB= 101586.716;
UEE= UeGB/UeNGB;

@FOR( POINTE( y) | y #LT# @SIZE(POINTE): !same as POINTW;
  @BIN( ZB( y));
    UEI( y) >  ELVL( y)*ZB(y);
    UEI( y) <=  ELVL( y+1)*ZB(y);
    CRee(y) = ECREDIT(y)*ZB(y);
      );
@SUM( POINTE( y) | y #LT# @SIZE( POINTE):  ZB( y)) = 1; !same as POINTW;
```

```
UEE= @SUM( POINTE( y) | y #LT# @SIZE( POINTE): UEI( y));
CRe1=@SUM( POINTE( y) | y #LT# @SIZE( POINTE): CRee( y)) ;

UrGB= @SUM(renewable(l): (Ure(l)*Are(l)*Ire(l)))/(UeNGB-UeGB);
@FOR( POINTRN( z) | z #LT# @SIZE( POINTRN): !same as POINTW;
  @BIN( ZC( z));
    UrGBI (z) >  RNLVL( z)*ZC(z);
    UrGBI (z) <=  RNLVL(z+1)*ZC(z);
    CRrr (z) = RNCREDIT(z)*ZC(z);
      );
@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN):  ZC( z)) = 1; !same as POINTW;
UrGB= @SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): UrGBI( z));
CRr=@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): CRrr( z)) ;

Cre2= @IF (Ie(3)#EQ# 1,1,0);
CRe3= @IF((Ie(1)+Iew(1)+Iew(2))#EQ# 3,1,0); !if 3 of them are selected by the model than cre3 is 3 else zero;
CRe4= @IF (Io(5)#EQ# 1,2,0);
CRs1= @IF (Io(6)+Io(7)#EQ# 2,3,0);
CRs2= @IF ((Io(8)+Io(9)) #EQ# 2,3,0);
CRm1= @IF (Io(10) #EQ# 1,2,0);
CRm2= @IF ((Io(11)+Io(12)+Io(13)) #EQ# 3,1,0);
CRy1= @IF ((Io(14)+Io(15)+Io(16)+Ie(3)) #EQ# 4,1,0);
CRy2= @IF (Io(17) #EQ# 1,1,0);
CRy3= @IF (Io(18) #EQ# 1,1,0);
CRa1= @IF(Io(19) #EQ# 1,2,0);
CRa2= @IF (Io(19)+Io(20) #EQ# 2,1,0);
CRa3= @IF (Io(21)+ Io(2) #EQ# 2,2,0);
CRyn1= @IF (Io(22) #EQ# 1,1,0);
CRyn2= @IF (Io(23) #EQ# 1,1,0);
CREDIT = 52+CRw1+CRw2+CRw3+CRw4+CRw5+CRr+CRe1+CRe2+CRe3+CRe4+CRs1+CRs2+CRy1+CRy2+CRy3+CRa1+CRa2+CRa3+CRyn1+CRyn2+CRm1+CRm2;
CREDIT >= 45;
CREDIT <= 64;

End
```

4-storey – Good Level:

Same code with Approved level only the change of credit levels below at the end.

```
CREDIT >= 65;
```

```
CREDIT <= 79;
```

<u>4 storey – Very Good level:</u>

Same code with Approved level only the change of credit levels below at the end.

```
CREDIT >= 80;
CREDIT <= 99;
```

<u>4 storey – Excellent level:</u>

Same code with Approved level only the change of credit levels below at the end.

```
CREDIT >= 100;
CREDIT <= 110;
```

<u>7 storey – Approved level:</u>

```
Model:
Sets:
POINTW: WLVL, WCREDIT, ZA, CRww, UwGBI;
POINTE: ELVL, ECREDIT, ZB, CRee, UEI;
POINTRN: RNLVL, RNCREDIT, ZC, CRrr, UrGBI ;
others/1..24/;
water/1..5/;
stenergy/1..4/;
energy/1..3/;
renewable/1..3/;
rainwater/1..2/;
waterenergy /1..2/;
group1(others):
Co, Io;
group2(water):
Cw,Iw,Cwn,Iwn,Uw,Uwn;
group3(energy):
Cen,Ien,Ce,Ie,Ue;
group4(stenergy):
Cestse,Iestse,Cesideal,Iesideal,Cesn,Iesn,Uestse,Uesideal;
group5(renewable):
Cre,Are,Ire,Ure;
group6(rainwater):
Crw,Irw,Urw;
group7(waterenergy):
Cew,Cewn,Iew,Iewn,Ueww,Uewwn,Uewe;
Endsets
```

Data:
Uw=17.695 0.928 5.526 2.431 2.156; !capacity;
Uwn=35.371 2.321 9.948 4.377 2.587;
Uewe=1484 2436 ;
Ueww=4.555 26.618 ;
Uewwn=9.110 51.373;
Cew=28700 23800 ;
Cewn=7000 11060;
Uestse=12448 3475 3018 93;
Uesideal=12908 3703 3140 100;
Ue=3332 103824 1854;
Ure=370 2000 2425;
Cw=17080 5320 7980 3920 35 ;
Cwn=7560 1120 1260 2240 4;
Crw= 6205 7370;
Co= 175 336 2190 9.8 56000 5740 840 83050 102080 44915 112 6.8 28 1325 1740 310 2040 1820 340 1150 505 53340 2280 13125;
Cestse= 90960 25830 32120 162125;
Cesideal= 168350 32130 42155 164840;
Cesn= 16320 21420 11675 46655;
Ce=21840 840 1550;
Cen=11340 364 250;
Cre= 115 1075 475;

WLVL, WCREDIT= !in order to show if the parameter between the WLVL give them specified the WCREDIT;

10000	0
85	1
70	2
50	3
40	4
30	4;

ELVL, ECREDIT= !in order to show if the parameter between the ELVL give them specified the ECREDIT;

0	0
0.13	1
0.19	2
0.25	3
0.31	4
0.37	5
0.43	6
0.49	7
0.55	8
0.60	9

```
  0.65    10
  0.70    11
  0.75    12
  0.80    13
  0.85    14
  0.90    15
  1.00    15;

 RNLVL, RNCREDIT= !in order to show if the parameter between the RNLVL give
them specified the RNCREDIT;
     0    0
  0.02    1
  0.05    2
   0.1    3
   0.2    4
   0.3    5
   1.0    5;

Enddata
W = @SUM(water(i):Cw(i)*Iw(i)+Cwn(i)*Iwn(i));
DW= @SUM(waterenergy (t):Iew(t)*Cew(t)+Iewn(t)*Cewn(t));
GW= @SUM(rainwater(j):Crw(j)*Irw(j));
STEN=     @SUM(stenergy(k):     Cestse(k)*Iestse(k)+Cesideal(k)*Iesideal(k)+
Cesn(k)*Iesn(k));
EN= @SUM (energy (m): Cen(m)*Ien(m)+Ce(m)*Ie(m));
OTH= @SUM(others(n): Co(n)*Io(n));
RN= @SUM(renewable(l): Cre(l)*Are(l)*Ire(l));
MIN= DW+W+GW+STEN+EN+OTH+RN; !minimizing the summations above;

@FOR(stenergy(k): @BIN(Iestse(k))); !defines binary variables;
@FOR(stenergy(k): @BIN(Iesn(k)));
@FOR(stenergy(k): @BIN(Iesideal(k)));
@FOR(energy(m): @BIN(Ien(m)));
@FOR(energy(m): @BIN(Ie(m)));
@FOR(waterenergy (t): @BIN(Iew(t)));
@FOR(waterenergy (t): @BIN(Iewn(t)));
@FOR(renewable(l): @BIN(Ire(l)));
@FOR(renewable(l): @GIN(Are(l))); !defines an integer and we want LINGO to
choose;

@FOR(water(i): @BIN(Iw(i)));
@FOR(water(i): @BIN(Iwn(i)));
@FOR(others(n): @BIN(Io(n)));
@FOR(rainwater(j): @BIN(Irw(j)));
@FOR(waterenergy (t): Iew(t)+Iewn(t)=1);
```

```
@FOR(water(i): Iw(i)+Iwn(i)=1); !to choose one of them only;
Are(1) <= 33; !the integers must be within these ranges;
Are(1) >= 0;
Are(2) <= 5;
Are(2) >= 0;
Are(3) <= 7;
Are(3) >= 0;
(Are(1)*Ure(1)*Ire(1)+ Are(2)*Ure(2)*Ire(2))<= 10000;
 !this calculation shouldnt exceed 10000;
 !to choose one of them only;
Urw(1)= 17.695*Iw(1)+ 35.371*Iwn(1); !This value is either 25.648 if Iw(1) is
preferred above, or 35.371 if Iwn(1) is preferred by the model;
Urw(2)= 2.156* Iw(5) + 2.587* Iwn(5)+ Urw(1); !This value is either 3.773+Urw(1)
if Iw(7) is preferred above, or 4.528 if Iwn(7)+Urw(1) is preferred by the model;
(Irw(1)+Irw(2))=1;
A=@SUM(water(i): Uw(i)*Iw(i)+Uwn(i)*Iwn(i));
B=@SUM(waterenergy (t): Ueww(t)*Iew(t)+Uewwn(t)*Iewn(t));
C= Urw(1)*Irw(1)+Urw(2)*Irw(2);
UwGB= A+B-C;
UwGB <= 85;
@FOR( POINTW( x) | x #LT# @SIZE( POINTW):
  @BIN( ZA( x));
    UwGBI( x) <=  WLVL( x)*ZA(x);
    UwGBI( x) >  WLVL( x+1 )*ZA(x);
    CRww(x) = WCREDIT( x)*ZA(x);
      );

@SUM( POINTW( x) | x #LT# @SIZE( POINTW):  ZA( x)) = 1; !choose only one
range;
CRw1 =   @SUM( POINTW( x) | x #LT# @SIZE( POINTW):  CRww( x)); ! For
the FOR loop above, calculated CRww is equal to CRw1;
UwGB   = @SUM( POINTW( x) | x #LT# @SIZE( POINTW): UwGBI( x));

CRw2= @IF((Iw(5)+Irw(1)+Irw(2)+Io(1)) #EQ# 3 ,2,0);
CRw3= @IF((Io(24)) #EQ# 1,2,0); !if total of Crws are greater and equal to 4 than
crw6 is 2 else zero;
CRw4= @IF(Io(2) #EQ# 1,2,0); !if Io(2) is 1 (if it is chosen by the model) than crw7
is 2 else 0;
CRw5= @IF ((Io(3)+Io(4)) #EQ# 2,2,0);
@FOR(stenergy(k): (Iestse(k)+Iesideal(k)+Iesn(k))=1); !For every k, choose
exaactly one of them);
@FOR(energy(m): (Ie(m)+Ien(m))=1);
D= @SUM( stenergy(k): Uestse(k)*Iestse(k)+ Uesideal(k)*Iesideal(k));
E= @SUM ( energy (m): Ue(m)*Ie(m));
F=@SUM (waterenergy (t): Uewe(t)*Iew(t));
```

```
G= @SUM(renewable(l): Ure(l)*Are(l)*Ire(l));
UeGB= D+E+F+G;
UeNGB= 167690;
UEE= UeGB/UeNGB;

@FOR( POINTE( y) | y #LT# @SIZE(POINTE): !same as POINTW;
  @BIN( ZB( y));
    UEI( y) >  ELVL( y)*ZB(y);
    UEI( y) <=  ELVL( y+1)*ZB(y);
    CRee(y) = ECREDIT(y)*ZB(y);
      );
@SUM( POINTE( y) | y #LT# @SIZE( POINTE):  ZB( y)) = 1; !same as POINTW;
UEE= @SUM( POINTE( y) | y #LT# @SIZE( POINTE): UEI( y));
CRe1=@SUM( POINTE( y) | y #LT# @SIZE( POINTE): CRee( y)) ;

UrGB= @SUM(renewable(l): (Ure(l)*Are(l)*Ire(l)))/(UeNGB-UeGB);
@FOR( POINTRN( z) | z #LT# @SIZE( POINTRN): !same as POINTW;
  @BIN( ZC( z));
    UrGBI (z) >  RNLVL( z)*ZC(z);
    UrGBI (z) <=  RNLVL(z+1)*ZC(z);
    CRrr (z) = RNCREDIT(z)*ZC(z);
      );
@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN):  ZC( z)) = 1; !same as
POINTW;
UrGB= @SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): UrGBI( z));
CRr=@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): CRrr( z)) ;

Cre2= @IF (Ie(3)#EQ# 1,1,0);
CRe3= @IF((Ie(1)+Iew(1)+Iew(2))#EQ# 3,1,0); !if 3 of them are selected by the
model than cre16 is 3 else zero;
CRe4= @IF (Io(5)#EQ# 1,2,0);
CRs1= @IF (Io(6)+Io(7)#EQ# 2,3,0);
CRs2= @IF ((Io(8)+Io(9)) #EQ# 2,3,0);
CRm1= @IF (Io(10) #EQ# 1,2,0);
CRm2= @IF ((Io(11)+Io(12)+Io(13)) #EQ# 3,1,0);
CRy1= @IF ((Io(14)+Io(15)+Io(16)+Ie(3)) #EQ# 4,1,0);
CRy2= @IF (Io(17) #EQ# 1,1,0);
CRy3= @IF (Io(18) #EQ# 1,1,0);
CRa1= @IF(Io(19) #EQ# 1,2,0);
CRa2= @IF (Io(19)+Io(20) #EQ# 2,1,0); !if Io(17) is 1 and Io(18) is too than cra2 is
1 else zero;
CRa3= @IF (Io(21)+ Io(2) #EQ# 2,2,0);
CRyn1= @IF (Io(22) #EQ# 1,1,0);
CRyn2= @IF (Io(23) #EQ# 1,1,0);
```

CREDIT = 52+CRw1+CRw2+CRw3+CRw4+CRw5+CRr+CRe1+CRe2+CRe3+CRe4+CRs1 +CRs2+CRy1+CRy2+CRy3+CRa1+CRa2+CRa3+CRyn1+CRyn2+CRm1+CRm2;
CREDIT >= 45;
CREDIT <= 64;

End

7 storey – Good level:

Same code with Approved level only the change of credit levels below at the end.

CREDIT >= 65;
CREDIT <= 79;

7 storey – Very Good level:

Same code with Approved level only the change of credit levels below at the end.

CREDIT >= 80;
CREDIT <= 99;

7 storey – Excellent level:

Same code with Approved level only the change of credit levels below at the end.

CREDIT >= 100;
CREDIT <= 110;

12 storey – Approved level:
Model:
Sets:
POINTW: WLVL, WCREDIT, ZA, CRww, UwGBI;
POINTE: ELVL, ECREDIT, ZB, CRee, UEI;
POINTRN: RNLVL, RNCREDIT, ZC, CRrr, UrGBI ;
others/1..24/;
water/1..5/;
stenergy/1..4/;
energy/1..3/;
renewable/1..3/;
rainwater/1..2/;
waterenergy /1..2/;
group1(others):
Co, Io;
group2(water):

```
Cw,Iw,Cwn,Iwn,Uw,Uwn;
group3(energy):
Cen,Ien,Ce,Ie,Ue;
group4(stenergy):
Cestse,Iestse,Cesideal,Iesideal,Cesn,Iesn,Uestse,Uesideal;
group5(renewable):
Cre,Are,Ire,Ure;
group6(rainwater):
Crw,Irw,Urw;
group7(waterenergy):
Cew,Cewn,Iew,Iewn,Uewe,Ueww,Uewwn;
Endsets
Data:
Uw=17.695 0.928 5.526 2.431 1.258; !capacity;
Uwn=35.371 2.321 9.948 4.377 1.509;
Uewe=2544 4176;
Ueww=4.555 26.618;
Uewwn=9.110 51.373;
Cew=49200 40800 ;
Cewn=12000 18960 ;
Uestse=19738 5856 3049 166;
Uesideal=20428 6239 3176 176;
Ue=5712 177984 1854;
Ure=370 2000 2425;
Cw=29280 9120 13680 6720 35;
Cwn=12960 1920 2160 3840 4;
Crw= 10635 12635;
Co= 175 576 2190 9.8 56000 9840 1140 142370 174995 76995 192 6.8 48 2285
2985 310 2040 1820 340 1150 505  91440 3910 22500;
Cestse= 155930 44280 32120 277930;
Cesideal= 288600 55080 42155 282585;
Cesn= 27980 36720 11675 79985;
Ce=37440 1440 1550;
Cen=19440 624 250;
Cre= 115 1075 475;

 WLVL, WCREDIT= !in order to show if the parameter between the WLVL give
them specified the WCREDIT;
 10000    0
   85     1
   70     2
   50     3
   40     4
   30     4;
```

```
 ELVL, ECREDIT= !in order to show if the parameter between the ELVL give them specified the ECREDIT;
    0     0
  0.13     1
  0.19     2
  0.25     3
  0.31     4
  0.37     5
  0.43     6
  0.49     7
  0.55     8
  0.60     9
  0.65     10
  0.70     11
  0.75     12
  0.80     13
  0.85     14
  0.90     15
  1.00     15;

 RNLVL, RNCREDIT= !in order to show if the parameter between the RNLVL give them specified the RNCREDIT;
    0     0
  0.02     1
  0.05     2
   0.1    3
   0.2    4
   0.3    5
   1.0    5;

Enddata
W = @SUM(water(i):Cw(i)*Iw(i)+Cwn(i)*Iwn(i));
DW= @SUM(waterenergy (t):Iew(t)*Cew(t)+Iewn(t)*Cewn(t));
GW= @SUM(rainwater(j):Crw(j)*Irw(j));
STEN= @SUM(stenergy(k): Cestse(k)*Iestse(k)+Cesideal(k)*Iesideal(k)+ Cesn(k)*Iesn(k));
EN= @SUM (energy (m): Cen(m)*Ien(m)+Ce(m)*Ie(m));
OTH= @SUM(others(n): Co(n)*Io(n));
RN= @SUM(renewable(l): Cre(l)*Are(l)*Ire(l));
MIN= DW+W+GW+STEN+EN+OTH+RN; !minimizing the summations above;

@FOR(stenergy(k): @BIN(Iestse(k))); !defines binary variables;
@FOR(stenergy(k): @BIN(Iesn(k)));
@FOR(stenergy(k): @BIN(Iesideal(k)));
@FOR(energy(m): @BIN(Ien(m)));
```

```
@FOR(energy(m): @BIN(Ie(m)));
@FOR(waterenergy (t): @BIN(Iew(t)));
@FOR(waterenergy (t): @BIN(Iewn(t)));
@FOR(renewable(l): @BIN(Ire(l)));
@FOR(renewable(l): @GIN(Are(l))); !defines an integer and we want LINGO to
choose;

@FOR(water(i): @BIN(Iw(i)));
@FOR(water(i): @BIN(Iwn(i)));
@FOR(others(n): @BIN(Io(n)));
@FOR(rainwater(j): @BIN(Irw(j)));
@FOR(waterenergy (t): Iew(t)+Iewn(t)=1);
@FOR(water(i): Iw(i)+Iwn(i)=1); !to choose one of them only;
Are(1) <= 33; !the integers must be within these ranges;
Are(1) >= 0;
Are(2) <= 5;
Are(2) >= 0;
Are(3) <= 11;
Are(3) >= 0;
(Are(1)*Ure(1)*Ire(1)+ Are(2)*Ure(2)*Ire(2))<= 10000;
 !this calculation shouldnt exceed 10000;
 !to choose one of them only;
Urw(1)= 17.695*Iw(1)+ 35.371*Iwn(1); !This value is either 25.648 if Iw(1) is
preferred above, or 35.371 if Iwn(1) is preferred by the model;
Urw(2)= 1.258* Iw(5) + 1.509* Iwn(5)+ Urw(1); !This value is either 3.773+Urw(1)
if Iw(7) is preferred above, or 4.528 if Iwn(7)+Urw(1) is preferred by the model;
(Irw(1)+Irw(2))=1;
A=@SUM(water(i): Uw(i)*Iw(i)+Uwn(i)*Iwn(i));
B=@SUM(waterenergy (t): Ueww(t)*Iew(t)+Uewwn(t)*Iewn(t));
C= Urw(1)*Irw(1)+Urw(2)*Irw(2);
UwGB= A+B-C;
UwGB <= 85;
@FOR( POINTW( x) | x #LT# @SIZE( POINTW):
   @BIN( ZA( x));
      UwGBI( x) <=  WLVL( x)*ZA(x);
      UwGBI( x) >  WLVL( x+1 )*ZA(x);
      CRww(x) = WCREDIT( x)*ZA(x);
        );

@SUM( POINTW( x) | x #LT# @SIZE( POINTW):  ZA( x)) = 1; !choose only one
range;
CRw1 =   @SUM( POINTW( x) | x #LT# @SIZE( POINTW):  CRww( x)); ! For
the FOR loop above, calculated CRww is equal to CRw1;
UwGB   = @SUM( POINTW( x) | x #LT# @SIZE( POINTW): UwGBI( x));
```

```
CRw2= @IF((Iw(5)+Irw(1)+Irw(2)+Io(1)) #EQ# 3 ,2,0);
CRw3= @IF((Io(24)) #EQ# 1,2,0); !if total of Crws are greater and equal to 4 than
crw6 is 2 else zero;
CRw4= @IF(Io(2) #EQ# 1,2,0); !if Io(2) is 1 (if it is chosen by the model) than crw7
is 2 else 0;
CRw5= @IF ((Io(3)+Io(4)) #EQ# 2,2,0);
@FOR(stenergy(k): (Iestse(k)+Iesideal(k)+Iesn(k))=1); !For every k, choose
exaactly one of them);
@FOR(energy(m): (Ie(m)+Ien(m))=1);
D= @SUM( stenergy(k): Uestse(k)*Iestse(k)+ Uesideal(k)* Iesideal(k));
E= @SUM ( energy (m): Ue(m)*Ie(m));
F=@SUM ( waterenergy (t): Uewe(t)*Iew(t));
G= @SUM(renewable(l): Ure(l)*Are(l)*Ire(l));
UeGB= D+E+F+G;
UeNGB= 278959.602;
UEE= UeGB/UeNGB;

@FOR( POINTE( y) | y #LT# @SIZE(POINTE): !same as POINTW;
  @BIN( ZB( y));
    UEI( y) >  ELVL( y)*ZB(y);
    UEI( y) <=  ELVL( y+1)*ZB(y);
    CRee(y) = ECREDIT(y)*ZB(y);
      );
@SUM( POINTE( y) | y #LT# @SIZE( POINTE):  ZB( y)) = 1; !same as POINTW;
UEE= @SUM( POINTE( y) | y #LT# @SIZE( POINTE): UEI( y));
CRe1=@SUM( POINTE( y) | y #LT# @SIZE( POINTE): CRee( y)) ;

UrGB= @SUM(renewable(l): (Ure(l)*Are(l)*Ire(l)))/(UeNGB-UeGB);
@FOR( POINTRN( z) | z #LT# @SIZE( POINTRN): !same as POINTW;
  @BIN( ZC( z));
    UrGBI (z) >  RNLVL( z)*ZC(z);
    UrGBI (z) <=  RNLVL(z+1)*ZC(z);
    CRrr (z) = RNCREDIT(z)*ZC(z);
      );
@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN):  ZC( z)) = 1; !same as
POINTW;
UrGB= @SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): UrGBI( z));
CRr=@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): CRrr( z)) ;

Cre2= @IF (Ie(3)#EQ# 1,1,0);
CRe3= @IF((Ie(1)+Iew(1)+Iew(2))#EQ# 3,1,0); !if 3 of them are selected by the
model than cre16 is 3 else zero;
CRe4= @IF (Io(5)#EQ# 1,2,0);
CRs1= @IF (Io(6)+Io(7)#EQ# 2,3,0);
CRs2= @IF ((Io(8)+Io(9)) #EQ# 2,3,0);
```

```
CRm1= @IF (Io(10) #EQ# 1,2,0);
CRm2= @IF ((Io(11)+Io(12)+Io(13)) #EQ# 3,1,0);
CRy1= @IF ((Io(14)+Io(15)+Io(16)+Ie(3)) #EQ# 4,1,0);
CRy2= @IF (Io(17) #EQ# 1,1,0);
CRy3= @IF (Io(18) #EQ# 1,1,0);
CRa1= @IF(Io(19) #EQ# 1,2,0);
CRa2= @IF (Io(19)+Io(20) #EQ# 2,1,0); !if Io(17) is 1 and Io(18) is too than cra2 is
1 else zero;
CRa3= @IF (Io(21)+ Io(2) #EQ# 2,2,0);
CRyn1= @IF (Io(22) #EQ# 1,1,0);
CRyn2= @IF (Io(23) #EQ# 1,1,0);
CREDIT =
52+CRw1+CRw2+CRw3+CRw4+CRw5+CRr+CRe1+CRe2+CRe3+CRe4+CRs1
+CRs2+CRy1+CRy2+CRy3+CRa1+CRa2+CRa3+CRyn1+CRyn2+CRm1+CRm2;
CREDIT >= 45;
CREDIT <= 64;

End
```

12 storey – Good level:

Same code with Approved level only the change of credit levels below at the end.

```
CREDIT >= 65;
CREDIT <= 79;
```

12 storey – Very Good level:

Same code with Approved level only the change of credit levels below at the end.

```
CREDIT >= 80;
CREDIT <= 99;
```

12 storey – Excellent level:

Same code with Approved level only the change of credit levels below at the end.

```
CREDIT >= 100;
CREDIT <= 110;
```

<u>15 storey – Approved level:</u>

```
Model:
Sets:
POINTW: WLVL, WCREDIT, ZA, CRww, UwGBI;
POINTE: ELVL, ECREDIT, ZB, CRee, UEI;
POINTRN: RNLVL, RNCREDIT, ZC, CRrr, UrGBI ;
others/1..24/;
water/1..5/;
stenergy/1..4/;
energy/1..3/;
renewable/1..3/;
rainwater/1..2/;
waterenergy /1..2/;
group1(others):
Co, Io;
group2(water):
Cw,Iw,Cwn,Iwn,Uw,Uwn;
group3(energy):
Cen,Ien,Ce,Ie,Ue;
group4(stenergy):
Cestse,Iestse,Cesideal,Iesideal,Cesn,Iesn,Uestse,Uesideal;
group5(renewable):
Cre,Are,Ire,Ure;
group6(rainwater):
Crw,Irw,Urw;
group7(waterenergy):
Cew,Cewn,Iew,Iewn,Uewe,Ueww,Uewwn;
Endsets
Data:
Uw=17.695 0.928 5.526 2.431 1.006; !capacity;
Uwn=35.371 2.321 9.948 4.377 1.207;
Uewe=3180 5220;
Ueww=4.555 26.618;
Uewwn=9.110 51.373;
Cew=61500 51000;
Cewn=15000 23700;
Uestse=24117 7289 3026 210;
Uesideal=24947 7765 3152 227;
Ue=7140 222480 1854;
Ure=370 2000 2425;
Cw=36600 11400 17100 8400 35 ;
Cwn=16200 2400 2700 4800 4;
Crw= 13295 15795;
Co= 175 720 2190 9.8 56000 12300 1800 177965 218745 96245 240 6.8 60 3485
3730 310 2040 1817 340 1150 505  114300 4880 28125;
```

```
Cestse= 194900 55350 32120 347410;
Cesideal= 360750 68850 42155 353230;
Cesn= 34970 45900 11675 99980;
Ce=46800 1800 1550;
Cen=24300 780 250;
Cre= 115 1075 475;

 WLVL, WCREDIT= !in order to show if the parameter between the WLVL give them specified the WCREDIT;
 10000    0
   85     1
   70     2
   50     3
   40     4
   30     4;

  ELVL, ECREDIT= !in order to show if the parameter between the ELVL give them specified the ECREDIT;
     0     0
   0.13    1
   0.19    2
   0.25    3
   0.31    4
   0.37    5
   0.43    6
   0.49    7
   0.55    8
   0.60    9
   0.65    10
   0.70    11
   0.75    12
   0.80    13
   0.85    14
   0.90    15
   1.00    15;

 RNLVL, RNCREDIT= !in order to show if the parameter between the RNLVL give them specified the RNCREDIT;
     0     0
   0.02    1
   0.05    2
    0.1    3
    0.2    4
    0.3    5
    1.0    5;
```

```
Enddata
W = @SUM(water(i):Cw(i)*Iw(i)+Cwn(i)*Iwn(i));
DW= @SUM(waterenergy (t):Iew(t)*Cew(t)+Iewn(t)*Cewn(t));
GW= @SUM(rainwater(j):Crw(j)*Irw(j));
STEN=@SUM(stenergy(k):Cestse(k)*Iestse(k)+Cesideal(k)*Iesideal(k)+
Cesn(k)*Iesn(k));
EN= @SUM (energy (m): Cen(m)*Ien(m)+Ce(m)*Ie(m));
OTH= @SUM(others(n): Co(n)*Io(n));
RN= @SUM(renewable(l): Cre(l)*Are(l)*Ire(l));
MIN= DW+W+GW+STEN+EN+OTH+RN; !minimizing the summations above;

@FOR(stenergy(k): @BIN(Iestse(k))); !defines binary variables;
@FOR(stenergy(k): @BIN(Iesn(k)));
@FOR(stenergy(k): @BIN(Iesideal(k)));
@FOR(energy(m): @BIN(Ien(m)));
@FOR(energy(m): @BIN(Ie(m)));
@FOR(waterenergy (t): @BIN(Iew(t)));
@FOR(waterenergy (t): @BIN(Iewn(t)));
@FOR(renewable(l): @BIN(Ire(l)));
@FOR(renewable(l): @GIN(Are(l))); !defines an integer and we want LINGO to
choose;

@FOR(water(i): @BIN(Iw(i)));
@FOR(water(i): @BIN(Iwn(i)));
@FOR(others(n): @BIN(Io(n)));
@FOR(rainwater(j): @BIN(Irw(j)));
@FOR(waterenergy (t): Iew(t)+Iewn(t)=1);
@FOR(water(i): Iw(i)+Iwn(i)=1); !to choose one of them only;
Are(1) <= 33; !the integers must be within these ranges;
Are(1) >= 0;
Are(2) <= 5;
Are(2) >= 0;
Are(3) <= 14;
Are(3) >= 0;
(Are(1)*Ure(1)*Ire(1)+ Are(2)*Ure(2)*Ire(2))<= 10000;
 !this calculation shouldnt exceed 10000;
 !to choose one of them only;
Urw(1)= 17.695*Iw(1)+ 35.371*Iwn(1); !This value is either 25.648 if Iw(1) is
preferred above, or 35.371 if Iwn(1) is preferred by the model;
Urw(2)= 1.006* Iw(5) + 1.207* Iwn(5)+ Urw(1); !This value is either 3.773+Urw(1)
if Iw(7) is preferred above, or 4.528 if Iwn(7)+Urw(1) is preferred by the model;
(Irw(1)+Irw(2))=1;
A=@SUM(water(i): Uw(i)*Iw(i)+Uwn(i)*Iwn(i));
B=@SUM(waterenergy (t): Ueww(t)*Iew(t)+Uewwn(t)*Iewn(t));
```

```
C= Urw(1)*Irw(1)+Urw(2)*Irw(2);
UwGB= A+B-C;
UwGB <= 85;
@FOR( POINTW( x) | x #LT# @SIZE( POINTW):
  @BIN( ZA( x));
    UwGBI( x) <=  WLVL( x)*ZA(x);
    UwGBI( x) >  WLVL( x+1 )*ZA(x);
    CRww(x) = WCREDIT( x)*ZA(x);
      );

@SUM( POINTW( x) | x #LT# @SIZE( POINTW):  ZA( x)) = 1; !choose only one range;
CRw1 =   @SUM( POINTW( x) | x #LT# @SIZE( POINTW):  CRww( x)); ! For the FOR loop above, calculated CRww is equal to CRw1;
UwGB   = @SUM( POINTW( x) | x #LT# @SIZE( POINTW): UwGBI( x));

CRw2= @IF((Iw(5)+Irw(1)+Irw(2)+Io(1)) #EQ# 3 ,2,0);
CRw3= @IF((Io(24)) #EQ# 1,2,0); !if total of Crws are greater and equal to 4 than crw6 is 2 else zero;
CRw4= @IF(Io(2) #EQ# 1,2,0); !if Io(2) is 1 (if it is chosen by the model) than crw7 is 2 else 0;
CRw5= @IF ((Io(3)+Io(4)) #EQ# 2,2,0);
@FOR(stenergy(k): (Iestse(k)+Iesideal(k)+Iesn(k))=1); !For every k, choose exaactly one of them);
@FOR(energy(m): (Ie(m)+Ien(m))=1);

D= @SUM( stenergy(k): Uestse(k)*Iestse(k)+ Uesideal(k)*Iesideal(k));
E= @SUM ( energy (m): Ue(m)*Ie(m));
F=@SUM ( waterenergy (t): Uewe(t)*Iew(t));
G= @SUM(renewable(l): Ure(l)*Are(l)*Ire(l));
UeGB= D+E+F+G;
UeNGB= 345509;
UEE= UeGB/UeNGB;

@FOR( POINTE( y) | y #LT# @SIZE(POINTE): !same as POINTW;
  @BIN( ZB( y));
    UEI( y) >  ELVL( y)*ZB(y);
    UEI( y) <=  ELVL( y+1)*ZB(y);
    CRee(y) = ECREDIT(y)*ZB(y);
      );
@SUM( POINTE( y) | y #LT# @SIZE( POINTE):  ZB( y)) = 1; !same as POINTW;
UEE= @SUM( POINTE( y) | y #LT# @SIZE( POINTE): UEI( y));
CRe1=@SUM( POINTE( y) | y #LT# @SIZE( POINTE): CRee( y)) ;

UrGB= @SUM(renewable(l): (Ure(l)*Are(l)*Ire(l)))/(UeNGB-UeGB);
```

```
@FOR( POINTRN( z) | z #LT# @SIZE( POINTRN): !same as POINTW;
  @BIN( ZC( z));
    UrGBI (z) >  RNLVL( z)*ZC(z);
    UrGBI (z) <=  RNLVL(z+1)*ZC(z);
    CRrr (z) = RNCREDIT(z)*ZC(z);
     );
@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN):  ZC( z)) = 1; !same as POINTW;
UrGB= @SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): UrGBI( z));
CRr=@SUM( POINTRN( z) | z #LT# @SIZE( POINTRN): CRrr( z)) ;

Cre2= @IF (Ie(3)#EQ# 1,1,0);
CRe3= @IF((Ie(1)+Iew(1)+Iew(2))#EQ# 3,1,0); !if 3 of them are selected by the model than cre16 is 3 else zero;
CRe4= @IF (Io(5)#EQ# 1,2,0);
CRs1= @IF (Io(6)+Io(7)#EQ# 2,3,0);
CRs2= @IF ((Io(8)+Io(9)) #EQ# 2,3,0);
CRm1= @IF (Io(10) #EQ# 1,2,0);
CRm2= @IF ((Io(11)+Io(12)+Io(13)) #EQ# 3,1,0);
CRy1= @IF ((Io(14)+Io(15)+Io(16)+Ie(3)) #EQ# 4,1,0);
CRy2= @IF (Io(17) #EQ# 1,1,0);
CRy3= @IF (Io(18) #EQ# 1,1,0);
CRa1= @IF(Io(19) #EQ# 1,2,0);
CRa2= @IF (Io(19)+Io(20) #EQ# 2,1,0); !if Io(17) is 1 and Io(18) is too than cra2 is 1 else zero;
CRa3= @IF (Io(21)+ Io(2) #EQ# 2,2,0);
CRyn1= @IF (Io(22) #EQ# 1,1,0);
CRyn2= @IF (Io(23) #EQ# 1,1,0);
CREDIT = 52+CRw1+CRw2+CRw3+CRw4+CRw5+CRr+CRe1+CRe2+CRe3+CRe4+CRs1+CRs2+CRy1+CRy2+CRy3+CRa1+CRa2+CRa3+CRyn1+CRyn2+CRm1+CRm2;
CREDIT >= 45;
CREDIT <= 64;

End
```

15 storey – Good level:

Same code with Approved level only the change of credit levels below at the end.

```
CREDIT >= 65;
CREDIT <= 79;
```

15 storey – Very Good level:

Same code with Approved level only the change of credit levels below at the end.

CREDIT >= 80;
CREDIT <= 99;

15 storey – Excellent level:

Same code with Approved level only the change of credit levels below at the end.

CREDIT >= 100;
CREDIT <= 110;