ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

DIRECT AND CROSS EVALUATION OF BUILDING RETROFITTING INTERVENTIONS ON SUSTAINABILITY INDEXES

M.Sc. THESIS

Doruk TAKMAZ

Energy Science and Technology Division

Energy Science and Technology Programme

SEPTEMBER 2019

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Thesis Advisor: Assoc. Prof. Dr. Hatice SÖZER

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

BİNA İYİLEŞTİRME UYGULAMALARININ SÜRDÜRÜLEBİLİRLİK ENDEKSLERİNE DİREK VE ÇAPRAZ ETKİLERİNİN DEĞERLENDİRİLMESİ

YÜKSEK LİSANS TEZİ

Doruk TAKMAZ

(301151028)

Enerji Bilim ve Teknoloji Anabilim Dalı

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Doruk Takmaz, a M.Sc. student of ITU Institute of Energy student ID 301151028, successfully defended the thesis/dissertation entitled “DIRECT AND CROSS EVALUATION OF BUILDING RETROFITTING INTERVENTIONS ON SUSTAINABILITY INDEXES”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Assoc. Prof. Dr. Hatice SÖZER** İstanbul Technical University	....
Jury Members :	**Prof.Dr. Üner ÇOLAK** İstanbul Technical University	....
	Prof. Dr. Zeynep Düriye BİLGE Yıldız Technical University	....

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To my family,

FOREWORD

Special thanks to Assoc. Prof. Dr. Hatice SÖZER, who has not stinted her concern and has shaped this thesis in the light of scientific foundations with her knowledge and experience, in planning, researching, execution and forming of this thesis.

Special thanks to Research Assistant Enver Cenan İnce, who has assisted me through this thesis with his extensive knowledge and considerate behaviour.

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Doruk Takmaz
(Environmental Engineer)

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ABBREVIATIONS

a : annual
ABM : agent based modelling
ASHRAE : American Society of Heating Refrigerating and Air Conditioning Eng
BEP : Building Energy Performance
^{0}C : centigrade
CBC : choice based conjoint analysis
CO1 : Predicted mean vote
CO2 : Predicted percentage of dissatisfied
CO_2 : Carbon dioxide
CO3 : Comfort parameter average value
CO4 : Local Thermal Comfort
CO5 : Percentage outside range
CO6 : Visual comfort
CO8 : Indoor air quality
COP : Coefficient of performance
DHW : Domestic hot water
DSI : District sustainability indicators
ECO1 : Investments
ECO10 : Accessed rents incl./excl. ancillary costs
ECO11 : Accessed rent increase (excl. ancillary costs)
ECO2 : Grants
ECO3 : Life cycle
ECO4 : Life cycle payback period
ECO5 : Total annual revenues discounted annual revenues and annuity
ECO6 : Energy production costs
ECO7 : Internal rate of return
ECO8 : Return of investment
ECO9 : Dynamic payback period
EIU : energy intensity of usage
EN 15251 : Indoor environmental criteria
EN 10551 : Ergonomics of the thermal environment. Assessment of the influence of the thermal environment using subjective judgement scales
EN1 : Density of final energy demand
EN11 : Temporal predictability and controllability of energy supply
EN12 : Visibility of technology
EN2 : Annual and maximum efficiency of energy sources
EN3 : Annual and maximum power of energy supply units
EN5 : Maximum load of thermal energy demand
EN6 : Level of consistency with national standard
EN8 : Degree of energetic self-supply thermal
EN9 : Net fossil energy consumed
ENV1 : Final energy consumption

ENV2 : Primary energy consumption
ENV3 : Greenhouse gas emissions
ENV4 : Eco-efficiency of hybrid systems
ENV5 : Ecological footprint
EPS : Electric Power Steering
EU : European Union
GDP : Gross Domestic Product
GEPA : Atlas of solar energy potential
GHG : Green house gas emissions
GIS : Geographical Information System
GPCI : Global Power City Index
GWP : Global Warming Potential
h : hour
ha : hectar
HVAC : heating ventilating air-conditioning
ICT : Information and communication technology
IES : Illumination Engineering Society
INT : Intervention
IRR : Internal rate of return
İŞKUR : Turkey Bussiness Agency
K : Kelvin
KPI : Key performance indicators
Kwh : kilowatt hours
LED : Light Emitting Diode
LEED : Leadership in Energy and Environmental Design
LCA : Life Cycle Analysis
m^2 : meter square
Misc. : Miscellaneous
Mm : milimeters
n.a. : not attended
NFEC : NF Energy Saving Corporation
NOx : Nitrogen Oxides
NPV : net present value
nZEB : nearly zero enegy buildings
O&M : operation and maintanence
OECD : Organisation for Economic Co-operation and Development
PBP : payback period
PD : Palladium
PMV : Predicted mean vote
PPD : Predicted percentage of dissatisfied
Ppm : parts per million
PV : Photovoltaic
R2Cities : Residential renovation towards nearly zero energy cities
RES : Renewable energy supply
SECo : Specific Energy Consumption Adjusted for Occupancy

SECu : Specific Energy Consumption Adjusted for Usage& Space Efficiency
SO_2 : Sulphur dioxide
SO11 **:** Accessibility of users with physical impairments
SO12 **:** Impact on energy poverty
T **:** time
TS 12460 **:** Standards for Arrangement of Buildings for Disabled People
TS 12576 **:** Accesibility regarding the design rules for structural measures and markets for pavement and accessibility in pedestrian crossings
TS 9111 **:** Standard for Accessibility Requirements for People with Disabilities and People with Mobility Restrictions
TSMS **:** Turkish State Meteorological Service
TUIK **:** Turkish Statistical Institute
u-value **:** thermal transmittance coefficient
UBEM **:** Urban Building Energy Modelling
UK **:** United Kingdom
UN **:** United Nations
UR1 **:** Impact of the refurbished district: efficiency of the urban system
UR2 **:** Urban complexity: Enterprises, civil organizations/associations
UR3 **:** Impact on pedestrian public spaces
UR4 **:** Impact on transport
US : United States of America
W : watt
yr : year

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DIRECT AND CROSS EVALUATION OF BUILDING RETROFITTING INTERVENTIONS ON SUSTAINABILITY INDEXES

SUMMARY

The main objective of this thesis is to identify the sustainability indexes for a specified area (Kartal District of Istanbul) and further to analyze influences of the building retrofitting interventions on them. Specifically, this thesis covers the effect of 8 interventions such as thermal insulation, window change, LED (Light Emitting Diode) lighting, heat pump, solar thermal panels, automation & monitoring systems, application of water saving systems and radiant heating on sustainability indexes which are grouped under 6 topics such as energy, economical, comfort, social, environmental and urban. At the same time, the interventions mentioned above have influences on 7 energy consuming parameters such as lighting, miscellaneous equipment, space heating, space cooling, pumps, ventilation fan, domestic hot water. Additionally, one part of the thesis examines effects of the sustainability indicators on each other such as the effect of an energy indicator on an economy indicator. Another part consists of the standardization of sustainability indexes according to national and international standards to classify the sustainability indicators.

In the introduction part, purpose of thesis is given and the literature is reviewed including studies that are related with the content of the thesis to be informed about the techniques and measures to evaluate sustainability indexes, energy efficient retrofitting interventions, mathematical models and related national and international standards. In the methodology part, the description of sustainability indexes is given in addition to their measurement technique. Then, the national and international standards are given to classify the sustainability indexes. Building retrofitting interventions are given with the scenarios. 6 scenarios are the combinations of 8 retrofitting interventions. The 7 energy consuming parameters are expressed. The methodology to measure the effects of retrofitting interventions on energy consuming parameters are given. The methodology to calculate the effects of interventions on sustainability indexes constitutes the next section. Methodology part ends with the techniques which indicate cross effects of sustainability indexes to each other. Furhermore, case study chapter begins with the general overview and climatic conditions for Kartal Demo Site. There are three buildings such as one elderly house, and two residential apartments. The meteorological information is included because it effects the selection of retrofitting strategies along with the configuration and type of selected strategies. Features of the building prior to retrofitting interventions are clearly identified in order to highlight the effects of intended retrofitting targets. Therefore, buildings envelope, mechanical systems, electrical systems are described. In order to enhance the inadequate parts for the demo site purpose and summary of the interventions are mentioned. Building energy simulation which is used to calculate the energy demand and comsumption of the buildings and the effects of retrofitting interventions is explained. Scenario 6 is chosen which includes all of the interventions.

Results section includes the qualitative and quantitative outcomes of mentioned methodologies. Results chapter begins with the evaluated sustainability index table. The classification results of sustainability index according to standards is expressed. Percentage effects of retrofitting interventions on energy consuming parameters are given. Therefore a sensivity matrix is formed including no sensivity, partly sensitive, reasonably sensitive and highly sensitive influences. Effects of interventions on sustainability indexes is shown in the next part with the intended effects and side effects. Cross effects of chosen sustainability indexes to each other concludes the results chapter. Discussion part to evaluate the results and provide conclusions are placed at the end of the thesis.

BİNA İYİLEŞTİRME UYGULAMALARININ, SÜRDÜRÜLEBİLİRLİK ENDESKLERİNE DİREK VE ÇAPRAZ ETKİLERİNİN DEĞERLENDİRİLMESİ

ÖZET

Bu tezin amacı, Kartalın Yakacık mahallesi için oluşturulan sürdürülebilirlik endekslerini belirlemek ve değerlendirmek bunun yanısıra; burada proje kapsamında seçilen üç binaya uygulanan iyileştirme müdahalelerinin enerji tüketen parametrelere ve sürdürülebilirlik endekslerine etkilerini belirlemektir. Bu bağlamda sekiz iyileştirme uygulamasının (ısı yalıtımı, cam değişimi, led ışıklandırma uygulaması, ısı pompası entegrasyonu, güneş paneli ekleme, otomasyon & izleme sistemlerinin kurulması, su tasarruflu armatürlerin eklenmesi ve radyant ısıtma sistemlerinin kurulması) sürdürülebilirlik endekslerine (enerji, ekonomi, konfor, sosyal, çevresel, kentsel) etkileri incelenecektir. Aynı zamanda az önce belirtilen bina iyileştirme uygulamalarının belirlenen yedi enerji tüketen parametreye (ışıklandırma, ısıtma, soğutma, pompalar, havalandırma fanları, evsel ısıtma suyu, çeşitli ekipmanlar) etkileri incelenmektedir. Buna ek olarak tezin bir kısmında belirlenen sürdürülebilirlik endekslerinin birbirlerine çaprazlama etkileri örneklendirilmektedir. Tezin bir diğer kısmında sürdürülebilirlik endekslerinin araştırılan ulusal ve uluslararası standartlara uygunluğu hesaplanmaktadır. Bu sayede yapılan bina iyileştirme uygulamalarının ulusal ve uluslarası standartlarda yarattıkları etki gözlemlenebilecektir.

Tezin giriş bölümü tezin amacı ile başlamaktadır. Ardından tezin içeriği ile alakalı çalışmaların incelendiği literatür taraması yer alacaktır. Literatür taraması sürdürülebilirlik endesklerini hesaplamada kullanılan teknikleri, enerji verimli bina iyileştirme uygulamalarını, kalitatif ve sayısal modelleri, ilgili ulusal ve uluslararası standartları içermektedir. Dünyada uygulanan sürdürülebilirlik indeksleri, bu indekslerin seçiminde, hesaplanmasında ve birbirleriyle kıyaslanmasında dikkate alınan esaslar incelenmekte ve Kartal Demo Alanı ile karşılaştırılması yapılmaktadır. Sürdürülebilirlik endekslerini doğrudan veya dolaylı etkileyen enerji, ekonomi, sosyal, çevresel, komfor ve şehircilik parametreleri detaylı şekilde irdelenmektedir. Bina bazındaki enerji verimli tekniklerin (enerji verimli camların kullanımı, enerji koruyan duvar yalıtım malzemelerinin kullanımı) ve yenilenebilir enerji kaynaklarının binalara entegrasyonunun sürdürülebilirlik alanında doğurduğu olumlu etkilere yer verilmektedir. Bina ve bölgesel bazda değerlendirilen sürdürülebilirlik kavramını etkileyen senaryolar ve uygulama kombinasyonları incelenerek Kartal saha çalışması ile benzerlik ve farkları ortaya konmaktadır. İstatistiksel methodlar ve bunların kullanılış biçimlerinin incelenmesi tezin methodolojisini oluşturmada altlık olarak kullanılmaktadır. Ülkemizde bu tezin kapsamı içinde yer alan sürdürülebilirlik endekslerinin tümünü tek tek inceleyen bir sürdürülebilirlik standardizasyonu bulunmamaktadır. Bundan dolayı dünyada uygulanan standardizasyon yöntemleri ve bunların dayandığı temeller incelenmekte, bu bağlamda bina enerji uygulamalarının

standartlara uygunluğu değerlendirilmiştir. Dolayısıla tezin bu bölümü bölgesel veya ulusal bazda sürdürülebilirlik incelemesi yapmak isteyen ya da sürdürülebilirlik endeksi oluşturmak isteyen yetkili otoriteleri ilgilendirmektedir. Aynı zamanda bina enerji modellemeleri ve bu modellemelerde dikkate alınan noktaların ekonomik, çevresel ve sosyal etkilerine değinilmiştir. Bina enerji modellemelerinde kullanılan metodların özellikleri ve bu özelliklerin Kartal saha çalışması ile ilgisi de belirtilmiştir. Literatürde yer alan bina iyileştirme çalışmaları ve bu iyileştirmelerin enerji korunumuna faydaları ile duyarlık analizi bağlamında incelemeleri irdelenmektedir.

Metodoloji kısmı, sürdürülebilirlik endekslerinin açıklamaları ve hesaplama yöntemleri ile başlamaktadır. Burada enerji, ekonomi, konfor, sosyal, çevresel ve şehircilik alanında seçilen indekslerin tanıtımlarına ve hesaplama yöntemlerine değinilmektedir. Ardından sürdürülebilirlik endekslerini sınıflandırmak adına seçilen standartlar belirtilmektedir. Bu standartlar tek bir kaynaktan alınmamıştır, ulusal ve uluslarası düzeyde standartlar seçilmektedir ve bina iyileştirme uygulamalarının bu standartlardaki etkisi gözlemlenmeye çalışılmaktadır. Bina iyileştirme uygulamalarının isimleri(ısı yalıtımı, cam değişimi, led ışıklandırma uygulaması, ısı pompası entegrasyonu, güneş paneli ekleme, otomasyon & izleme sistemlerinin kurulması, su tasarruflu armatürlerin eklenmesi ve radyan ısıtma sistemlerinin kurulması)tablo halinde belirtilmektedir. Bunun ardından sekiz bina iyileştirme uygulamasının kombinasyonları olan altı senaryo gösterilmektedir. Yedi adet enerji tüketen parametre (ışıklandırma, ısıtma, soğutma, pompalar, havalandırma fanları, evsel ısıtma suyu, çeşitli ekipmanlar) bu bölümde listelenmektedir. Bundan sonra bina iyileştirme uygulamalarının enerji tüketen parametlere etkilerini ölçmek için uygulanan metodoloji bölümü yer almaktadır. Bu bölümde iyileştirme yapılırken hedeflenen enerji koruma etkilerinin yanı sıra yan ve olumsuz etkilere de yer verilmektedir. Ardından bina iyileştirme uygulamalarının sürdürülebilirlik endekslerine olan etkilerini hesaplamada kullanılan metodoloji yer almaktadır. Bu kısım binaların şehir bazındaki sürdürülebilirliğe etkisinin önemini açıkça göstermektedir. Metodoloji bölümü sürdürülebilirlik endekslerinin birbirlerine olan çaprazlama etkilerinin hesaplanma yöntemi ile son bulmaktadır. Çapraz etkileri incelemedeki hedef birbirinden bağımsız hesaplanmış sürdürülebilirlik indekslerinin aslında birbirinden ne oranda etkilendiğini kanıtlamaktır.

Sonrasında Yakacık vaka analizi kısmı gelmektedir. Bu bölüm Yakacık demo alanının genel bakışı ve iklimsel koşulları ile başlamaktadır. Demo alanı üç bina incelemesinden oluşmaktadır. Bu binaların ikisi konut apartman olup biri büyük ölçekli bir huzurevidir. Bölgeye ait meteorolojik veriler bina iyileştirme uygulamalarının seçimini ve konfigürasyonlarını etkilediği için burada yer almaktadır. Binanın iyileştirme uygulamalarından önceki durumu; bina dış cephesi, mekanik sistemleri ve elektrik sistemleri kapsamında anlatılmaktadır. Bu eksiklikleri gidermek bağlamında uygulanan iyileştirmelerin amaçları ve özetleri bir sonraki kısmı oluşturmaktadır. Bina enerji simülasyonu binanın enerji ihtiyacı, enerji tüketimi ve uygulanan iyileştirmelerin etkilerini ölçmek amaçlı kullanılmaktadır. Aynı zamanda bina enerji simulasyonu binanın mevcut enerji etüdünü analiz etmekte de kullanıkmaktadır. Sekiz uygulamayı da içeren altı kodlu senaryo demo alanı için uygun görülmektedir.

Sonuç bölümü, değerlendirilen sürdürülebilirlik endekslerin hesaplanmış tablosu ile başlamaktadır. Ardından sürdürülebilirlik endesklerinin standartlara göre durumları tablo halinde sunulmaktadır. Takip eden bölümde bina iyileştirme uygulamalarının enerji tüketen parametrelere yüzdesel etkileri yer almaktadır. Bu kısımda duyarlılık analizi matriksi yer almaktadır. Bu matriks: duyarlı olmayan, kısmi duyarlı, orta derecede duyarlı ve çok duyarlı etkileri içermektedir. Diğer bir yandan bina iyileştirme uygulamalarının sürdürülebilirlik endesklerine hedeflenen ve yan etkileri detaylı bir tabloda sunulmaktadır ve açıklanmaktadır. Sonuç bölümünün sonunda sürdürülebilirlik endekslerinin birbirlerine olan çaprazlama etkilerinin beş örneği yer almaktadır.

Tartışma bölümü sonuçların değerlendirilmesi ve önerilerin sunulması ile tezin sonunu oluşturmaktadır.

1.INTRODUCTION

1.1 Purpose of Thesis

Defining and measuring sustainability indicators are the current concern of the world. The purpose of thesis is to identify and analyze the sustainability indexes such as energy, economy, comfort, social, environmental and urban, in the area of Yakacık (Kartal District of Istanbul) and their affecting factors. There are 12 energy index, 11 economic index, 8 comfort index, 12 social index, 5 environmental and 4 urban index. Not all of the indexes can be evaluated for Kartal demo site and the evaluated indexes are determined in the following chapters. The thesis aims to present the effects of various building retrofitting interventions such as thermal insulation, window change, LED lighting, heat pump, solar thermal panels, automation & monitoring systems on defined sustainability indexes. The important point is that there are side effects of interventions rather than intended targets positively and negatively on sustainability indexes. Furthermore, the effects of retrofitting interventions on energy consuming parameters such as lights, misc. equipment, space heating, space cooling, pumps, ventilation fan and domestic hot water. There is also side effects on interventions rather than intended influences positively and negatively. In order to examine various retrofit strategies, different simulations were conducted with the aim of reaching to the maximum effect. On the other hand, standardization of the sustainability indexes are tried to be formed by comparing the results of sustainability indexes with international and national standards. Statistical cross effects of sustainability indexes to each other is the other part that are included in the thesis.

1.2 Literature Review

The determination and measurement of the factors that constitute sustainability have been recently discussed by numerous researchers. Various retrofitting applications have been conducted in order to become more sustainable in energy, economic, social, urban, and environmental aspects. In this thesis, numerous different literature pieces are examined, which define and describe sustainability indexes, interventions, energy consuming parameters and certain standards that are formed by policy makers.

Various studies focus on the ways of understanding energy measures and how energy efficiency indicators are related and how they can be used together to provide cost-effective energy developments towards sustainability. Therefore, it is important to understand that energy efficiency can be calculated through various indicators such as the usage of many different indicators in this study with the same purpose (Sekki, Airaksinen and Saari, 2017). In regard of encouraging building energy efficiency, it is examined how an indicator may be useful for giving the accurate decisions (T. Sekki et al., 2016). The study was conducted through the examination of different indicators, which describe buildings' (with various operational units) annual energy consumption. Energy Intensity of Usage (EIU), Specific Energy Consumption Adjusted for Occupancy(SECo) and Specific Energy Consumption Adjusted for Usage and Space Efficiency (SECu) are the indicators to understand the effectiveness of space utilization. EIU calculates energy usage per resident and energy usage per annual operating times, however it does take physical floor area into account. SECo and SECu remunerate the building's ability of conducting efficient space usage (Sekki, Airaksinen and Saari, 2017). In addition, similar to the input that is used for the energy simulation of Kartal Demo Site, building occupancy can be measured through the amount of occupants and the building's annual operating hours. It has been found that the correct information concerning occupancy is helpful in energy consumption in several ways such as realizing the ways energy is consumed by a building to help in cost-saving enterprises relating energy efficiency and using building automation systems depending on actual occupancy to make energy consumption savings (Sekki, Airaksinen and Saari, 2017). Relations between building occupants and building lead to enhanced improvement technologies for sustainability of the building (Santoli et al., 2014). On the other hand, sustainability indicators are formed for local improvement (Huang, Wong and Chen, 1998).

Energy efficiency and assisting energy efficient areas are important to understand. The usage of energy for daycare facilities and university areas at Espoo, Finland is examined (Sekki, Airaksinen and Saari, 2015). Two sample studies are benefited in order to prepare a labelling diagram along with Key Performance Indicators (KPI)s and an instrument to assist with energy efficient areas. The study concentrates on an energy positive neighborhood and ways in order to evaluate an area's energy positivity level. Also, the study helps to understand how an area's energy positivity level may increase and progress. On-site energy ratio, annual mismatch ratio and other mismatch indicators are used to evaluate the energy positivity level of an area. Furthermore, the study describes the urban design application, which provides data concerning the costs and environmental influences for various energy solutions through time for energy protective urban planning. The tool helps to make comparisons concerning numerous future improvement designs and their influences on energy demand and supply. These future improvement designs correspond to the different combinations of interventions that are applied to the buildings in Kartal case. It has been confirmed that newly developed KPIs (Annual Mismatch Ratio, Maximum Hourly Surplus, Maximum Hourly Deficit, Monthly Ratio of Peak hourly demand to Lowest hourly demand) provide powerful understandings to the decision making process relating environmental and economic effects of future development scenarios (Ala-Juusela et al., 2016).

There are various indicators of a sustainable city such as poverty rate (economic efficiency), population density (social harmonization), air pollution index (ecological balance), and average daily rubbish collection per person (environmental services). According to the study made in order to measure the sustainability of 15 major cities in Malaysia, none of those cities have achieved sustainability (showed moderate level), but most of them achieved human well-being development (Choon et al., 2011). People adaptation to sustainable living of life is important as much as planning sustainable cities (O'Keefe, 2013). Therefore, social acceptance for the applications used on Kartal Demo Site has been highly taken into consideration for the project.

In common with Kartal Demo Site, the importance of the usage of renewable energy and creating relating solutions for the problems of sustainability have been recently discussed. Determinations of PMV and PPD indicators are used depending on EN ISO 10551 for the necessities of the survey (comfort). Metabolic rate is considered as 1.2 met units considering ASHRAE Standard 55-2010 for resting situation (Ashrae 55: 2010). It is important to understand and examine the policies concerning solid waste diminishing, green-house gas and renewable energy in order to develop and create solutions relating the issues of sustainability (Munoz and Navia, 2018).

It is crucial to understand how to create living areas suitable with nature, which helps individuals to address the importance of logical sustainable urban planning (Bayramoğlu et al., 2017). Urban quality depends on environmental, urban, and building perspectives. Qualitative and quantitative elements construct sustainability indicators. Structurally analogous to Kartal study, initial part of the study concentrates on building a methodology, which assists individuals to understand the evaluation of urban life's quality depending on questionnaires and objective and subjective indicators in order to improve sustainability indexes at city level. The secondary step of the study assesses the city of Cagliari (Italy) in order to observe if this methodology is applicable on likewise urban areas. Cities containing significant environmental purposes are considered as sustainable cities, which are elaborated with their focus on the balance among infrastructures, urban metabolism, and automation and monitoring technologies (Höjer and Wangel, 2015).

Fundamental scientific properties can help in the transition of energy systems through creating sustainability principles. The study has taken place as understanding sustainability problems, formulating a proper definition for primary energy sources that can assist in the energy transition, examining transition technologies through the usage of fundamental scientific properties, and providing a discussion concerning the ways possible transition scenarios relating more sustainable energy systems can be improved. Energy, entropy, exergy and emergy analysis are the factors that have been taken into account in order to understand the effectiveness of energy transformations (Wang, Wennerstein and Sun, 2017).

On the other side, making sensitivity analysis between constituents is effective in determination of sustainability. Vesler and Hesler used a sensitivity model to be able to cope with development problems in Ping-Ding, China (Vester and Hesler, 1982). The relating features of a society and simulation of the society's improvement through the usage of quantitative data have been taken into consideration in order to determine the sustainability of a native society, which has been applied through the methods by Sensitivity Model. Various researchers worked on a methodology considering non-linear regression analysis aiming to observe the present degree of energy consumption and capacity for the implementation of retrofit. Sensitivity examinations have been applied to examine the effect of crucial parameters' variations as energy cost and discount (Chidiac, et al, 2011; Poirazis, Blomsterberg, and Wall, 2008; Susorova et al., 2013; Kanagaraj and Mahalingam, 2011; and Kneifel, 2010). In Kartal Case, Sensitivity Analysis is used to understand the level of energy consuming parameters' sensitivity against building retrofitting interventions.

Well-known scenario techniques are usually categorized as predictive, normative and explorative scenarios. There is also another categorization of forecasting and backcasting scenarios (Quist, 2007). In Kartal Case, forecasting scenarios are used which begin with baseline situation and assume various implementations combining with assumptions (Wang, Wennerstein and Sun, 2017). Specifically, future improvements scenarios have been used to analyze the methods to improve energy transformation technologies. An optimization model is commonly used to analyze costs and effectiveness of technology performances. Furthermore, Agent-based Modelling (ABM) is a method assisting in energy transformation technologies through the usage of evolutionary-based principles, which stems from coactions among agents and their adaptive behaviors. The study has determined the Stirling engine to describe the possible interpretations of technology development, which explains how high efficiency of energy transformation can be obtained such as from heat source to electricity. Secondary criteria such as environmental impacts, geographical suitability of primary energy sources, critical raw materials, social impacts such as poverty, employment and healthcare, and risk factors are proven to be effective in creating more sustainable energy processes (Wang, Wennerstein and Sun, 2017). Furthermore, according to the sensitivity analysis, by increasing PV area, surplus electricity production can be increased, which causes short-term efficiency with respect to the present energy mix. Another crucial result of the sensitivity analysis includes how changing the heat supply such as from fossil-fuel to district heating, helps with refurbishment having lowest environmental impact and how energy performance can be developed by the similar rates through the substitution of gas heating with district heating. (Passer et al., 2016). In this regard, research relating energy management and the ways to plan sustainable energy usage is very important.

Another research proposes a methodology concerning GIS (Geographical Information System)-based district energy modeling through the usage of bottom up approach. According to the methodology, energy outcomes coming from the simulations (through a computing server) are put onto the GIS (through census survey data), which identifies energy efficient areas from non-efficient ones. In addition, GIS-based methodology can assist relating authorities in order to set apart energy inefficient areas and develop solutions for sustainable energy usage in those areas (Ali et al., 2018). Patricia Demarco discusses the industrial past of a city which has a high level of pollution. She also provides crucial elements of social, ethical and economical aspects of the discussed city. She argues the requirement of preserving sustainability on Earth, which also requires preserving the environment (Silverman, 2018). Kılkış discusses the quantification of the compound carbon emission through a carbon equivalency metric for buildings. A net-zero carbon building's relation with a net-zero energy building has been discussed. The level of energy savings, energy load reduction's quantity and waste energy capturing measures are the elements that the net-zero conception depends on (Kılkış, 2007). Ecological footprint in terms of carbon equivalent is calculated as an indicator for Kartal Demo Site. The energy demand can be associated with various qualitative and quantitative elements. A multi-level cross-impact approach has been applied in order to understand the description and quantification of the data aiming to reach scenario examination. It is important to consider global, national and local levels. With the purpose of keeping the impacts of global warming by 20^0C, the European Union has been trying to decrease greenhouse gas emissions by 20% between the years of 1990 and 2020 (Vögele et al., 2017). In addition, the greenhouse gas emissions must be decreased by 80-95% when compared to the gas emissions during the year of 1990 (A Roadmap for moving to a competitive low carbon economy in 2050). Depending on the introduction of Weimer-Jehle, the Cross-Impact Analysis has been improved to assist with a methodical formation of qualitative and or semi-qualitative scenarios. This approach has been used in numerous energy-related analyses (Jenssen T, Weimer-Jehle W.). Continuos scenarios for the heating energy consumption as a main reference point for policy (Renn et al., 2009) and health care (Weimer-Jehle et al., 2012) should be applied cautiously by the authorities as supporting mediums. In addition, Urban Building Energy Modelling (UBEM) refers to the numerical modeling and simulation of the capacity of a set of buildings in an urban context, to account for not only the dynamics of distinctive buildings but more significanly, the inter-building impacts (Hong, 2018).

Energy modeling of buildings is applied by giving the model known building features to predict intended elements in order to simulate existing condition and the effect of various retrofitting strategies to expose energy saving (ASHRAE. Chapter 19: energy estimating and modeling methods. ASHRAE handbook of fundamentals. Atlanta: ASHRAE; 2013.) National and worldwide statistics concerning a certain year. This approach may help relating authorities to determine necessary areas, which can be improved in regards of energy saving methods and sustainability. System constituents form a feedback framework; increase or decrease in one constitute provoke changes in the other constitute, which proves the formation of cause and effect relations among the constitutes (Clayton, A., Radcliffe, N., 1996. Sustainability, A Systems Approach, Earthscan Publications, London.) The same procedure has been applied for Kartal Demo Site.

Numerous studies that are set as a source for Kartal Demo Site, have analyzed the environmental and economical perspectives of the buildings (Ferrali and Beccali, 2017). Kurnitski examined cost-effective resolutions and nearly zero energy building energy performance degrees. The building is inside the Politecnico di Milano University in Italy (Kurnitsky et al., 2011). Numerous researchers used diverse optimized simulation in order to discover cost-effective and nZEB resolutions regarding the Directive 2010/31/UE (Directive, 2010) (Hamdy, Hasan and Siren, 2013). Payback periods of the refurbishments have been analyzed by Wang et al. and Malatji (Wang et al., 2014; Malatji et al., 2013). Also, Becirovic and Vasic examined longer payback periods (13 years on average) (Be´cirovi´c and Vasi´c, 2013).

Traditional and neoclassical theories were used by Godrun and Giffinger concerning urban growth and development to assess criteria for the ranking of smart cities, and also to create an evaluation for the ranking’s quality. There are two main perspectives concerning the assessment of urban life’s quality, which are objective approach (resolving information from government data collections) and subjective approach (using social survey methods) (Marans and Stimson, 2011).

Furthermore, the importance of anthropocentric approaches has been realized in terms of understanding people’s demands in order to create sustainable resolutions (Monfaredzadeh and Berardi, 2015).

Specifically, construction properties have been collected through the analysis of archive information and through firsthand observation (Ferrali and Beccali, 2017). The samples of buildings had parallel properties, which are the age of the buildings, the sizes, and the operating hours (Sekki, Airaksinen and Saari, 2017). The consequences of the study could be applied to most of the buildings, which have same archetype, but every building owns different speciliaties (Ferrali and Beccali, 2017).

Many organizations or decision makers have contributed to the construction of sustainability indicators and provide some level of standardization for the classification of the relating indicators. For this thesis, national and international standars have been found specifically for most of the sustainability indicators and indicators are rated according to a determined range to observe the impacts of building retrofitting interventions.10% of cost effective energy saving may be achieved by 2020 and also 20% of it by 2030 (Sekki, Airaksinen and Saari, 2017). 50% of the world's population reside in cities and the rate is expected to rise to 80% by 2050. Cities are responsible for 80% of worldwide CO2 emission. In addition, buildings all over the world are found to consume 40% of global energy. International organizations such as the European Commission aim to reduce this consumption by 80% until 2050 (EC Directive, 2010). Earth Summit in Rio, UN Framework Convention on Sustainable Development, the OECD, and the US Presidential Council on Sustainable Development have been paying close attention to the sustainability and relating policies (Chan and Huang, 2004). The current EU directives have been taken into consideration for various building studies. Some of those studies mostly emphasize the ways to reach energy efficiency solutions instead of cost efficiency (Ferrali and Beccali, 2017).

Siemens Organization has developed a Green City Index, which emphasizes the importance of sustainability for corporate aims and strategy. The index includes 8 criteria that are CO2 emissions, energy, buildings, transport, water, waste and land use, air quality and environmental management (European Green City Index, 2012).

Forum for the Future has developed the Sustainability Cities Index that has the purpose of examining England's 20 cities depending on their environmental, economic and social performances. The index has three indicators, which are 'environmental performance, life quality and future strategies concerning becoming prepared for a higher-level sustainable future' (Forum for the future, 2010).

European Foundation has developed Urban Sustainability Indicators that are also designed to measure the performance of sustainability, which are "Global Climate Indicator, Air Quality Indicator, Acidification Indicator, Ecosystem Toxification

Indicator, Urban Mobility Indicator or Clean Transportation Indicator, Waste Management Indicator, Energy Consumption Indicator, Water Consumption Indicator, Nuisance Indicator, Social Justice Indicator, Housing Quality Indicator, Urban Safety Indicator, Economic Urban Sustainability Indicator, Green, Public Space ad Heritage Indicator, Citizen Participation Indicator and Unique Sustainability Indicator" (Urban Sustainability Indicators. European Foundation, 2012).

Japan has also had proposals in regard of examining sustainability performances, which is called the Global Power City Index (GPCI) analyzing 35 big cities of the World concerning six functions that are "economy, research and development, cultural interaction, accessibility, environment and livability" (Global Power City Index, 2011).

China's sustainability index named as the Urban China Initiative (prepared by Columbia University, Tsinghua University and McKinsey Company) includes five indicators that are 'resource efficiency, basic needs, environmental health, built medium and interdependency to sustainability' (The Urban China Initiative, 2010).

Moreover, the program named as the Green Communities created by the United States Environmental Protection Agency is a web-based tool that assist societies in order to reach to a high degree of sustainability. The tool includes a five-step planning scheme and two indicators, which are 'domain-based indicators and goal-based indicators' (Green Communities, 2012).

Furthermore, the Department for Communities and Local Government of the UK Government has created Eco-Town Standards, which include 11 elements that are 'carbon emissions, employment, transport, local services, green infrastructure, biodiversity, water, flood risk, waste, healthy living and landscapes. The standards help to identify areas that have sufficient capacity for being an 'Eco-town' (Eco-town Standards, 2008).

Lastly, the Ministry of Environmental Protection of China has developed the elements of eco-town building in 2003. According to the study, the city should reach to 19 indicators covering 3 topics, which are 'economic development, environmental protection, and social development' (MEP, 2007). Moreover, standardized measures should be used in order to achieve sustainable development (Hodge and Hardi, 1997).

Energy consumption of buildings and districts is a crucial element of sustainability, which has been analyzed in different researches. The interventions in this paragragh which has become as an inspirational literature source, are discussed or applied in this thesis. An important study develops energy performance to reach the nearly Zero Energy Building (nZEB) requirements by detecting a building's energy retrofit (Ferrali and Beccali, 2017). The analysis of studies conducted by Harvey describes that various studied cases succeeded with at least 50% energy use reduction considering the effects of present conventional practice (Harvey, 2009). It is important to understand that through using high-level technological solutions relating retrofit, improving primary demands is definitely possible by 40%. In addition, the energy utilization can be reduced up to zero by using renewable energy resources (Ferrali and Beccalli, 2017). The building retrofit measures have been examined depending on their economics performances along depending on their primary energy consumption efficiency. The economic performances have also been examined with respect to the total annual cost, the net present value, and the payback time. The study shows that by using well-proven technological techniques to retrofit a building, primary energy consumption could be considerably decreased. Through improving the thermal resistance of roofs and facades, a high level of reduction can be conducted. Furthermore, using groundwater heat pumps causes successful consequences and more reduction may be conducted when a grid connected PV system is applied on the roof. Installation of controlled mechanical ventilation systems including heat recovery shows successful results through an energy perspective; however, it is not economically efficient as it is not affordable (Ferrali and Beccali, 2017). The study includes an environmental assessment that has two different regeneration proposals, which are dependent on the energy level (minimum and high quality), energy production that is composed of solar thermal and photovoltaic panels, a renewable energy assumption, and finally the consequences of the climate change considering the findings of the Austrian Panel on Climate Change. Cumulative energy demand, ecological scarcity, global warming potential, non-renewable and concerning building life cycles are included as environmental indicators for the assessment. The assessment produces important results concerning succeeding with the optimal refurbishment such as the occurrence of high-quality retrofitting of the building envelope with solar thermal panels and PV panels. (Passer et al., 2016) Due to the retrofitting wall and roof insulation, a high-level of energy saving for residential areas can be succeeded. The classes of building retrofitting include heating and cooling demand decrease, usage of energy-efficient equipment, application of renewable energy sources, and alterations of human behavior in time and location (Passer et al., 2016). The transformation of university buildings toward Net Zero Energy Buildings is discussed depending on student comfort analysis. The method consists of a questionnaire and monitoring, which occurr in an architecture faculty in Spain. Students' responses are recorded in terms of understanding the ways in order to succeed in more energy saving. Energy saving methods (can be succeeded with useful applications in the building) and provides comfortable environment for the building users. According to the study, lower indoor temperatures are mostly preferred by students such as 20 – 22.5 ◦C (during their classroom activity). It has been found that comfort requirements for a healthy educational environment can be achieved at the same time with increasing energy saving for the buildings. Removing thermal bridges, exploiting air heat recovery methods, and developing the windows are some retrofitting methods for winter in order to decrease energy usage of the buildings, which is capable of providing an energy saving up to 62%. In addition, by the usage of natural ventilation and eliminating the application of air-conditioning, overheating issues that occur in the summer can be improved and comfort conditions can be achieved (Irulegi et al., 2017).

It is significant to understand the unapparent elements of energy consumption. In the study, electricity and natural gas are chosen as primary elements of energy relating the residential sector. The information is collected through surveys and interviews. At the later stages of the study, factor analysis is used in order to determine more latent factors of energy consumption. As a different perspective from Kartal Project, production, family characteristics, conservation importance, heat transfer and air infiltration, hot water system, inefficiency, lighting, age of building and heating system, computer type, fuel for preparing food, neighborhood safety and security, number of occupants working full-time, and conversion of light to heat are the variables used in the factor analysis. The study concludes that all variables except lighting, computer type, and conversion of light energy to heat have important impacts on energy consumption. In regard of pragmatizing the energy usage for the household sector, social endeavors by authorities are suggested in order to succeed in effective usage electricity and gas consumption. (Najmi, G. and Keramati, 2014). This study examines that historical and traditional buildings have no difference concerning energy retrofitting measures except the need to save buildings' visuality and fabric (Webb, 2017). While determining energy retrofits, the study concentrates on examination pathways, criterion and resolution process. Providing wall and underground insulation, changing windows and lamps, improving HVAC, heating equipment and altering management schedules are regarded as general retrofits of buildings (Kolokotsa et al., 2009). As the fuel and energy resources have been declining, energy prices and the harm mankind is causing for the environment have been highly increasing. The research focuses on the ways in order to improve energy efficiency and environmental resolution through the development of aesthetic properties for energy-economic residences.

There are 4 fundamental methods in order to project sustainable cities, which are city planning, architectural-planning, constructive, and engineering. The most important trends for planning a sustainable city are based on energy protection, economical aspects, and the sensible usage of the sources of energy. Among the mentioned methods, most relevant ones are alternative energy sources, usage of integrated perspectives, automation, taking advantage of renewable energy sources, and economic assessment. The city of Umea is used as an example for the usage of centralized domestic hot water, wind turbine, solar cells, and the providing of energy-efficient LED lighting. Such as Kartal Demosite, the opinions of the local resident and experts were taken, and technical solutions were improved accordingly (Konyuk et al., 2018). Charles Eley focuses on buildings' having to be designed in order to use less energy, which highly accounts for renewable energy integration. Specifically, he mentions concerning the importance of efficient daylight usage, Low-E glass, insulating material, natural ventilation that determine the energy consumption of lighting, heating, cooling and ventilation (Manzo, 2018). Margaret Robertson discusses exhaustive approaches including different components of sustainability such as energy, cities, climate, environment, ecosystems, water, social equity, food, product life cycles and more. Concerning thesis, the part about tracking of LEED Standards the methods used such as night ventilation, passive cooling with cross ventilation and evaporative cooling tower, daylight maximization and renewable energy usage are the beneficial examples (Robertson, 2018). Mouzon clarifies that act of people are more significant than technology such as sophisticated glass, solar power, modification about LEED (Forsyth, 2011).

In this study, the sustainability indexes formed by various organizations mentioned above are examined and relevant sustainability indexes are formed according to Kartal demo site. The sustainability indicators are grouped under the topics of energy, economy, comfort, environmental, social and urban. The measurement methods for sustainability indexes are compared and the calculation techniques are decided accordingly. The standardization of sustainability indexes is questioned and appropriate classification techniques are determined. On the other hand, applied interventions are investigated about decreasing energy consumption of buildings and integrating new energy efficient technologies to buildings towards sustainability with economical, environmental and social point of view. Specific day care facilities and other type of buildings are reviewed about retrofitting technologies to find optimum solutions on Kartal demo site. Different sensitivity analyses methods and scenario formation techniques to validate the outcomes to integrate them into the thesis. The above mentioned studies in literature are benefited to form the parts of this study.

2. METHODOLOGY

2.1 Sustainability Index Identification and Calculation Methods at District Scale

The selected indexes are determined and calculated in the scope of R2Cities project in order to observe the level of the building retrofitting interventions to compare the results with baseline situation that is the prior to the stage in which the interventions were applied. The indexes aim to examine the intended and side affects of the building retrofitting interventions and the degree of success of interventions at district scale. With the knowledge of the importance of building's being the main component of a district, analyzing a building or group of buildings leads to better understanding of requirements and weaknesses that can be renovated at district scale. Although different indexes, weighting methods and calculation techniques are examined in the literature of global reference, Concerto Premium Guidelines are chosen, since they are regarded as representative and suitable with the data obtained from the Kartal Demo Site. As the project is within the European Union framework, partners of the project are in the same opinion to choose the indexes from Concerto Premium Guidelines.

The energy, economy, social, environmental and urban indexes are calculated according to the methods of Concerto Premium Guidelines (Concerto, 2012). The comfort indexes are based on Fanger methods (Fanger, 1970) and ASHRAE standards (ASHRAE, 2001).

The figure 2.1 shows the steps of the methodology part:

2.1.1 Energy index

2.1.1.1 Density of final energy demand (EN1)

Density of final energy demand (kWh/m^{2}year) has been calculated considering both heating, domestic hot water, cooling and electricity final demands for Kartal. In other words, the indicator is identified as the rate of final energy demand (for thermal energy and electricity) of an interdependent group of buildings and representative aspect of a

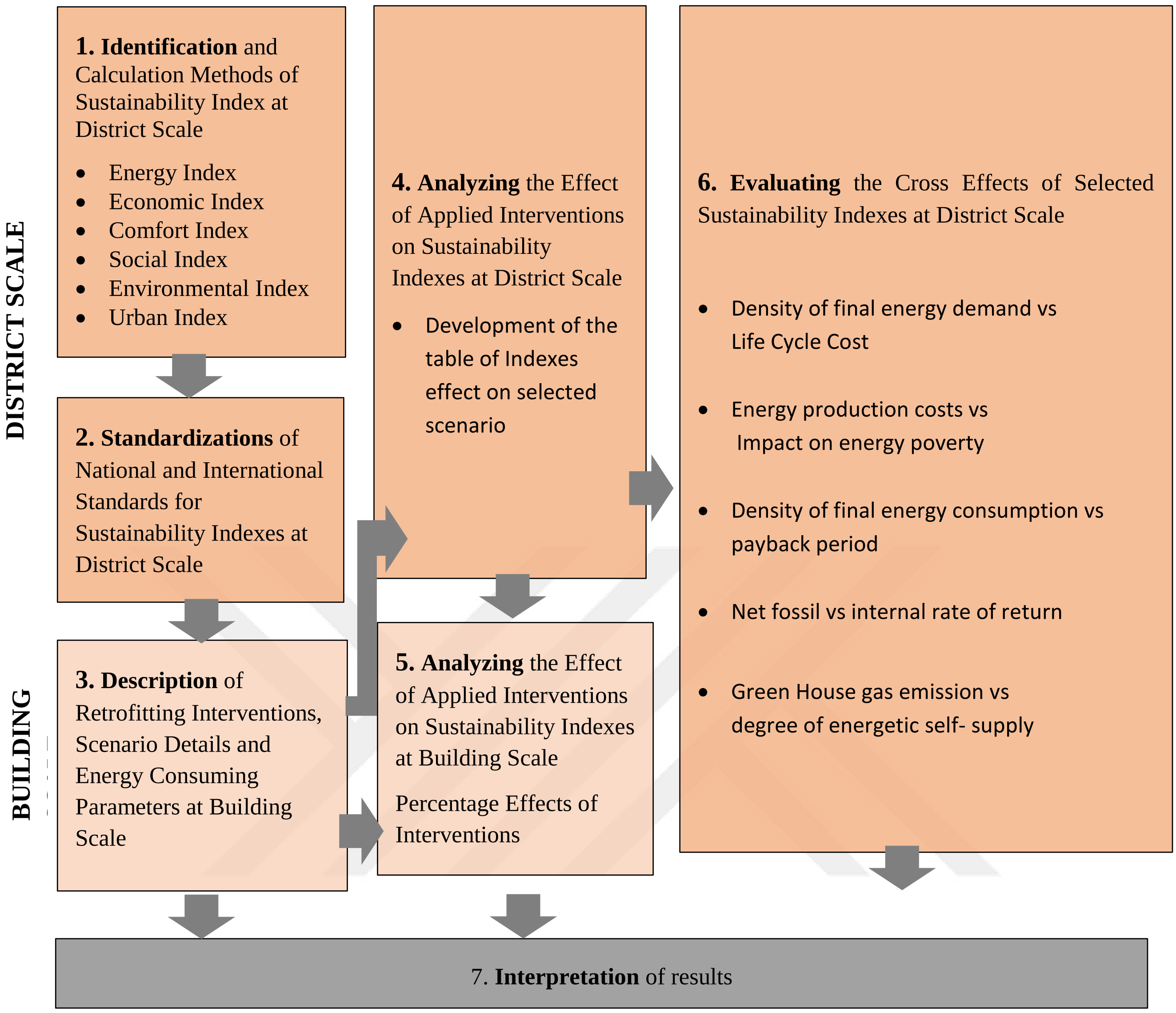


Figure 2.1: Metholdology Scheme

the buildings. Following the CONCERTO Premium guidelines, the application area should be considered as the set of space cooling, space heating, domestic water heating and electrical appliances.

$$DEN_{EC,I,t} = \frac{\sum_{AA=AA1}^{AA4} In_{EC,AA,I,t}}{Cap_I} \quad (2.1)$$

Where a: is referred to an annual measure. In the literature it can be found also as yearly (yr). Therefore, a and yr are equivalent notations.

$DEN_{EC,I,t}$ Density of final energy demand of a group I of buildings in years t $[kWh/yr]$

$In_{EC,AA,I,t}$ $[kWh/yr]$ energy flow into group of buildings for intervention area AA in t year

Cap_I Area of group I of buildings I (km^2 territory area, buildings)

$$In_{EC,AA,I,t} = \sum_{i \in I} In_{EC,AA,i,t} \quad (2.2)$$

2.1.1.2 Annual and maximum efficiency of energy sources (EN2)

The efficiency of an energy source can be stated as average or as maximum efficiency through a year. Unit of this index is kWhout/kWhin. In other words, it is the ratio of the output energy to input energy. This SI gives information about the amount of energy that energy sources utilize to generate energy.

Although, average efficiency and maximum efficiency are given below, maximum efficiency calculation results will be used in further examination.

Average efficiency

$$Ef_{s,EC,t,avg} = \frac{1}{EN_{s,EC,t}} \quad (2.3)$$

$Ef_{s,EC,t,avg}$ Average energy outcome by energy source s per energy input (demand) based on year t $[kWh/kWh]$

$EN_{s,EC,t}$ Energy demand by energy source s divided by the production of the outcome through year t $[kWh/kWh]$

Maximum efficiency

$$Ef_{s,EC,t,max} = \max_{k=1 \ldots K} \left(\frac{1}{EN_{s,EC,\Delta t_k}} \right) \quad (2.4)$$

$Ef_{s,EC,t,max}$ Maximum energy outcome by energy source s per energy input (demand) through a section of year t $[kWh/kWh]$

$EN_{s,EC,\Delta t_k}$ Energy demand by energy source s divided by the production of the outcome of energy through year Δt_k as part of a section of year t (kWh/kWh)

2.1.1.3 Annual and maximum power of energy sources (EN3)

The power of an energy source or a group of energy sources in process can be described as average or as maximum power per year. The average power is identified as the ratio of energy outcome of the energy source over a period of time. The maximum or average power in operation can be compared to the maximum design potential in order to understand the level of usage of the energy source.

The annual maximum and the monthly average power provided by the energy supply units are calculated starting from monthly average and annual maximum energy demands, applying the efficiency of the distribution/regulation system. Also the monthly average and the maximum annual degree of utilization have been defined as ratio between power provided by energy supply unit, and the nominal capacity of energy supply unit. However, average efficiency and maximum efficiency are given below, maximum efficiency calculation results will be used in further examination. Unit is the ratio of kW/kW.

Average power

$$Po_{s,EC,t,avg} = \frac{Out_{EC,s,t}}{8760 * CAP_{s,EC}} \quad (2.5)$$

$Po_{s,EC,t,avg}$ Average power by energy source s per energy input through year t $[kW/kW]$

$OUT_{EC,s,t}$ Outcome energy flow of energy source from energy supply units in year t $[kWh/a]$

$Cap_{s,EC}$ Capacity of energy sources concerning the outcome of energy carrier $[kW]$

Maximum power

$$Po_{s,EC,t,max} = \max_{k=1...K}\left(\frac{Out_{EC,s,t,\Delta t_k}}{\Delta t_k * 8760 * CAP_{s,EC}}\right) \quad (2.6)$$

$Po_{s,EC,t,max}$ Maximum power of energy carrier by energy sources s per energy input (demand) through section of year $[kW/kW]$

$OUT_{EC,s,t,\Delta t_k}$ Outcome energy flow of energy source from energy supply unit s based on year Δt_k (k=1,…,K) as part of a section of year t $[kWh/a]$

$Cap_{s,EC}$ Capacity of energy source s concerning the outcome of energy carrier (kWh)

2.1.1.4 Maximum load of electricity demand (EN4)

The load profile determines the demand features per time. The electricity supplier need to handle the maximum load. The load profile provides data about the probabilities or capacity of demand management, storage, and self-supply by renewables etc.

Unit: kW

Load profile

$$LP_{I,EC=electricity,t,\Delta t_k} = \frac{\sum_{AA1}^{AA4} In_{EC,AA,I,\Delta t_k}}{\Delta t_k * 8760} \quad (2.7)$$

$LP_{I,EC=electricity,t,\Delta t_k}$ Load of group of buildings concerning energy carrier = electricity in Δt_k $(k = 1, \ldots, k)$ as part of a section of year t (kW)

$In_{EC,AA,I,\Delta t_k}$ Input energy flow into group of buildings for application area in Δt_k $(k = 1, \ldots, k)$ as part of a section of year t (kWh/a)

Peak load

$$LP_{I,EC=electricity,t,max} = max_{k=1,\ldots,k}\left(LP_{I,EC=electricity,t,\Delta t_k}\right) \quad (2.8)$$

$LP_{I,EC=electricity,t,max}$ Peak load of a group of buildings concerning energy carrier related to a section of year t $[kW]$

$LP_{I,EC=electricity,t,\Delta t_k}$ Load of group I of buildings concerning energy carrier = electricity in Δt_k $(k = 1, \ldots, k)$ as part of a section of year t (kWh)

2.1.1.5 Maximum load of thermal energy demand (EN5)

The load profile determines the demand features through time. The thermal energy supplier need to fullfill the maximum load. The load profile provides data about the probabilities or capacity of supply-side, demand-side and storage in addition to management. The indicator can cover the heating and cooling supply for the district or the application area.

Maximum load and load profile of thermal energy demand [kW] has been calculated as the monthly average power demand and the annual maximum power demand. The values come from energetic simulations.

Load profile

$$LP_{I,AA,t,\Delta t_k} = \frac{\sum_{EC} In_{EC,AA,I,\Delta t_k}}{\Delta t_k * 8760} \quad (2.9)$$

$LP_{I,AA,t,\Delta t_k}$ Load of group I of buildings concerning application area in Δt_k $(k = 1, \dots, k)$ as part of a section of year t (kW)

$In_{EC,AA,I,\Delta t_k}$ Input energy flow into group of buildings for application area in Δt_k $(k = 1, \dots, k)$ as part of a section of year t concerning energy carrier [kWh/a]

Peak load

$$LP_{I,AA,t,max} = max_{k=1,\dots,k}(LP_{I,AA,t,\Delta t_k}) \quad (2.10)$$

$LP_{I,AA,t,max}$ Peak load of a group of buildings concerning application area through a section of year t (kW)

$LP_{I,AA,t,\Delta t_k}$ Load of group of buildings concerning application area in Δt_k $(k = 1, \dots, k)$ as part of a section of year t (kW)

2.1.1.6 Level of compliance with national standards (EN6)

The level of compliance with national standards is determined as ratio between [(kWh/m^{2}year)/(kWh/m^{2}year)] final energy demand of an individual building and final energy demand of an operationally similar building which is built in accordance with the national minimum needs in local regulation. *(Building Energy Performance Regulation (BEPtr)).* It should be noticed that the retrofitted building is evaluated under the national minimum neccesity for new constructions.

$$DA_{I,t,final/primary} = \frac{\sum_{i \in I} Cap_i * DA_{i,REF,final/primary}}{\sum_{i \in I} Cap_i} \qquad (2.11)$$

$DA_{I,t,final/primary}$ Level of consistency of a group I of buildings with national standards concerning total final/primary energy through an annual data of year t (%)

$DA_{i,REF,final/primary}$ Level of building i's according to national standards concerning total final/primary energy through annual data of year t using reference building of the same type as [%]. Calculated following the next formula:

$$DA_{i,REF,final/primary} = \frac{EN_{i,t\ final/primary}}{EN_{REF,t\ final/primary}} \qquad (2.12)$$

$DA_{i,REF,final/primary}$ Level of building according to national standards concerning total final/primary energy through yearly data of year t using reference building of the same type as i [%]

Cap Floor area of the building (m^2)

2.1.1.7 Level of correspondance of simulated final energy demand and monitored energy consumption (EN7)

The level of correspondance of simulated final energy demand and monitored energy consumption is identified as the division of the simulated final energy demand of a building to the monitored final energy consumption of a building over a year. This SI provide an opportunity to compare the simulation and real case results.

This SI cannot be calculated for proposed scenarios but can be worked out monitored consumptions are available.

Unit: %

$$DC_{I,t} = \frac{\sum_{i \in I} Cap_i * DC_{i,t}}{\sum_{i \in I} Cap_i} \qquad (2.13)$$

$DC_{I,t}$ Level of correspondance of a group I of buildings concerning calculated final energy demand and monitored consumption based on yearly data of year t (%)

$DC_{i,t}$ Level of building i's correspondance of calculated final energy demand and monitored energy consumption throughannual data of year t $[kWh/(m^2\ a)]$ Calculated following the next formula:

$$DC_{i,t} = \frac{ENm_{i,t\ final/primary}}{ENd_{i,t\ final/primary}} \quad (2.14)$$

Cap_i Floor area of building i $[m^2]$

2.1.1.8 Level of energetic self-supply (EN8)

The level of energetic self-supply is described as the division of on site generated energy and the local demand throughout a period of time (usually one year). The indicators are individually describing thermal energy and electricity. In addition, the quantity of locally generated energy can be shown as by renewable energy sources generated energy or via heat pumps produced energy. In short, the degree of energetic self-supply [%] for heating and electricity has been calculated as the division of the total final energy demand to the energy provided by renewable sources.

$$ESS_{AA,I,t,RES} = \frac{\sum_{EC} RES_{EC,I,t}}{\sum_{EC} In_{EC,AA,I,t}} \quad (2.15)$$

$ESS_{AA,I,t,RES}$ Usage of renewable energy in energy demand of group I of buildings for application area in year t [%]

$In_{EC,AA,I,t}$ Input energy flow into group I of buildings for application area in year t concerning energy source) $[kWh/a]$

$RES_{EC,I,t}$ Renewable energy in energy carrier supplying group I of buildings in year t [kWh/a] Calculated following the next formula:

$$RES_{EC,I,t} = \frac{RES_{i,t\ final/primary}}{EN_{i,t\ final/primary}} \quad (2.16)$$

2.1.1.9 Net fossil energy consumed (EN9)

The Net Fossil Energy utilized (kWh/m^2) is the final energy consumed within the boundary of the district not including the renewable energies locally produced or the renewable fraction of the energies acquired from external grids. This DSI is calculated as below equation.

NFEC = Total density of primary demand * (100-% of Renewables (EN8))

2.1.1.10 Marketspace of the technology in order to measure the level of innovation (EN10)

The level of innovation of a technical measurement can be shown by the distribution of this technology in the local market within one country and year. Unit is percentage.

$$MST_{s,t} = \frac{SV_{[s],t}}{SV_{[s]*,t}} * 100 \qquad (2.17)$$

$MST_{s,t}$ Marketspace of energy source s in from a demand point of view comparable energy sources in year t [%]

$SV_{[s],t}$ Sales volume of energy sources of the same types as s in year t [€]

$SV_{[s]*,t}$ Sales volume of energy sources of the same types as s (from a demand point of view) in year t [€]

2.1.1.11Temporal predictability and controllability of energy supply (EN11)

The temporal foreseablity and controllability of an energy source or a group of energy sources is chosen using a qualitative scale.

$$TCP_s = TCP_{[s]}$$

TCP_s Temporal predictability and controllability of energy supply unit s [scale: 1, 2, 3]

$TCP_{[s]}$ Temporal predictability and controllability of energy supply units of the same type as s [scale: 1, 2 and 3]

Table 2.1 : Temporal predictability and controllability.

Qualitative Scale	
Low predictability and controllability	1
Medium predictability and controllability	2
High predictability and controllability	3

2.1.1.12 Visibility of technology (EN12)

The visibility of a source is measured using a qualitative scale.

$$VT_s = VT_{[s]}$$

VT_s Visibility of energy supply unit s [scale: 1, 2, 3 (i.e. low/medium/high visibility)]

$VT_{[s]}$ Visibility of energy supply units of the same type as s [scale: 1, 2 and3]

Table 2.2 : Scale of visibility of technology.

Qualitative Scale	
Low visibility	1
Medium visibility	2
High visibility	3

2.1.2 Economic index

It should be noted that the measurements are conducted by taking the 2012 EUR/TRY currency for economic indexes. The calculations are based on euro while taking grants from European Union for the project called R2Cities.

2.1.2.1 Investments (ECO1)

It represents the cost of the retrofitting interventions, including total renumeration until the first function of the building after the retrofitting. In addition, the investments are based on the dimensions of the building (e.g. net floor area) in order to develop the comparability.

Unit: €/m^2

$$\bar{I}_{I,t} = \frac{\sum_{i\in I} I_{i,t}{}_{,t}}{\sum_{i\in I} Cap_i} \quad (2.18)$$

$\bar{I}_{I,t}$ Specific investment for a set of buildings; during construction period t [€/m^2]

$I_{i,t}$ Investment for building i; during construction period t [€]

Cap_i Floor area of building i [m^2]

2.1.2.2 Grants (ECO2)

It takes into account all the grants that can be applied to the projects or to a single intervention. Grants are described as the section of the investment that is donated by a grant supplier.

Unit is €/m^2

$$\overline{IG}_{I,t} = \frac{\sum_{i\in I} IG_{i,t}{}_{,t}}{\sum_{i\in I} Cap_i} \tag{2.19}$$

$\overline{IG}_{I,t}$ Specific investment grants for a set of buildings I; during construction period t [€/m^2]

$IG_{i,t}$ Grants for building i; during construction period t [€]

Cap_i Floor area of building i [m^2]

2.1.2.3 Life cycle cost (ECO3)

Life Cycle Cost (LCC) is calculated as net present value which is achieved by discounting all expenses during the scope of system to the present with a calculated discount rate, *(d)*. This methodology provides the possibility of comparing different systems and investments where the expenses differ during the calculation period.

The total life cycle cost is the sum of net present values of all renumeration expense, maintenance expense, replacement expense, energy and water expense of the building within the designated period *(t)*, as its generalized formula is stated below. Unit is €/m^2

$$\overline{LCC}_{I,t} = \frac{\sum_{i\in I} LCC_{i,t}{}_{,t}}{\sum_{i\in I} Cap_i} \tag{2.20}$$

$$\overline{LCC}_{i,t} = \frac{LCC_{i,t}}{Cap_i} \tag{2.21}$$

$\overline{LCC}_{I,t}$ Life cycle cost for a set of buildings I; during period t [€/m^2]

$LCC_{i,t}$ Life cycle cost for building i; during period t [€], following next formula:

$$LCC_{i,t} = \sum_{0}^{t} \frac{C_g + C_m}{(1+r)^t} \pm V_r(\frac{1}{(1+r)^N}) \tag{2.22}$$

C_g Cost of operation. These include the energy costs and the economic savings due to the energy savings [€]

C_m Cost of maintenance. [€]

t Year for which the operating cost is being determined

N Lifetime of the building

r Calculated discount rate $[-]$

V_r Residual value at the end of the lifetime and eventual disposal costs. [€]

Cap_i Floor area of building i [m^2]

2.1.2.4 Life cycle payback period (ECO4)

The life cycle payback period is the time period which equalizes life cycle costs of two or more scenarios consists of planned, alternative or existing investments to capital costs. The period of equalization of the capital costs of retrofitting suggestions to the cost savings resulting from retrofitting suggestions is an important consideration.

In this project, different retrofitting suggestions will be compared with each other and with the existing building in order to specify the most suitable retrofitting option in terms of investment expenditure and cost savings according to different demo site needs and budget.

Unit: yr

$$LCPP_{i,t} = \frac{investment_{t_0} + other\ investment_{t_0} - base\ line\ investments_{t_0}}{\frac{1}{t} * \sum_0^t (grants_t + \Delta\ Annual\ depreciation_t + \Delta\ Annual\ maintenance\ costs\ saved\ _t + Annual\ cost\ savings\ _t)} \quad (2.23)$$

$$LCPP_{i,t} = \frac{LCC_{i,t} - LCC_{i_0,t}}{\overline{CF}_{i,t}} \quad (2.24)$$

$LCPP_{i,t}$ Life cycle payback period for building during period t [yr]

$LCC_{i,t}$ Life cycle cost for building during period t [€]

$LCC_{i_0,t}$ Life cycle cost for building i for base line scenario (no intervention); during period t [€]

$\overline{CF}_{i,t}$ Average cash flow for building during period t [€].

$$\overline{CF}_{i,t} = \frac{\sum_{t=0}^{t} CF_{i,t}}{t} \quad (2.25)$$

$CF_{i,t}$ Cash flow for building i during period t, including: investment grants, Total annual depreciation, cost of operation and maintenance [€]

t Year for which the operating cost is being determined

2.1.2.5 Total annual revenues (ECO5)

It is the totality of the revenues produced by the retrofitting intervention, like the cost savings given by the energy savings or the Operation and Maintenance (O&M) cost savings, in the annual period.Unit: €/yr

$$\overline{CF}_{i,t} = \frac{\sum_{t=0}^{t} CF_{i,t}}{t} \tag{2.26}$$

$$STR_{i,t,t_0} = Average\ grants + Average\ \ maintenance\ costs\ saved + Average\ cost\ savings \tag{2.27}$$

$$STR_{i,t,t_0} = SER_{i,el,t,t_0} + SGR_{i,t,t_0,spec} + SNGNER_{i,t,t_0}$$

STR_{i,t,t_0} Sum of discounted total annual income of building i based on data of year t and with discount base in year t_0 [€]

SER_{i,el,t,t_0} Sum of discounted total annual energy-sales income of building i based on data of year t and with discount base in year t_0 [€]

$$SER_{i,el.,t,t_0} = \sum_{t'=t_2}^{t_2+EL_{(i)}} \left(\frac{1}{(1+r)^{t'-t_0} * ARRER_{i,t,t'}}\right) \tag{2.28}$$

$ARRER_{i,t,t'}$ Annual requirement related energy-sales income of building i in year t' based on energy flow of year t [€/yr]

t_2 Year of constructionend of building i

r Interest rate for calculations

$SGR_{i,t,t_0,spec}$ Sum of discounted total yearly grants income of building i over the expected lifetime based on data of year t and with discount base in year t_0 [€]

$$SGR_{i,t,t_0,spec} = \sum_{t'=t_2}^{t_2+EL_{(i)}} \left(\frac{1}{(1+r)^{t'-t_0} * (ACRR_{i,t'} + ARRGR_{i,t,t'})}\right) \tag{2.29}$$

$ACRR_{i,t'}$ Yearly capital-related income of building I in year t' [€/yr]

$ARRGR_{i,t,t'}$ Yearly requirement-related grant income of building I in year t' based on energy flow of year t [€/yr]

t_2 Year of constructionend of building i

r Interest rate for calculations

$SNGNER_{i,t,t_0}$ Sum of discounted total annual non-energy-sales non-grant income of building I based on data of year t and with discount base in year t_0 [€]

$$SNGNER_{i,t,t_0} = \sum_{t'=t_2}^{t_2+EL_{(i)}} \left(\frac{1}{(1+r)^{t'-t_0} * (ARRNGNER_{i,t',t} + AORR_{i,t,t'} + AOR_{i,t,t'})}\right) \quad (2.30)$$

$ARRNGNER_{i,t',t}$ Yearly needed non-grant non-energy-sales revenues of building in year t' based on energy flows of year t [€/yr]

$AORR_{i,t,t'}$ Yearly operation-related revenues in year t' based on data of year t [€/yr]

$AOR_{i,t,t'}$ Annual other revenues in year t' based on data of year t [€/yr]

$EL_{(i)}$ Expected lifetime of a building of the same type as i [yr]

t_2 Year of construction end of building i

r Interest rate for calculations

2.1.2.6 Energy production costs (ECO6)

The energy production costs are identified as sum of discounted total annual costs subtraction or sum of discounted total yearly income except annual energy. Unit: €/kWh

$$\overline{EPC}_{s,EC,t,t_0} = \frac{(Energy\ production\ units\ investment + Sum\ of\ discounted\ energy\ costs - Sum\ of\ discounted\ annual\ cost\ savings\ )(€)}{20(yr) * (Annual\ heating\ (Primary\ Energy\ Demand)\left(\frac{kWh}{yr}\right) + Annual\ electric\ (Primary\ Energy\ Demand)\left(\frac{kWh}{yr}\right))} \quad (2.31)$$

$$\overline{EPC}_{s,EC,t,t_0} = \overline{STC}_{s,EC,t,t_0} - \overline{SGR}_{s,EC,t,t_0} - \overline{SNGNER}_{s,EC,t,t_0}$$

$\overline{EPC}_{s,EC,t,t_0}$ Energy production expense of energy sourcess for the generation of the outcome of energy carrier through data of year t and with discount base in year t_0 [€/kWh]

$\overline{STC}_{s,EC,t,t_0}$ Sum of discounted total yearly expense of energy source s for the production of the outcome of energy carrier based on data of year t and with discount base in year t_0 [€/kWh]

$\overline{SGR}_{s,EC,t,t_0}$ Sum of discounted grant income of energy sources for the generation of the outcome of energy carrier through data of year t and with discount base in year t_0 [€/kWh]

$\overline{SNGNER}_{s,EC,t,t_0}$ Sum of discounted non-grant non-energy-sales income of energy sources s for the generation of the outcome of energy carrier EC based on data of year t and with discount base in year t_0 [€/kWh]

where T represents the operative lifetime of the investment and k is the WACC.

2.1.2.7 Internal rate of return (ECO7)

The internal rate of return is the interest rate that complies with the present value of future cash generation to the early cost of the project. It complies with the same logic as NPV, the most important differentiation is selecting a discount rate depending upon the risk of the project, this technique depends on an iterative process to understand which discount rate will bring the NPV to equal zero. In a simpler way, the IRR can be defined as the value of WACC for which the NPV is nullified.

The IRR, which is expressed as %, can be calculated by differentiating the discount rate used in the NPV measurement until the NPV is equal to zero. Investments are compared against a required rate of return: if the project's internal rate of return is greater than required rate of return then it can be accepted, otherwise it should be rejected. The IRR will show the annualized rate of return generated over time by the project. Unit: %

$$r^*_{REF,(t),t_0} = r\ (variable) with\ NPV_{REF,(t),t_0}\ (r) = 0 \qquad (2.32)$$

$r^*_{REF,(t),t_0}$ Internal rate of return of investment with regard to data of year (t) and with the discount base in year t_0 using reference unit REF [-]

r Interest rate for calculations (variable) [-]

$NPV_{REF,(t),t_0}$ Net present value of investment with respect to annual data of year (t) with discount base in year t_0 using reference unit [€]

2.1.2.8 Return of investment (ECO8)

The Return on Investment provides a further degree of information than the PBP by considering the actual lifetime of the retrofitting intervention. It explains the return of the measure expressed in percentage. It is measured by dividing the total energy and Operations and Maintenance O&M savings exceeding the initial investment, so the net profits of the intervention, by the prelimnary investment and get it into a percent. To compute annual return it is necessary to divide this value by the duration of the project. Like PBP, ROI does not consider the time value of money and the advantage of compound interest. The ROI can be evaluated using the following formula:
Unit: %

$$ROI = \frac{Net\ present\ value}{-Discounted\ Cash\ Flows * 100} \tag{2.33}$$

$$ROI = \frac{Total\ Energy\ Savings[€] + Total\ \Delta OandMCosts[€] - Initial\ Investment\ Cost\ [€]}{Initial\ Investment\ Cost\ [€]} \tag{2.34}$$

To compute annual return it is necessary to divide this number by the duration of the project.

2.1.2.9 Dynamic payback period (ECO9)

The Payback Period is expressed by the time neccesary for gained savings to become equal to the prelimnary investment, commonly indicated in years. The PBP method ignores any benefits that occur after that the investment is, indeed, “paid back” and the time value of money, thus underestimating the value of a longer-term investment. Therefore, it cannot permit to distinguish between projects with equal payback periods, so even if it gives a sensitive evaluation of the investment, it cannot be taken into account alone as index to establish the feasibility of an investment. The payback period can be calculated using the following expression:
Unit: yr

$$DPBP[y] = \frac{investment_{t_0} + other\ investment_{t_0} - base\ line\ investments_{t_0}}{Average\ discounted\ Cash\ Flow} \tag{2.35}$$

$$PBP[y] = \frac{Initial\ Investment\ Cost\ [€]}{As\ \left[\frac{kWh}{y}\right] \cdot Tariff\ \left[\frac{€}{kWh}\right] + ApRES\ \left[\frac{kWh}{y}\right] \cdot Tariff\ \left[\frac{€}{kWh}\right] + \Delta OandMCosts\left[\frac{€}{y}\right]} \tag{2.36}$$

The yearly gain is the yearly generation through renewable energy sources and operation and maintenance costs is the difference between the functioning and maintenance expenses before and after the retrofitting intervention

2.1.2.10 Accessed rents including/excluding ancillary costs (ECO10)

The accessed rents of a building or a group of buildings can be shown considering secondary expenses and excluding secondary expenses. In order to enhance the comparability among buildings, the rent depends on the dimension of the buildings (e.g. net floor area). Unit: €/ (m^2 yr)

$$AR_{I,(t)} = \frac{\sum_{i \in I} Cap_i * AR_{i,t}}{\sum_{i \in I} Cap_i} \tag{2.37}$$

$AR_{I,(t)}$ Accessed rents incl./excl. ancillary expense of a set of buildings in year t [€/ (m^2 yr)]

$AR_{i,t}$ Accessed rents incl./excl. ancillary expense of building in year t [€/ (m^2 yr)]

Cap_i Floor area of building i [m^2]

2.1.2.11 Achieved rent raise (excluding ancillary costs) (ECO11)

The accessed rent raise of a retrofitted building is described as difference of the achieved rents after and before the retrofitting. Secondary expenses are not included. Theoretically, this indicator can be measured the same recent constructions, if the achievable rent for an operationally comparable recent constructed building depending on the new local minimum requirements is explained. In order to ensure the comparability among buildings, the data is concerned with the dimension of the building (e.g. gross net floor area). Unit: €/ (m^2 yr)

$$AR_{I,I_{REF},(t),(t_1),(t_2)} = \frac{\sum_{i \in I} Cap_i * AR_{i,REF,t,t_1,t_2}}{\sum_{i \in I} Cap_i} \tag{2.38}$$

$AR_{I,I_{REF},(t),(t_1),(t_2)}$ Achieved rents increase of set of buildings in year (t) using set I_{REF} of reference buildings [€/(m^2 yr)]

AR_{i,REF,t,t_1,t_2} Achieved rents increase of building i in year t compared to reference building REF in year t* [€/ (m^2 yr)]

Cap_i Floor area of building i [m^2]

2.1.3 Comfort index

2.1.3.1 Predicted mean vote (CO1)

Predicted mean vote (PMV) is a representative indicator for thermal comfort of residents. High indoor environmental quality could be considered as one of the most important expected services provided by buildings. There is not a specific scenario for the customization of indoor environmental capacity; however, the public industry perspective is well constructed. As a result, numerous objective parameters are described by the individual sensation of indoor environment is thought to correlate.

The service quality provided to the resident (or building user) is shown by documenting the indoor environment situations. The category of indoor environment monitoring usually correlates to the parameters, which are significant for the residents' health and comfort (thermal and visual conditions, indoor air quality, etc.) These comfort service degrees generally symbolize the building process mechanism target (e.g., indoor air temperature, relative humidity). Several of the above measures are used by control processes for thermal environment regarding sensory feedback to the control perspective.

Thermal comfort is succeeded when the heat produced by the human body is capable of dissipating, namely, when the thermal equilibrium including the surrounding is protected. Elements that are affecting thermal comfort are heat conduction, convection, radiation, and evaporative heat loss.

The Predicted Mean Vote (PMV) is understood depending on the expected metabolic rate and the wearing insulation, and capacity indicators, which are the calculated or expected air temperature, mean radiant temperature, relative air velocity, and air humidity. The PMV associates the influences of the two individual parameters and the four thermal balance environmental parameters, and it assumes the mean thermal sensation using a scale of seven-point thermal sensation. In the basis of this, Fanger who imrpoved a method of equations that integrates the influence of the six parameters in an operational relationship assessing an indicator named as the *Predicted Mean Vote* (PMV).

$$PMV = f(M, I_{cl}, v_{air,} \theta_{air}, \theta_r, RH) \quad (2.39)$$

where *Metabolism rate [M], Clothing level [I_{cl}], Air Temperature [θ_{air}], Mean Radiant Temperature [θ_r], Air velocity [v_{air}], and Humidity [RH]*

Fanger determined the PMV with the following empirical equation:

$$PMV = (0.303 \cdot e^{-0.036 \cdot H} + 0.0275) \cdot L \quad (2.40)$$

$$L = q_{met,heat} - f_{cl}h_c \cdot (\theta_{cl} - \theta_{air}) - f_{cl}h_r \cdot (\theta_{cl} - \theta_r) - 156 \cdot (W_{sk,req} - W_a) - 0.42 \cdot (q_{met,heat} - 18.43) - 0.00077M \cdot (93.2 - \theta_{air}) - 2.78M \cdot (0.0365 - W_a) \quad (2.41)$$

$$q_{met,heat} = M - w \quad (2.42)$$

M = rate of metabolic generation per unit DuBois surface area, Btu/h · ft^2

w = human work per unit DuBois surface area, Btu/h · ft^2

f_{cl} = ratio of clothed surface area to DuBois surface area (A_{cl}/A_D)

h_c = convection heat transfer coefficient, Btu/h · ft^2 · ºF

θ_{cl} = average surface temperature of clothed body, ºF

θ_{air} = air temperature

h_r = radiative heat transfer coefficient, Btu/h · ft^2 · ºF

θ_r = mean radiant temperature, ºF or ºR

W_a = air humidity ratio

W_{sk} = saturated humidity ratio at the skin temperature

Evaluating CO1, total PMV rate is given as an average value for each building annually. As above scale the values are between -3 (too cold) and +3 (too warm) where 0 is neutral and the most desired result.

Table 2.3 : Predicted mean vote.

Scale of termal gradient	
3	Hot
2	Warm
1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

PMV is calculated for a particular space and a certain moment, for Kartal Demo Site; it will be calculated for relevant spaces of each building (e.g. living rooms in three different dwellings where conditions may differ such as under the roof vs. first floor or different orientations) and in two different moments of the year, which are the coldest and the hottest days.

Another possible evaluation is to apply PMV to the design conditions considered for the different scenarios: selected set point temperatures, air humidity ratio (if treated) and air velocity. This would ratify the accordance to ISO EN 15251 for indoor thermal comfort by meeting specified design values for indoor temperature during heating and cooling periods.

In order to evaluate CO1 indicator, each of these parameters should be explained for a given zone. Thus, with dynamic hourly simulation tools like e-Quest, thermal capacity indicators of a building or a specific area can be understood.

In PMV measurement, e-Quest offers dynamic measurement for PMV scale depending on Fanger’s perspective. In order to succeed with this, physical conditions of structural components and site-related conditions (i.e. weather, solar irradiation, orientation etc.) must be associated with the simulation model. Seperately, thermal operation and the values of average clothing are described into the simulation model. Through the usage of mentioned variables, e-Quest measures PMV values both as a distribution for the whole year and also as an average value for each building and each developed scenario.

2.1.3.2 Predicted percentage of dissatisfied (PPD) (CO2)

The PPD index (predicted percentage dissatisfied) is taken from the PMV index and assumes the percentage of thermally displeased individuals among a large number of people. Generally, a dissatisfaction of 10% measurement for the body thermal comfort is taken into account regarding the identification of expected thermal conditions. This conincides with a PMV in the range of –0.5 to +0.5. It must be emphasized that the minimum rexpected PPD is 5%, even if the outcome is a neutral thermal sensation (PMV=0) as it is not optional to please each individual as a result of the inter-individual discrepancies.

Fanger developed the index of *Predicted Percentage of Dissatisfied* (PPD) as a quantitative measurement relating the thermal comfort of a number of people at a specific thermal environment. Fanger correlated the PPD to the PMV as follows Unit: %

$$PPD = 100 - 95\, e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)} \quad (2.43)$$

Based on PMV scale, PPD is automatically calculated as a CO_2 comfort indicator.

2.1.3.3 Comfort parameter average value (hours) (CO3)

A parameter must be defined that evaluates the deviation of the objective function when compared with the comfort boundaries. This parameter allows assessing the degree of compliance for a determinate control strategy under a previously defined comfort condition.

Comfort parameter average value refers to the comfort-zone exceedance range, which according to EN15251 should be between 3%-5% and being calculated as the period of time that comfort conditions are above or below the accepted parameter (e.g. comfort temperature +/- amplitude or PMV, PPD values).

For Kartal case comfort parameter average value is measured in Design Builder considering PMV rates on the annual basis. According to Fanger and ISO 7730, thermal comfort is provided in range of "-0,5<PMV<+0,5" values. As a result, exceeded hours are described as discomfort hours.

When evaluating CO3, annual exceeded hours are summed and accordingly Comfort parameter average value in the units of hours is found. Unit: h/year

$$deviation^i = \frac{\sum_j^{time}\left(t * \left|comf_j^i - comf_{setpointi}^{max,min}\right|\right)}{time} * \frac{100}{comfort\ range} \quad (2.44)$$

time: *period while the comfort has been tested*

t: *time period when there is NO comfort in the occupied zone*

$comf_j^i$: *comfort value for the instant j under the definition i*

$comf_{setpointi}^{max,min}$: *comfort max, min value under definition i*

comfort range: *amplitude of the comfort zone under the definition I*

If the comfort parameter is over (under) the maximum (minimum) allowable value, the absolute difference of both values will be multiplied by the time period that this comfort value is out of range. The sum of all this values divided by the total length of the test will be the average of the deviation. In order to have always a clear magnitude of the deviation, the resulting values will be divided by the amplitude of the comfort range and expressed in percentage values.

The result gives a numerical value for the increment to be done to the accepted boundary conditions to be in the range, or how far the values are out of the bounds.

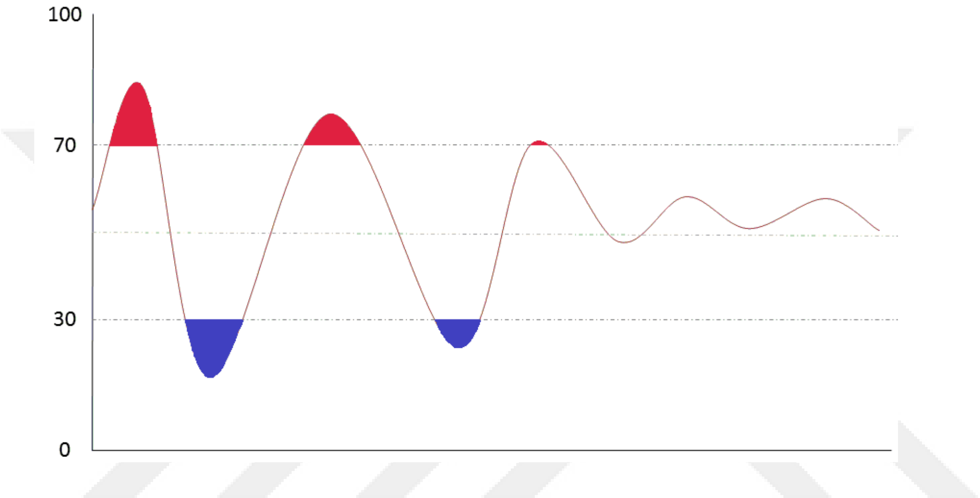


Figure 2.2 : Sample value for comfort parameter for a determinate day with allowable value (30-70).

Within EN 15251 there is a definition of acceptable time periods "out of comfort". This time period is fixed to 24 minutes every 8 hours (considered working time during the day). The definition of this kind of average value for comfort parameters will permit the evaluators or the building managers to measure in absolute terms the differences obtained. In the supposed case that the discomfort reached in 24 minutes will be maximum (100%), it could be evaluated the difference obtained between our value and the permitted one (temperatures, CO_2, ppm, etc.) shows a sample result of 2.86% in 24 hours' time and 8.6% in 8 hours base time.

If the accepted 24 minutes with a 100% of discomfort happens, the value will be 1.25% in a day and 3.75% in 8 hours working day. These values are 228% higher than those permitted by the norm for the complete day/working period, but still relatively small deviations compared to the acceptable zone (red peaks over 70 correspond to 12.5%·h and blue peaks under 30 are 15%·h).

2.1.3.4 Local thermal comfort (CO4)

The desired thermal environment for an area could be chosen from among three categories explained by the standard ISO 7730:2005. Each category describes a maximum percentage displeased for the body as a whole (PPD) and a PD for every type of local displeasing. The types of the thermal indoor environment are shown in the following table 2.4

Table 2.4 : Building categories according to thermal indoor environment.

Category	Thermal state of the body		Local discomfort			
	PPD [%]	PMV	DR [%]	PD [%] caused by		
				vertical air temperature difference	warm or cool floor	radiant asymmetry
A	<6	–0.2<PMV<+0.2	<10	<3	<10	<5
B	<10	–0.5<PMV<+0.5	<20	<5	<10	<5
C	<15	–0.7<PMV<+0.7	<30	<10	<15	<10

According to pre-found PPD and PMV rates, local thermal comfort category is defined as CO4.

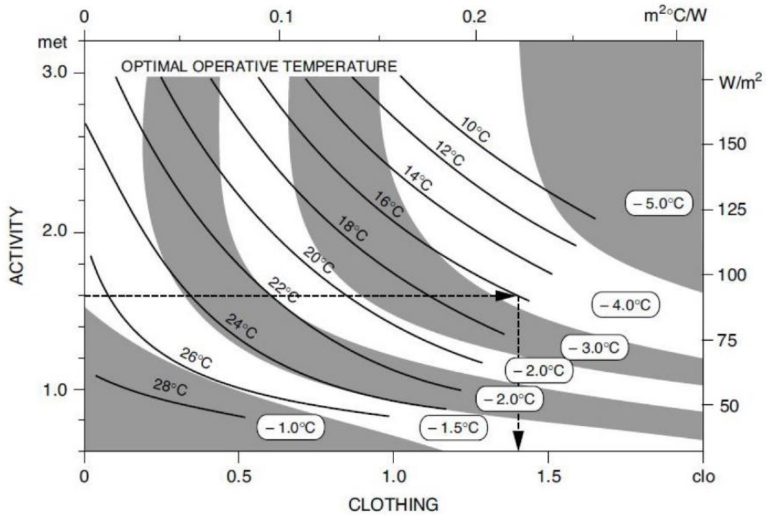


Figure 2.3 : Optimal operative temperature as a function of the activity and clothing.

The operative temperature, t_0, is explained as the uniform temperature of a virtual black enclosure in which a resident could replace the exact heat amount with radiation and convection as in the real non-uniform medium. The suitable room operative temperature may be defined as an activity and clothing function. For a given area, a suitable operative temperature correlating to PMV=0, based on the clothing and the activity of the residents is expressed depending on ISO 7730:2005.

2.1.3.5 Percentage outside range [CO5]

The percentage outside range is identified as a time interval (T) when inner thermal comfort is not inside of the expected interval depending on the intended classification. In other words, it associates with discomfort hours, which are identfied in CO3 percentage in a year (8760 hours). Unit is %.

$$POR = \frac{\sum Discomfort\ Hours\ \ on\ Annual\ Basis}{8760} \qquad (2.44)$$

2.1.3.6 Visual comfort [CO6]

Aspects as glare, luminance or the spectrum of the light that affect the indoor environment visual comfort. In the case of this evaluation, illumination levels (no daylighting) will be considered as indicator of visual comfort, which is defined as the degree of light falling (luminous flux) on a surface field. Unit: lux. Calculation of a single space can be formulated as it follows;

$$\text{Illuminantion Level (lux)} = \frac{\sum \text{Light flux (lm)}}{\text{Area of the space } (m^2)} = \frac{I \cdot cos\theta}{D^2} \qquad (2.45)$$

In the Illuminating Engineering Society (IES) standards, minimum acceptable IES illumination levels are given in the following table 2.5

Table 2.5 : Guideline of IES Standards Illumination Levels.

Building Areas	IES Illumination Level (Lux)
Living rooms and bedrooms	50
Casual reading	150
Studies desk	300
Bed lead kitchen	150
Bathrooms	100
Halls and landings	150
Stairs	100
Workshops	300
Garages	50

For Kartal Case, visual comfort is evaluated in resident rooms (For building 1) and livingrooms (for building type 2 and 3) since they are the most occupied rooms. Each scenario, especially covering LED technologies, is evaluated in Kartal Demo Site. Total light flux is determined based on light flux of one lighting source and total number of lighting sources. With respect to total light flux and building area “Illumination level” is found. According to results, LED technologies have a significant impact on visual comfort; leading an increase from 472 lux to 618 lux in terms of visual comfort in Kartal.

2.1.3.7 Acoustic comfort (CO7)

The main purpose of the performance indicators concerning the acoustic comfort in an area is to ensure acoustic components of a building that assist with clear speech communication among the residents of the building. Performance indicators on the following subjects are needed to achieve this purpose:

- indoor ambient noise levels
- airborne sound insulation between spaces
- airborne sound insulation between corridors or stairwells and other spaces
- impact sound insulation of floors
- reverberation
- speech intelligibility

Nonetheless, considering that to obtain necessary data to calculate all these indicators is not straightforward, and that the scope of the methodology presented by R2CITIES does only affect some of them, the indicators to be used in the framework for this evaluation can be reduced to:

- background noise (L_A [db])
- reverberation time (T [s])

This DSI will not be calculated but will be measured after that residents will settle the buildings.

2.1.3.8 Indoor air quality [CO8]

The Indoor Air Quality indexes are indicators that reflect the level of contamination and the quality of indoor air in areas. CO8 refers to carbondioxide concentration in a space and CO_2 concentration can be calculated using following formula;

$$CO2\ concentration\ in\ space[ppm] = \left(\left[\frac{CO2_{gen}}{OA}\right] * 10^6\right) + CO2_{out} \quad (2.47)$$

$CO2_{gen}$= CO2 generation rate per person [L/min]

OA = Outdoor airflow rate per person [L/min]

$CO2_{out}$ = CO2 concentration in outdoor air [ppm]

CO_2 generation rate per person can be interpreted by following figure based on the activity.

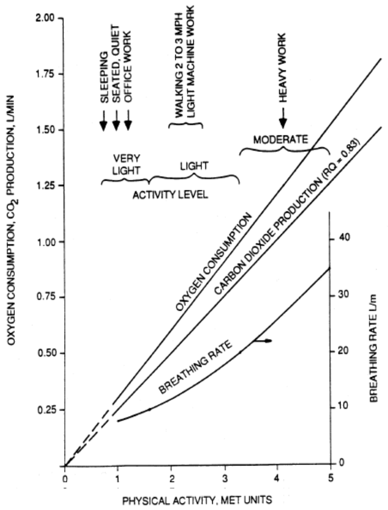


Figure 2.4 : CO_2 production (ASHRAE 62.1)

Taking supplied outdoor air and CO_2 concentration in outdoor air into account, indicator CO8 is evaluated. According to EN ISO 15251 standards, CO_2 should be between certain kind of values for different types of buildings. Building categories and acceptable values for each building category is defined in following Table 2.6;

Table 2.6 : Building categories and acceptable CO_2 values for each building.

Category	Explanation	Corresponding CO2 above outdoors in PPM
I	High level expectation It is recommended for spaces by very sensitive and fragile with spacial requirements like handicapped, sick, very young children and elderly person	350
II	Normal level expectation It should be used for new buildings and renovations	500
III	An acceptable, modarate level of expectation It may be used for existnig buildings	800
IV	Values outside the criteria for the above categories This category should only be accepted for a limited part of the year	<800

In Kartal Demo site, a typical bedroom is selected for CO_2 emission calculations in Building Type 1. Since Building Type 1 has mechanical ventilation, outdoor air flow rate per individual has been used in calculations as well as CO_2 generation for per person and CO_2 concentration of outdoor air in Istanbul which is 400 pm in average (Denli et al., 2014). For Type 2 and Type 3, there is no mechanical ventilation, therefore CO_2 concentration will not be calculated. Then, according to the EN15251, the following acceptable air flow rates (air change level) which are recommended for each room of the buildings are given in following table 2.7:

Table 2.7 : Air change rates for each dwelling room.

Category	Air Change rate (a)		Living room and bedrooms, mainly outdoor airflow		Exhaust air flow		
	l/s, m^2 -1	ach	l/s, pers(b) -2	l/s/m^2 -3	Kitchen (4a)	Bathrooms (4b)	Toilets -4
I	0,49	0,7	10	1,4	28	20	14
II	0,42	0,6	7	1	20	15	10
III	0,35	0,5	4	0,6	14	10	7

2.1.4 Social index

2.1.4.1 Socio-demographic features (SO1)

This indicator is highly important within diagnosis phase because it can offer the

causal factors for the status of building quality and performance. Furthermore, it will be useful to define their main needs and opportunities. This indicator, as far as the GDP level and investment capacity are highly important when developing a specific business models adapted to the real needs (particular requirements of the stakeholders and specific economic, social and physical situations).

Calculation method:

This indicator will be calculated by surveys, interviews or by the census and register of inhabitants.

The main information to be obtained is the age distribution, the proportions of females and males, marital status, household configuration (main characteristics: number of members, etc.), country of birth and language barriers.

Table 2.8 : Indicators scoped by SO1.

Indicator	Unit
Age distribution	% aged 0-18 years, % 19-30 years, %31-65 and % aged 66 years or older.
Marital status	%
Household configuration: number of members	Average number
Country of Birth	% (of foreign nationality)
Language barriers	%

2.1.4.2 Housing tenure (SO2)

This indicator is highly important for diagnosis phase because it can show the level of interest of the tenants in the rehabilitation works due to its housing tenure**.**

Calculation method:

This indicator will be calculated by surveys, interviews or by the census and municipal register of property.

Unit: % per tenure status.

2.1.4.3 GDP level and investment capacity (SO3)

The gross domestic product (GDP) is one of the most significant economic indicators associated to be considered when establishing the business models and the investment capacity of the neighbours. It represents an extensive measurement of the economic activity of the neighbours and shows the direction of comprehensive economic activity.

The difficult access to capital is one of the most important aspects for the lack of interest in rehabilitation works. This barrier is associated with in many countries has grown household spending.

In many cases the GDP per capita is low and over it weighs a mortgage and other household expenses that may be associated with socio-demographic characteristics such as family size, age, etc.

Calculation method:

This indicator can be evaluated with information from various sources: from the census interview, credit sources, etc. It should be associated with socio-demographic characteristics and housing tenure indicators for a clear view of the investment capacity. Unit: €/per capita

2.1.4.4 Employment rate (SO4)

This indicator is very important for several situations. Firstly, in the diagnostic phase is used to evaluate the economic profile of the district's inhabitants (in general terms), very important aspect to assess the technological opportunities or aids they could access. Secondly, the valuation of the employment rate along the project can assess its impact on local employment generation. Therefore, it can be assessed another positive impact of the rehabilitation works: it can increase the productive level and the local economic growth, one of the three key vectors for sustainable development. In order to assess the impact on the production of local employment must access the statistics from previous employment agency and 'post-intervention dates.

Calculation method:

The employment ratio is calculated in the first stage by surveying neighbours to develop a profile. But the aspect associated to the employment rate of the whole district inhabitants, the data can be obtained from the Labour Force Survey- the National Institute of Statistics- (TUİK in Turkey)

The second aspect associated to the employment rate during and after rehabilitation works development (design/construction/operation) the date can be obtained from the national office of employment (İŞKUR in Turkey) and from the administrative office of each demo project (procurement record). Unit: %

2.1.4.5 Level of acceptance by inhabitants, owners, tenants (SO5)

This cumulated indicator emphasizes the satisfaction of different participants such as stakeholders, inhabitants, owners, tenants, citizens of the community etc by the questionare with measurements. This could include the retrofittingt of houses, the integration of passive technologies the application of outreach, district heating, training, energy control. The indicator is calculated by surveying neighbours.

2.1.4.6 Degree of information and direct participation (SO6)

This indicator implies the stage of before the inhabitants were informed, throughout and after the project measures. This cumulated indicator is composed of many aspects and records as the degree of satisfaction with project measure relating data and the extent of people involving in the R2CITIES relevant decision-making processes such as planning and implementation. The indicator is calculated by surveying neighbours.

2.1.4.7 Level of civil participation (SO7)

The aim of this indicator is to evaluate the degree of participation of inhabitants in the decision-making processes.

The citizen participation in decision making is essential. Since the main purpose of urban renewal is to advance the quality of life of users and the development of community, it is essential to them the participation in making decisions throughout the process. But, they are indispensable in the development of management and maintenance strategies of buildings, condominiums and districts.

Thus, this element is associated with to the social dialogue within the society and outside the society with professionals and projects´ stakeholders. According to CONCERTO guidelines it must be evaluated the attitudes (Cultural norms, routine habits and practices); openness (Degree of tolerance/interest of inhabitants/ stakeholders to new themes) and finally it should be evaluated the awareness of the understanding of the neighbours about the specific intended energy conservation measures implemented.

This indicator should be calculated by analysing the number of collectives in the district and also by evaluating the % of participation in the whole process (participation in briefings, campaigns and negotiation), the quantity of (Complaints, suggestions, etc.)

2.1.4.8 Active or proactive householders' attitude (SO8)

This indicator supplies data on the attitude of the householders. It emphasizes householders' playing a role in any type of information system on their energy consumption such as diaries, questionnaires regarding energy consumption, surveys and energy billing documents.

Furthermore, it also describes the ways householders have altered their energy consumption attitude. The cumulated indicator also includes the demand of people to make investments in energy efficiency measuresements such as thermal insulation, energy efficient tolls or making more expenses on renewable energy and clean electricity.

It will be done a survey to the householders and interviews to the building administrator and maintenance operators where information of this indicator will be obtained.

2.1.4.9 Internal comfort perception after the implementation of measures (SO9)

This indicator is associated on how the users perceived the level comfort of the buildings at the operation phase. This indicator is directly associated to the comfort index assessed before.

Calculation method:

It will be done a Survey to the users of the buildings.

It’s important to get in the following data: Age, gender, activities at home, time inside the house (hourly and per week), clothes, season and so on. The evaluation of the survey must be done based on the already mentioned calculation index and the results should be compared with results of the monitoring platform. In this sense the pattern for the Survey must be associated with the buildings under monitoring.

2.1.4.10 Quality of the building as a place to live and work (SO10)

This indicator is associated on how the users perceived the level quality of the buildings as a place to live and work. This indicator also includes the level of pleasure with a district as a place to live, work and to operate. It will be done a Survey to the users of the buildings and by the census.

2.1.4.11 Accessibility of users with physical impairments (SO11)

This indicator is based on the analysis of accessibility for people with disabilities in buildings. Although this indicator is to be set for several areas of development including the city itself, transport and buildings, in this project it will be focused on the analysis of the latter. In the building, it is important to address accessibility from the outside, in their environment and interior.

The equal opportunities approach taken as the axis of current social policies, must to include the right to the city of those sectors of the population characterized by their reduced ability or mobility. The quality of design, safety, comfort, innovation, functionally, independence and standardization are the features that will shape a universal accessibility.

The conditional factors for calculate this indicator are the national accessibility legislation. Within the framework it must be validated if the intervention improves the accessibility or not.

The accessibility of users with physical impairments has been assessed according to the general characterization proposal defined in *TS 9111: (The requirements of accessibility in buildings for people with disabilities and mobility constraints*)

2.1.4.12 Impact on energy poverty (SO12)

This indicator allows to evaluate the quality of life of the inhabitants in relation with the access (if they can pay for) they have to the energy for supply its needs of indoor environmental quality as a guarantee of their health and wellness.

This indicator is associated with the energy costs, household income and the quality of the building. The quality of the building may affect the energy consumption of building and the comfort levels indoor. As the R2CITIES implementation will affect directly the quality of the buildings, this indicator is so relevant for evaluating the *impact of the project in the quality of life of the inhabitants.*

The household are energy poor when they spend more than 10% of their earnings to pay energy bills and also when they cannot afford the energy to meet their neccessities of cooling, heating, domestic hot water or other household uses (e.g. cooking, etc.) That may affect the psyche of the individual. In our case, although the neighbours being energy poor or not, the project will impact positively avoiding this risk.

This indicator should be calculated at the diagnosis phase to have a baseline for a comparative assessment after rehabilitation works. Thus, it should be obtained the impact of the project in the energy poverty of the district inhabitants.

It should be evaluated what percentage of the household's income is devoted to the energy bill costs or the percentage of percentage satisfied with the environmental quality of housing.

The household's income taken as a baseline (within diagnosis phase) should be used for the following calculations.

This formula must be used to calculate the energy poverty before and after rehabilitation works, within diagnosis and evaluation phases respectively.

$$Ep\ (\%) = \frac{Average\ annual\ energy\ bill\ cost * 100}{Average\ annual\ Rent} \qquad (2.48)$$

Average annual rent data acquisition is a subject of particular discussion. Whenever there is a minimum wage rate regulation for a certain country this minimum should be considered in order to present the most critical situation. Otherwise the average may be based on surveys or statistical data.

The comparative assessment or the impact of the project on energy poverty should be calculated as follows:

$$\text{IEp}\ (\%) = \text{Ep after works} - \text{Ep baseline} \qquad (2.49)$$

The impact on energy poverty has been defined for each scenario as the ratio between the annual average energy bill per dwelling, and the average annual wage per dwelling

$\text{IEp}\ (\%) = \text{Ep after works} - \text{Ep baseline}$from national statistical data. The average annual energy bill has been calculated as the sum of the natural gas bill and the electricity bill. Natural gas and Electricity cost have been calculated according to national statistical data. (Source:*TS911: The requirements of accessibility in buildings for people with disabilities and mobility constraints. TS 12576: Urban roads - Structural preventive and sign design criteria on accessibility in sidewalks and pedestrian crossings. TS 12460: Urban roads - Rail transport system - Design rules for restricted and elderly in facilities)*

2.1.5 Environmental index

2.1.5.1 Final energy consumption (ENV 1)

This indicator corresponds with the final usages of the energy for various areas of implementation within the building such as space cooling, space heating, electrical appliances and domestic water heating. They are also considered the auxiliary electricity consumption associated to the installations and lighting. The user dependant electricity consumption such as refrigerator are not taken into consideration. The energy demand relies on the measured aspects however the energy consumption depends on metered values. In order to enhance the compatibility among buildings, the overall energy demand is associated with the dimension of the building such as heated floor area or net floor area and the related time interval such as year.

The indicator will be used in order to assess the energy efficiency of the buildings in terms of the thermal quality of the building' envelope, the effectiveness of the cooling and heating systems, the electrical tools. Unit: kWh/ (m^2 yr)

The calculation method, according to CONCERTO is:

$$DEN_{I,t} = \frac{\sum_{i\in I} \; EN_{i,t} * Cap_i}{\sum_{i\in I} Cap_i} \tag{2.50}$$

$DEN_{I,t}$ = final energy consumption of group I of buildings considering annual data of year t [kWh/(m^2·yr)]

$EN_{i,t}$ = final energy consumption of building i considering annual data of year t [kWh/(m^2·yr)]

Cap_i = Floor area of building i [m^2]

According to that the final energy consumption has been evaluated using dynamic energy simulations and the subsystems efficiency values form national unified norms (BEP-Tr) and it describes a scenario characterized by a final energy demand.

2.1.5.2 Primary energy consumption (ENV2)

The primary energy consumption of a building includes the energy which is utilized within the supply chain and the final energy consumption. Hence, this indicator includes dissimilarities in the energetic effort in regards of the supply chain of various energy sources such as electricity vs natural gas. Unit: kWh/(m^2·yr)

The calculation method, according to CONCERTO is:

$$PEN_{I,t} = \frac{\sum_{ieI} \; PEN_{i,t} * Cap_i}{\sum_{ieI} Cap_i} \tag{2.51}$$

$PEN_{I,t}$ = Primary energy consumption of group of buildings considering yearly data of year t [kWh/(m^2·yr)]

$PEN_{i,t}$ = Primary energy consumption of building based on yearly data of year t [kWh/(m^2·yr)]

Cap_i = Floor area of building i [m^2]

Based on above formula this indicator has been evaluated using dynamic energy simulations and the primary energy conversion factor and it describes a scenario characterized by a Primary Energy Consumption. Turkey: *Turkish Building Energy Performance Regulation, 2008* (http://www.bep.gov.tr/)

2.1.5.3 Greenhouse gas emissions (ENV3)

The greenhouse effect of anthropogenic origin produced by emissions associated with human activities should be distinguished from the natural greenhouse effect, vital to all living beings on the planet. Human emissions of Green House Gas (GHG), such as carbon dioxide and methane increase the absorption of infrared radiation in the Earth's atmosphere, which leads to an increase in the temperature of the surface of the Earth.

The impact of a gas emitted can be expressed in terms of its potential of global warming or Global Warming Potential (GWP) in CO_2 equivalent emissions. Numeric indicator of the global warming potential is obtained from the weighted sum of the emitted mass of each pollutant multiplied by its characterization factor (GWP).

The greenhouse gas, particulate matter, NOx and SO_2 emissions of a building imply the emissions which are formed by various areas of application such as space cooling, space heating, electrical appliances, domestic hot water. Other calculations of this indicator the emissions by the manufacturing of the building elements are considered or not considered. In order to enhance the comparability between buildings, the emissions are connected to the dimension of the building such as heated floor area or gross floor area. and the specified interval such as year. The greenhouse gases are evaluated as t of CO_2 or CO_2 equivalents.

Material M corresponds to CO_2 or CO_2 equivalents (and as first approximation particulate matter, NOx, SO_2).

Calculation method:

Unit: t/(m^2·yr)

$$EM_{I,M,t} = \frac{\sum_{ieI} \; EM_{i,M,t} * Cap_i}{\sum_{ieI} Cap_i} \tag{2.52}$$

$EM_{I,M,t}$ = Emissions of material M by set I of buildings considering annual data of year t [t/(m^2·yr)]

$EM_{i,M,t}$ = Emissions of material M by building i considering annual data of year t [t/(m^2·a)]

$$EM_{i,M,t} = \frac{\sum_{EC} \sum_{AA=AA1}^{AA4} (In_{EC,AAi,t} * (EF_{EC,M,direct} + EF_{EC,M,indirect})) + Cap_i * EF_{[I],M}/EL_{[i]}}{Cap_i} \qquad (2.53)$$

$In_{EC,AAi,t}$ Input energy flow into building i for application area in year t concerning energy carrier source [kWh/yr]$EF_{EC,M,direct}$ Direct emission factor for energy carrier concerning material [t/ kWh]

$EF_{EC,M,indirect}$ Indirect emission factor for energy carrier concerning material M [t/ kWh]

$EL_{[i]}$ Expected lifetime of a building of the same type as i [yr]

$EF_{[I],M}$ (Indirect) emission factor concerning material M for construction of a building of the same type as i [t/m^2]

Cap_i = Floor area of building i [m^2]

The calculation method includes the assessment of a 50 year period, in order to include the different maintenance and replacement operations that a building suffers during its life time. After the calculation for the 50 years, the results have normalized to one year time period and 1 m^2 of conditioned area.

The systems boundaries and the stages included are:

Retrofitting actions- For each INT the retrofitting activities have been assessed, including materials and processes involved.

Maintenance operations- Including the maintenance and replacement of the items installed during the retrofitting stage. Thermal and electricity consumption has been obtained from the energy simulation e-Quest.

End of life- The end of life stage has been evaluated for the items involved in the retrofitting activities, always allocating the processes depending on the life period of each item and the life time period of the assessment.

2.1.5.4 Eco-efficiency of hybrid systems (ENV4)

This indicator is to evaluate the advantages of the combination of hybrid systems (passive and active) in the design of the buildings. It is based on the proposed Relative Carbon Burden Indicator, (Tucker et al., 2009). The calculation is associated to the different INT scenarios studied. The scenarios may be created from a mix of options related to the energy efficiency of building envelope, the local distributed generation systems (RES and low emission), and number and efficiency of domestic appliances.

The performance assessment should be done via an eco-efficiency metric that measures the economic and environmental (restricted to CO_2) expenditure of a certain arrangement of hybrid building operating within the context of a prescribed scenario:

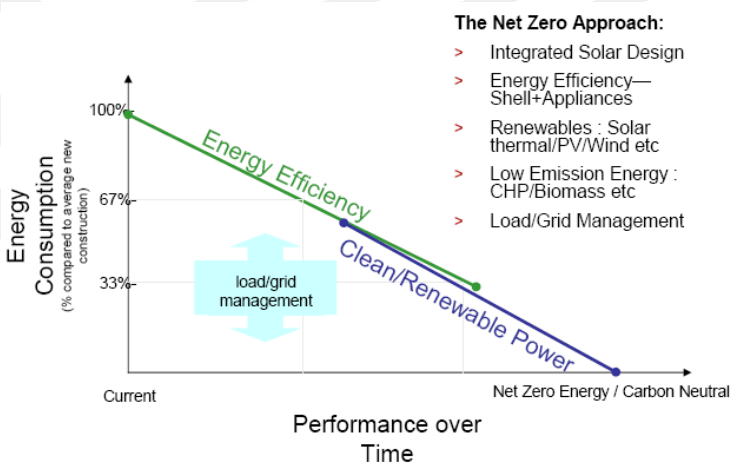


Figure 2.5 : Eco-efficiency of hybrid buildings (Source: Swinburne University of Technology).

Unit: €/t CO_2

$$\text{Eco} - \text{efficiency} = \frac{\text{Cost of hybrid building (or some components thereof)}}{\text{CO2 emissions (converted to a carbon cost)}} \qquad (2.54)$$

Cost of the hybrid building_ For each scenario, the costs of retrofitting, maintenance, thermal and electricity energy has been calculated according to the data available in the Economic index ECO 1 investment and the expected thermal and electricity costs per year depending on the source used.

CO2 emissions (converted to a carbon cost)- results coming from the previously described indicator ENV 3 GHG emissions results and introducing the national average conversion factor 7,27 €/t CO_2 (Source: Send Eco. Average value for 2015) in each case.

Finally, the indicator compared to the baseline, following next formula:

$$Comparative\ Evaluation\ of\ Eco-Efficiencies = \frac{Eco-efficiency\ of\ scenario\ X}{Eco-eficiency\ scenario\ baseline} \quad (2.55)$$

2.1.5.5 Ecological footprint (ENV5)

The ecological footprint concept introduced by Wackernagel and Rees is an analysis of the direct effects of urban development on the planet. It allows a true vision of sustainability that demonstrates the impact of urbanization on the finite capacity of the planet. The simple definition is terrestrial soil from which the city depends for its operation. The city needs to operate material and energy resources as well as a place to dispose of solid waste, liquid and gaseous. (Bettini, 1998; Rogers, 2001; Terradas, 2001). The soil every town used to meet these needs becomes a value of the ecological footprint.

The computation is performed in units of area (hectares) and may include locations that are far from the study area.Unit: Ha yr/m^2yr

$$\text{Ecological Footprint} = \text{urban soil for supplies} + \text{soil for Waste} \quad (2.56)$$

2.1.6 Urban index

2.1.6.1 Efficiency of the urban system (UR1)

This is a key indicator which pretends to achieve the maximum efficiency of the urban system, an efficient use of the resources with a minimum effect within the ecosystem.

The expression E/H is associated with the expression efficiency and urban sustainability guide since it considers two aspects important for it: the consumption of resources, streamlining supporting ecosystems and urban organization.

The current model is characterized by the increasing inefficiency: because resource consumption increases without growing urban organization.

The sustainable city model would reverse the process reducing resource consumption while increasing urban organization. The decline of the equation in time would be a guide for the sustainability of the city. The city is conceived with sustainability criteria articulates its organization in order to anticipate the future due to urban pressures on land systems. Thus, reducing consumption (E) is related models land use, urban planning, mobility, architecture and urban metabolism. Also important is the lifestyle, which is closely linked to the above mentioned.

The efficiency of the urban system (Ef) is calculated as follows:

$$E_f = E/H \tag{2.57}$$

$E = PEN + \ final\ energy\ consumption\ of\ the\ materials\ LCA\ analysis$)

$H = Urban\ complexity$ (the next indicator)

2.1.6.2 Urban complexity: Enterprises, civil organizations/associations (UR2)

focused on juridical persons: enterprises, institutions and associations. Those in turn established multivariate relationships between them, with varying degrees of expertise. With increasing urban complexity increases the diversity of juridical persons and the level of knowledge treasured. Thus, a greater number of activities thrive on the synergies that provide increasing complexity. Attracting investments also increases as increasing the economic capital and social capital.

This indicator is calculated as follows:

$$H = -\sum_{i=1}^{n} Pi\ log_2\ Pi\ (*) \tag{2.58}$$

The H value is a measure of the information in a message and is calculated using the formula from the Shannon Information Theory. H is the diversity and unity is the bit of information per individual. Pi is the probability of occurrence, indicates the number of members that meet a peculiarity in all community members. The maximum H is obtained with the maximum difference of their information and their maximum eq frequency. It is to know the number of information carriers, capable of contact, quantity and diversity in one place. Carriers of urban information system are legal entities classified by categories: economic activities, organizations and institutions, social capital and economic capital. Information needed is specified below:

- Identification of juridical persons: Two legal entities are different when one brings in relation to the other, some added value, any information that makes it different. The urban fabric is usually a specialization that makes the activity is maintained in space and time (economic activities, institutions, facilities and urban associations).
- Some countries have developed new classification system that encompasses economic activities, institutions, associations, etc. support corporate systems. Classification is divided into 6 levels with a pyramidal hierarchical manner where the numeric codes are integrated in the immediately preceding level.
- (*) Grid Reference (GRID 200 x 200 m cell width
- The number of enterprises, civil organizations/associations within the Grid reference must be defined from the census.

2.1.6.3 Impact on pedestrian public spaces (UR3)

This indicator is directly related with the surface for pedestrian mobility and available as living, leisure, exercise, exchange and other multiple uses for promoting social cohesion. It represents the space that ensures urban functionality and a new conception of the public space where other services uses are contemplated with speed limited to 10 km/h (transport and distribution services, emergency vehicles and residents) compatible with pedestrian and cyclist mobility and incompatible with the passing vehicle and public transport surfaces circulating peripheral channels.

By evaluating the results of this indicator it is estimated the impact of the actions to be performed under this project over the public spaces.

According to [REF] adopting spatial reference as the superblock on a GRID 400 x 400 m. it is contemplated that the percentage of public road for pedestrians and other uses of public space, including service roads with speed limit of 10 km h and stay spaces (parks, gardens, etc.) shall be at least 75%.

$$PPE = \left(\frac{\sum pedestrian\ ways\ and\ others\ uses\ (m2)}{total\ ways\ surface\ (m2)(*)}\right) X\ 100 \quad (*)\ reference\ grid \qquad (2.60)$$

2.1.6.4 Impact on transport (UR4)

The purpose of this indicator is to evaluate the percentage of public road for automobile traffic and public transport on surface. One of the challenges of urban development plans is the structuring of the road in superblocks to reinvent the public space from the rearrangement of surface mobility. In this way environmental parameters related stay spaces, noise, pollution and energy consumption are improved and new utilities and functions of public spaces are given. However, the calculation of this indicator in the context of thesis is intended to assess the impact of the project on the initial percentage of residents’ road for passing vehicles or public transport in the renovated district.On a grid of 400 x 400 m, estimate the % for automobile traffic and public transport on surface.

$$iT = \left(\frac{\sum motorized\ transport\ surface\ (m2)}{total\ road\ surface\ (m2)(*)} \right) X\ 100 \quad (*)\ reference\ grid \qquad (2.61)$$

All of the above sustainability indexes are calculated according to Concerto Indicator Guide (Concerto, 2012) The sustainability indexes are selected amongst above mentioned are listed in table 2.9 with their units.

Table 2.9 : Selected sustanability indexes.

Section		SI	Units
Energy Index	EN1	Density of final energy demand	kWh/m^{2}y
	EN2	Annual and maximum efficiency of energy sources	kWh/kWh
	EN3	Annual and Maximum and power of energy sources	kW/kW
	EN5	Maximum load of thermal energy demand	kW
	EN6	Level of consistency with national standards	%
	EN8	Level of energetic self-supply thermal	%
	EN9	Net fossil energy consumed	kWh/m^2
Economi Index	ECO1	Investments	€/m^2
	ECO3	Life cycle cost (20 years)	€/m^2
	ECO4	Life cycle payback period	year
	ECO5	Total annual revenues discounted annual revenues and annuity	€/year
	ECO6	Energy production costs	€/kWh
	ECO7	Internal rate of return	%.
	ECO8	Return of investment	%
	ECO9	Dynamic payback period	year
	ECO10	Accessed rents incl./excl. ancillary costs	€/m^{2}year
	ECO11	Acccessed rent increase (excl. ancillary costs)	€/m^{2}year
Comfort Index	CO1	Predicted Mean Vote	n.a.
	CO2	Predicted percentage of dissatisfied	%
	CO3	Comfort parameter average value	h/year
	CO4	Local thermal comfort	scale
	CO5	Percentage outside range	%

Table 2.10 (continued): Selected sustainability indexes.

Section		SI	Units
Social Index	CO6	Visual comfort	lux
	CO8	Indoor air quality	ppmCO
	SO11	Accessibility of users with physical impairments	n.a.
	SO12	Impact on energy poverty	%
Environmental Index	ENV1	Final energy consumption	kWh/m^{2}year
	ENV2	Primary energy consumption	kWh/m^{2}year
	ENV3	Greenhouse gas emissions	t/m^{2}year
	ENV4	Eco-efficiency of hybrid systems	%
	EN5	Ecological footprint	Ha/person
Urban Index	UR1	Impact of the refurbished district: efficiency of the urban system	n.a.
	UR2	Urban complexity: Enterprises, civil organizations/associations	%
	UR3	Impact on pedestrian public spaces	%
	UR4	Impact on transport	%

2.2 National and International Standards for Sustainability Indexes at District Scale

The sustainability indexes should be evaluated and categorized according to specific international and national standards to observe the benefits of the applied interventions. The corresponding values of sustainability indexes of 6th scenario, which is the accepted scenario and baseline cases are examined. The standards are chosen according to relevance with the indexes. The evaluation criteria for different standards varies in format such as lettering (A,B,C), intervals, percentage, below or upper limits, survey. Each considered standard for the indexes are stated below:

2.2.1 Standardization for energy indexes

- Standardization for the Indexes of EN1, EN5, EN9

BEP-TR can be defined as a document containing information on the energy requirements and energy consumption classification of the buildings as the minimum quality level, insulation properties and efficiency of heating/cooling systems.

The purpose of the BEP(Building Energy Performance) Regulation is to consider climatological conditions, the interior requirements, local circumstances and cost effectiveness to determine of calculation formulas to ensure the assessment of total energy utilization of a building, constitute classification framework in terms of energy and GHG emissions, specify minimum energy performance requirements for new and retrofitted buildings, evaluate the feasibility of renewable energy sources, management of cooling and heating systems, limitation of GHG emissions, specification of performance and implementation criteria in buildings and preservation of environment. The BEP Regulation is constituted with the use of related European Union Standards ASHRAE standards, and Turkish Standards. For the computation of reference building energy consumption calculation of the heating, cooling, lighting, ventilation, hot water loads are taken into consideration. In relation with that loads greenhouse gas emissions are determined.

For the comparison of the values on energy consumption per meter square and greenhouse gas emissions with the reference values, scenario 6 values are used to classify to building performance between A-G classes which is shown in table below.

Table 2.11 : BEP Classification Chart.

BEP -TR Buildings Classes Accordingto Energy Consumption	Scale	Unit
A	0-39	kWh/m^{2}y
B	40-79	kWh/m^{2}y
C	80-99	kWh/m^{2}y
D	100-119	kWh/m^{2}y
E	120-139	kWh/m^{2}y
F	140-174	kWh/m^{2}y
G	175-	kWh/m^{2}y

Calculation method:

$$Ep, EP = 100x(1 - (EPr - EPa)/EPr) \quad (2.60)$$

Where

EPr: energy performance of the reference building

Epa: energy performance of the actual building

Ep, EP: the comparison of energy performance value of the actual building to reference building

- Standardization for EN 6

Level of consistency with national standards especially suffice the boundary limits is essential for retrofitted and new buildings. Therefore, hundred percent accordance is expected for that index in BEP Standards.

- Standardization for EN 11

The classification for that index is based on the survey on experts and project participants. Temporal predictability and controllability of energy supply is determined according to the table 2.1

- Standardization for EN 12

The classification for that index is based on the survey on experts and project participants.

Visibility of technology is determined according to qualitative scale Table 2.2

2.2.2 Standardization for economic indexes

For investments (ECO1) in retrofitting and renovation projects, investments of 60 €/m^2 for minor renovation, 140 €/m^2 for moderate renovation and 330 €/m^2 for extensive renovation are determined to be necessary depending on the EU standards (Galgoczi, 2015).

In regards of life-cycle payback period (ECO4), 6 to 10 years are highly suggested depending on the Guidelines for Life Cycle Cost Analysis.

When the research comes to internal rate of return statistics, IRR (ECO 7) of 4.907% to a maximum of 12.980% is suggested for investments, which develop the buildings' quality (Bonazzi & Iotti, 2016).

In addition, an approximate of 47% of return of investment (ECO 8) is found be optimal considering couple of researches conducted (Tadeu et al., 2016).

Furthermore, 21 years of dynamic payback period (ECO 9) is encouraged depending on Life Cycle Cost & Benefit Analysis conducted by numerous researchers (Bleyl et al., 2017).

Achieved rent increase (ECO 11) is found to be 10.68% from years 2012 to 2013 in Turkey (blog.milliyet.com.tr, 2019).

2.2.3 Standardization for comfort indexes

- Standardization for CO1 and CO2

PPD (CO2) is calculated according to PMV(CO1) so that same classification method is used for that indicators according to EN 15521.

Table 2.12 : Comfort categories according to EN 15251.

comfort categories according to EN 15251	Classes
-0.7 to -0.5 and 0.5 to 0.7	C
-0,5 to -0,2 and 0.2 to 0.5	B
-0,2 to 0,2	A

- Standardization for CO3

Within EN 15251 there is a definition of acceptable time periods “out of comfort”. This time period is fixed to 24 minutes every 8 hours (considered working time during the day).

The classification shows a sample result of 2.86% in 24 hours’ time and 8.6% in 8 hours base time.

- Standardization for CO4

According to ISO 7730:2005 the classification is separated to 3 categories such as A,B,C. shown in Table 2.4

- Standardization for CO5

According to EN 15521 1.25% to 3.25% is acceptable for that index.

- Standardization for CO6

The Guideline of IES Standards Ilumunation level is taken into accout as shown in Table 2.5

- Standardization for CO8

For the “Indoor Air Quality”, ISO 15251 Standards are taken into account in the table 2.6

2.2.4 Standardization for Environmental Indexes

- Standardization for ENV1 and ENV 2

As shown for the standardization for EN1, for the comparison of the values on energy consumption per meter square and greenhouse gas emissions with the reference values, scenario 6 values are used to classify to building performance between A-G classes which is shown in table 2.10

Calculation method:

$$Ep, EP = 100x(1 - (EPr - EPa)/EPr) \qquad (2.62)$$

Where

EPr: energy performance of the reference building

Epa: energy performance of the actual building

Ep, EP: the comparison of energy performance value of the actual building to reference building

- Standardization for ENV3

The standardization of ENV3 is evaluated according to BEP Regulation which was identified in the section of the standardization of EN1 index.

$$Ep, SEG = 100x\left(1 - \frac{SEGr - SEGa}{SEGr}\right) \qquad (2.63)$$

EP, SEG: the comparison of greenhouse gas emission value of the actual building to reference building

SEGr: greenhouse gas emission of the reference building

SEGa: greenhouse gas emission of the actual building

- Standardization for ENV 5

Ecological footprint should be between 3.4 to 4.5 global hectares per person depending on European Environment Agency ("Ecological footprint of European countries", 2019).

2.2.5 Standardization for social and urban indexes

There is no national and international standardization or limit found for social and urban sustainability indexes.

2.3 Building Retrofitting Interventions, Scenario Details and Energy Consuming Parameters at Building Scale

There are eight building retrofitting interventions that are decided to be applied on three buildings. However, all of the interventions are not applied to all three buildings. All applied building retrofitting interventions are shown on the table 2.12 below:

Table 2.13 : Summary of main solutions for the buildings.

SOLUTION	CODE
Thermal insulation	INT1
Radiant heating	INT2
Solar thermal systems	INT3
Building appliances and lighting systems	INT4
Energy automation and monitoring system	INT5
Windows replacement	INT6
Application of water saving systems	INT7
Heat pump	INT8

Based on the energy model prepared to show the existing building energy performance, different scenarios are generated by the application of of above mentioned INT's in table 2.13. Those generated scenarios are explained in detail below:

- The First scenario takes into account envelope in terms of thermal insulation of exterior and underground wall INT1
- The Second scenario is more extended than first scenario which includes thermal insulation, window retrofit and solar thermal applications. INT1, INT3 and INT6
- The Third scenario consists of thermal insulation, window retrofit, solar thermal applications and LED lighting. INT1, INT3, INT4 and INT6
- The Fourth scenario combines heat pump with thermal insulation, window retrofit, and LED lighting. INT1, INT4, INT6 and INT8
- The Fifth scenario covers thermal insulation, window retrofit, LED lighting, heat pump and solar thermal system. INT1, INT3, INT4, INT6 and INT8
- Finally, the sixth scenario incorporates, thermal insulation, window retrofit, LED lighting, heat pump, solar thermal system, radiant heating, monitoring and automation and water saving system. INT1, INT2, INT3, INT4, INT5, INT6, INT7 and INT8

Table 2.13 represent the summary of scenarios and the energy savings achieved based on previous case, which has no intervention application.

Table 2.14 : Interventions of each scenario and savings for the building.

	INT1	INT2	INT3	INT4	INT5	INT6	INT7	INT8	Savings (%)
Scenario 1	•								10
Scenario 2	•		•			•			23
Scenario 3	•		•	•		•			34
Scenario 4	•			•		•		•	54
Scenario 5	•		•	•		•		•	57
Scenario 6	•	•	•	•	•	•	•	•	76

The energy consuming parameters that are taken into counted are listed below.

- Lighting
- Miscellaneous Equipment
- Space Heating
- Space Cooling
- Pumps
- Ventilation fan
- Domestic Hot Water

2.4 The Effects of Interventions on Energy Consuming Parameters at Building Scale

The effects of each intervention on energy consuming parameters are investigated and important points are determined. In addition, this section represents the numerical calculations of effects of interventions to the energy consuming parameters.

The purpose of this part is to exhibit the effects of interventions negatively or positively that improve the energy performance of the building. Recalling that, there are 6 different scenarios which are composed of various combinations of 8 interventions such as thermal insulation, radiant heating, solar thermal systems, LED lighting with sensors, energy automation and monitoring system, windows replacement, application of water saving systems and heat pump, affecting 7 energy consuming parameters such as lights, misc. equipment, space heating, space cooling, pumps, ventilation fan and domestic hot water.

Based on the result of the most effective scenario explained in case study section, the individual effects of interventions and their effect to the total energy consumption is calculated. 2 interventions, such as radiant heating and water saving appliances are negligible in terms of energy consuming parameters.

2.5 The Methodology for the Effect of Applied Interventions on Sustainability Indexes at District Scale

The effects of interventions on sustainability indexes are weeded out from the 6 scenarios to observe individual effect of each scenario. Therefore, a Choice-Based Conjoint Analysis (CBC), which is a preference study, is used to analyze the discussed values. Conjoint Analysis may be benefited in order to examine the information concerning its relating components considering the products' qualitative properties. For each property's levels, a qualitative part-worth benefit value is calculated and is described in a correlation (Kuhfeld, 2005). This methodology has also been used in order to analyze the housing choices of elderly for their retirement (Choong & Cham, 2015). Part-worth benefits are considered in order to examine the preferences' relative strengths. Positive and negative values for each property's levels exist in the analysis. The calculations for each level contributes differently to the total utility, which emphasizes the difference among importance of each level and if a level contributes more than another one to the total utility, that level is found to be more preferred (Low et al., 2013; Choong & Cham, 2015).

2.6 Cross Effects of Selected Sustainability Indexes at District Scale

R Studio is a software that is used for calculation, graphics and statistical computation. It enables a programming language, high level graphics and complex calculations, interfaces to other software programs and used for debugging of datas. In this thesis, R Studio is used to measure the cross effects of sustainability indicators. Specifically, R Studio is used to measure how much one percentage change of one index alters the other index by percentage. For instance, change in life cycle cost is determined when density of final energy demand changes by one percent (RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/).

Regarding the application of R-Studio in the thesis, the purpose is to analyse the effect of one sustainability index onto another index by the usage of statistically appropriate equations. Initially, excel sheet that contains values of two predetermined crossed indexes for baseline case and six scenario is imported into R Studio. Specifically, the "x" values in the excel sheet represent sample values of the effector index. The "y" values in the excel sheet represent the corresponding sample data of the affected index. Secondly, logarithm is calculated for the 'y' values; the reason of the application of logarithm for the 'y' values is to indicate percent change in a more concise way by eliminating the confusion that can be born from the usage of large values. Thirdly, the sample data from 'x' and 'y' values from the excel sheet, which is under the same scenario is matched for two compared indexes to construct statistically meaningful cross-effect relationship. Furthermore, in order to avoid non linearity, linear regression method is used such as lm(y ~ x) which means adjusting a linear model with y as a response and x as a predictor. Moreover, through the recalling of the general formula of lny= a + bx, in the resulting "coefficients": 'intercept' part refers to "a" and the "x"value refers to "b". Lastly, when the derivation of both sides are taken, e^b gives the percentage unit change for the affected index when one percentage unit change is conducted for the affector.

The compared indexes are matched as below:

- Density of final energy demand vs life cycle cost
- Energy production costs vs impact on energy poverty
- Density of final energy consumption vs dynamic payback period
- Net fossil energy consumed vs internal rate of return
- Greenhouse gas emissions vs degree of energetic self-supply

➢ EN1(Density of final energy demand) vs ECO3 (Life cycle cost)

- Data prepared from excel is imported into R Studio Software

The process is listed as below

- The values are checked if they are properly imported into the software.
- Natural logarithm of the affected values (y values) is taken to simplify the res ults for easier comparison. The ratio of the change between scenarios are the important factor. Below are the results of the natural logarithm (ln) of the above column for y values in table 2.15.

[1] 6.575076 [2] 6.642487 [3] 6.601230 [4] 6.289716 [5] 6.291569 [6] 6.280396 [7] 6.244167

- In order to avoid non linearity, linear regression method is used such as lm(y ~ x) which means adjusting a linear model with y as a response and x as a predictor. > regresyon<-lm(y~x)
- This expression in R Studio leads to that general formula lny= a + bx where, b =-0.8421578 and a= 6.038132
- When all values are positioned in the equation. lny= 6.038132 + -0.8421578x
- Hence, e^(-0.8421578)=0.43 This result shows that one percantage change in EN1 leads to 0.43 percentage change in ECO3.

Table 2.15 : EN1 – ECO3 Scenario Results

	EN1(x)	ECO3(y)
Baseline	209.71	717
Scenario 1	185.08	767
Scenario 2	153.06	736
Scenario 3	134.46	539
Scenario 4	83.77	540
Scenario 5	80.75	534
Scenario 6	73.82	515

- ECO6(Energy production costs) SO12(Impact on energy poverty)

There are different elements that effect the rent costs of the buildings such as age, heating costs, security, location, distance to transportation, connection to public areas (hospitals, schools, shopping centers, etc.). Based on that, the energy poverty in case of high energy consumption because of poor insulation or inefficient heating systems decreases the rent costs of the buildings.

- Data prepared from excel is imported into R Studio Software.

Table 2.16 : ECO6 – S012 Scenario Results

	ECO6(x)	SO12(y)
Baseline	0.044	101
Scenario 1	0.044	95
Scenario 2	0.041	86
Scenario 3	0.015	54
Scenario 4	0.026	74
Scenario 5	0.024	73
Scenario 6	0.013	65

The process is listed as below

- The values are checked if they are properly imported into the software.
- Natural logarithm of the affected values (y values) is taken to simplify the results for easier comparison. The ratio of the change between scenarios are the important factor. Below are the results of the natural logarithm (ln) of the above column for y values in table 2.16.
  [1] 4.615121 [2] 4.553877 [3] 4.454347 [4] 3.988984 [5] 4.304065 [6] 4.290459 [7] 4.174387
- In order to avoid non linearity, linear regression method is used such as lm(y ~ x) which means adjusting a linear model with y as a response and x as a predictor. > regresyon<-lm(y~x)
- This expression in R Studio leads to that general formula lny= a + bx where, a =3.884 and b= -0.6931
- When all values are positioned in the equation. lny= 3.884 + -0.6931x
- Hence, e^(-0.6931)= 0.5002 This result shows that one percantage change in ECO6 leads to 0.5002 percentage change in SO12.

➢ ENV1(Density of final energy consumption) vs ECO9 (Dynamic payback period)

The investment for the retrofitting of the buildings aims to be beneficial in the following years by decreasing the maintanence cost of the building in terms of energy consumption by decreasing heating, cooling and electricity costs.

- Data prepared from excel is imported into R Studio Software.

Table 2.17 : ENV1 – ECO9 Scenario Results

	ENV1(x)	ECO9(y)
Baseline	629.14	0
Scenario 1	555.25	219.3
Scenario 2	459.18	32.9
Scenario 3	403.37	14
Scenario 4	354.39	15.7
Scenario 5	345.34	15.7
Scenario 6	324.55	17

The process is listed as below

- The values are checked if they are properly imported into the software.
- Natural logarithm of the affected values (y values) is taken to simplify the res ults for easier comparison. The ratio of the change between scenarios are the important factor. Below are the results of the natural logarithm (ln) of the above column for y values in table 2.17.

  [1] -Inf [2] 5.390441 [3] 3.493473 [4] 2.639057 [5] 2.753661 [6] 2.753661

  [7] 2.833213

- In order to avoid non linearity, linear regression method is used such as lm(y ~ x) which means adjusting a linear model with y as a response and x as a predictor. > regresyon<-lm(y~x)
- This expression in R Studio leads to that general formula lny= a + bx where, a=0.2531 and b= 0.6097
- When all values are positioned in the equation. lny= 0.2531 + 0. 0.6097 x
- Hence, e^(0.6097)= 1.84 This result shows that one percantage change in EN V1 leads to 1.84 percentage change in ECO9.

➢ EN9(Net fossil energy consumed) vs ECO7(Internal rate of return)

In the scope of retrofitting net fossil energy consumption is intended to be substitute with renewable energy sources such as heat pumps and solar thermal systems and more efficient usage of energy such as insulation and led lighting.

- Data prepared from excel is imported into R Studio Software.

Table 2.18 : EN9 – ECO7 Scenario Results

	EN9(x)	ECO7(y)
Scenario 1	555.25	2.39
Scenario 2	358.09	10.42
Scenario 3	294.45	19.13
Scenario 4	124.89	17.72
Scenario 5	111.99	17.78
Scenario 6	103.23	16.83

The process is listed as below

- The values are checked if they are properly imported into the software.
- Natural logarithm of the affected values (y values) is taken to simplify the res ults for easier comparison. The ratio of the change between scenarios are the important factor. Below are the results of the natural logarithm (ln) of the above column for y values in table 2.18.

  [1] 0.8712934 [2] 2.3437270 [3] 2.9512578 [4] 2.8746939 [5] 2.8780742 [6] 2.8231630
- In order to avoid non linearity, linear regression method is used such as lm(y ~ x) which means adjusting a linear model with y as a response and x as a predictor. > regresyon<-lm(y~x)
- This expression in R Studio leads to that general formula lny= a + bx where, a=3.469375 and b= 0.0525924
- When all values are positioned in the equation. lny= 3.469375 + 0.0525924 x
- Hence, e^(0.0525924)= 1.054 This result shows that one percantage change i n EN9 leads to 1.054 percentage change in ECO7.

➢ ENV3(Greenhouse gas emissions) vs EN8(Degree of energetic self-supply)

Degree of energetic self supply is related with conservation of energy and renewable energy sources which decreases the primary energy consumption in terms of the costs for transportation of energy to the buildings and production of net fossil energy.

- Data prepared from excel is imported into R Studio Software.

Table 2.19 : ENV3 – EN8 Scenario Results

	ENV3(x)	EN8(y)
Scenario 2	0.1323	36.83
Scenario 3	0.0975	36.44
Scenario 4	0.1083	62.08
Scenario 5	0.1038	66.15
Scenario 6	0.0935	64.94

The process is listed as below

- The values are checked if they are properly imported into the software.
- Natural logarithm of the affected values (y values) is taken to simplify the res ults for easier comparison. The ratio of the change between scenarios are the important factor. Below are the results of the natural logarithm (ln) of the

above column for y values in table 2.19.

[1] 3.606313 [2] 3.595667 [3] 4.128424 [4] 4.191925 [5] 4.173464

- In order to avoid non linearity, linear regression method is used such as lm(y ~ x) which means adjusting a linear model with y as a response and x as a predictor. > regresyon<-lm(y~x)
- This expression in R Studio leads to that general formula lny= a + bx where, a= 4.968 and b= 0.920282
- When all values are positioned in the equation. lny= 4.968 + -0.928869 x
- Hence, e^(0.920282)= 2.51 This result shows that one percantage change in ENV3 leads to 2.51 percentage change in EN8.

3. CASE STUDY

3.1 General Overview and Climate Condition for the Buildings

The selected buildings are located at Yakacik district of Kartal. The building is a residential building constructed at 2005. The building appears as single concrete blocks and has 8 stories. The Building is located in southeast of Istanbul metropolitan area in Kartal District. The total area of retrofitting is 18.813 m^2. It had very poor external wall insulation. Poor external wall insulation represents the main problem related to energy losses. The building is equipped with poor quality building systems especially in lighting applications and domestic hot water production. (Sözer et al. Article in Press) Therefore, energy efficiency strategies were set accordingly. Figure 3.1 shows the front view and the location of the building in Turkey.

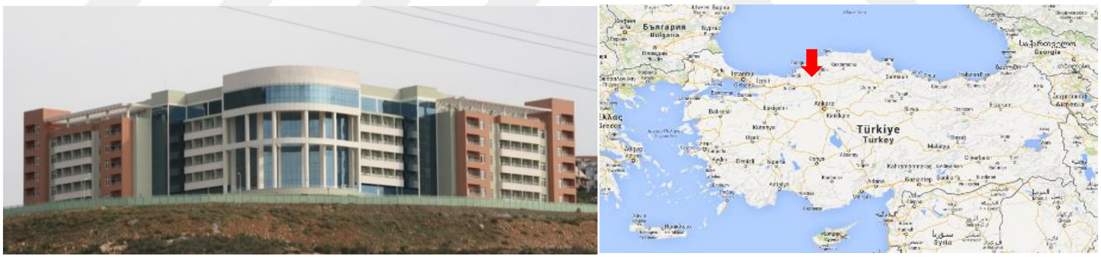


Figure 3.1 : The front view of the building 1 and the location of the buildings.

Figure 3.2 : Location of the 3 buildings.

Table 3.1 shows the monthly temperature and precipitation data for Kartal. Minimum, maximum and average temperature is given both in Celsius units and precipitation is given in mm units. The amount of difference in precipitation between the wettest and

Figure 3.3 : External view of 3 buildings.

Table 3.1 : Monthly temperature and precipitation data for Kartal District of Istanbul.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg Tempreature (Cº)	6.3	6.8	8.1	12.5	16.9	21.4	23.9	23.8	20.6	16	12.2	8.7
Min Tempreature (Cº)	3.3	3.7	4.4	8	12	16.2	18.6	18.8	15.8	12.1	8.7	5.7
Max Tempreature (Cº)	9.3	9.9	11.8	17	21.9	26.6	29.2	28.8	25.4	20	15.7	11.7
Precipitation/Rainfall (mm)	99	67	65	50	33	25	22	31	47	73	87	117

driest month of the year is 95 mm. The average temperature during the year varies nearly17.6 C degrees. July is the hottest month of the year with an average temperature of 23.9 degree Celsius and the lowest average temperature in the year is January with 6.3 degree Celsius. With 22 mm of precipitation, driest month is July. The average rainfall is observed in December with an average of 117 mm rainfall. (TSMS, 2017)

3.2 Features of the Building Prior to the Interventions

The envelope in terms of window type and wall insulation, mechanical systems for heating and cooling purposes and electrical properties related with lighting and fire protection system of the building is mentioned below.

3.2.1 Building envelope

The walls of the building own two different properties:

- Exterior walls of the residence rooms are insulated with 5 cm low density expanded polystyrene (EPS), which is a low density insulation material;
- Exterior walls of the common areas do not have thermal insulation.

Buildings has a pitched roof with asphalt mixed water insulation and EPS insulation. Various kind of windows such as glass and window frame related with the location of the building. Residential rooms contain double glazed windows with aluminum frame work and public spaces have double glazed windows with vinyl frame. Curtains are used in residential rooms for preservation from excessive sunlight and heat intake while protecting the privacy of the residents.

3.2.2 Mechanical systems

Two-pipe fan-coil systems are used to heat and cool the spaces in the entire building. Additively to these elements, air handling units are used for space heating, space cooling and ventilation in the restaurant, swimming pool and the conference room.

3.2.3 Electrical systems

Fluorescence lamps are used in public areas while incandescent lamps are placed in bedrooms. Electrical boards and fire protection sensors are located on each part.

3.3 Intended Purpose of Interventions

3.3.1 INT1: Thermal insulation

The purpose of this intervention is to decrease building heat loss with integration of new insulation material. In order to investigate façade insulation alternatives, different U values with different insulation materials have being analyzed respectively. Considering exterior wall, three U values are examined in addition to this, in respect to soil contact wall, one alternative is considered. Changes in energy consumption of the building were compared by employing different U values.

3.3.2 INT 2: Radiant heating

The aim of this intervention is to reduce space heating consumption with a novel and energy saving system while enhancing the comfort level of indoor spaces.

3.3.3 INT 3: Solar thermal systems

Main advantage of this intervention is taking advantage of solar energy free resource. Solar thermal systems harvest the sun’s thermal energy in order to generate domestic hot water. Basically, the systems that will be considered for Kartal demo site consist of flat plate solar collectors.

3.3.4 INT 4: Building lighting systems

The concern of this intervention is to decrease energy consumption of lighting system with integration of LED lighting and sensor technology. First, halogen lamps are changed with LED lighting appliances and then sensors are placed accordingly.

3.3.5 INT 5: Monitoring and automation system

The function of this intervention is reducing energy consumption of the building with integration of automation and energy monitoring system by observing deficient points.

3.3.6 INT 6: Windows replacement

The importance of this intervention is to reduce the building's heat loss with integration of double glazed and lower U-value window. In the baseline case, building 1 has windows with specifications of 3.4 W/m^2 K U-value. However, with this scenario U value will be changed to 1.2 W/m^2 K by application of better specified windows. Additionally, shading coefficient and solar transmittance values will be 0.29 and 0.58 respectively. INT6 will be considered as the renovation of all windows.

3.3.7 INT 7: Application of water saving systems

The goal of this intervention is to decrease water utilization with water efficient equipment; rainwater reuse system and grey water reuse system to save water and more energy.

3.3.8 INT 8: Ground source heat pump

The target of this intervention is to decrease heating and cooling consumption with integration of a trending system is called heat pump.

3.4 Summary of Individual Interventions

8 applications have been developed according to the needs of 3 buildings. In Kartal Demo Site, building 1 is large scale nursing home building and other two buildings are small-scale residential apartments. Different types of alternatives have been taken into consideration. For Building 1, six options have been developed. However, for Building Type 2 only first two scenarios (insulation and solar thermal system renovation) and for Building Type 3, only first three scenarios (insulation, solar thermal renovation and LED lighting) have been evaluated. Most obvious finding to emerge from this study is that reducing energy consumption of all buildings up to 76%.

Concerning insulation of the building envelope, analysis results have shown that energy efficiency is provided with a lower U-value. With regard to the results, U value = 0.327 W/m^{2}K is accepted for exterior wall with respect to its lower U-value in Building 1. Also, U value = 0.482 W/m^{2}K is accepted for underground wall. INT1 is selected for all Building types (1, 2 & 3) in Kartal. For Building Type 2 & 3; U value of insulated wall is calculated as 0.42 W/m^{2}K based on the physical conditions of exterior wall.

With respect to radiant heating, INT2 is applied due to its energy savings potential for the heating system compared to the existing condition. Radiant heating system is applied to Building 1.

Considering solar thermal system, INT3, is applied due to simulation results. Simulations have indicated that integration of solar thermal system is helpful for Istanbul climate by the means of generating DHW. Solar thermal systems for DHW needs will be applied to all building types 1, 2 and 3 in Kartal Demo Site.

Concerning lighting system, INT4 which is LED lighting with sensor is applied according to its energy efficiency capacity for electricity consumption. INT4 is implemented for Building Type 1 and 3 for application.

Automation and monitoring system, INT5 is applied in Building Type 1 on the basis of its energy savings ratios by tracking the issues in the system instantaneously to apply the solution on time.

Considering glazing, INT6 is applied which leads to all windows replacement in Building Type 1.

With respect to water saving system, INT 7 is implemented on the basis of its energy saving potential compared to existing condition which includes grey water reuse, rain water reuse and installation of water efficient equipment. INT7 is considered in Building Type 1 in Kartal.

Concerning heat pump, ground source heat pumps are accepted in Building Type 1.

3.5 Building Energy Simulation

Energy analysis of the 18,000 m^2 building is figured out in dynamic simulation modelling software called eQuest for 365 days and 8760 hours per year. All considerations that have impacts on heating cooling, electricity demands were modelled in detail to get certain results for energy consumption. Building shape, climatic components, building orientation, heating ventilating and air conditioning elements, interior constituents, management preferences and schedules were identified in eQuest. Properties of explained elements were evaluated depend on the real situation of the buildings. It must be emphasized that system configuration in the building is not just for choosing the accurate system, but also for confirming the system consistencies.

With suitable systems and proper optimizations, buildings' energy concept; as a result, energy consumption of the district is enhanced. By the summation of the data mentioned above 7,760.815 kWh energy consumption per year is calculated by eQuest.

Table 3.2 shows the changes caused by interventions in kWh units. Table 3.3 indicates the percentage effects of each scenario to the energy savings by the addition of different INTs which brings the solution that INT2 (radiant heating) and INT7 (Application of water saving systems) has positive effects on energy saving but when considered with other interventions, the effects of these two building retrofitting interventions on energy performance of the buildings and sustainability indexes are neglected for this study.

Scenario 6 is chosen as seen in the table 3.3, it decreases the energy consumption most. It includes LED lighting, exterior and underground wall insulation, all window changes, automation and monitoring, ground sourced heat pumps, radiant heating and water saving appliances.

Table 3.2 : Energy demand of scenarios for energy consuming parameters Kartal-Yakacik (kWh/year).

	Energy demand (kWh/year)						
	Base case	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Lighting	1,335,877	1,335,877	1,335,877	287,213	287,213	287,213	287,213
Misc. Equip	449,102	449,102	449,102	449,102	449,102	449,102	404,192
Space Heating	3,674,672	2,950,762	2,465,705	2,958,111	1,354,815	1,354,815	352,015
Space Cooling	904,417	921,601	701,828	436,537	271,526	271,526	155,56
Pumps	308,252	285,442	190,5	174,471	174,471	174,471	54,252
Ventilation fan	456,81	447,674	407,018	399,252	399,252	399,252	193,687
DHW	631,685	628,527	418,807	423,229	632,949	423,229	423,229
Total	7,760,815	7,018,985	5,975,828	5,122,138	3,569,975	3,337,150	1,862,596

Table 3. 3: Energy demand of scenarios for energy consuming parameters Kartal-Yakacik (%).

	Energy savings (%)					
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Lights	0	0	78.5	78.5	78.5	78.5
Misc. Equip	0	0	0	0	0	10
Space Heating	43665	32.9	43604	54.2	54.2	88.1
Space Cooling	-1.9	43577	37.8	37.8	37.8	82.8
Pumps	43562	38.2	43.4	43.4	43.4	82.4
Ventilation fan	2	43718	43628	43628	43628	57.6
DHW	0.5	33.7	33	-0.2	33	33
Total	10	23	34	54	57	76

4.RESULTS

4.1 Calculated Sustanability Indexes for Kartal Demo site at District Scale

The results of district scale of sustainability indexes are shown in table 4.1. The codes, description, unit, value and scenario equivalent value is included in the below table 4.1. Specific indexes under the topic energy, economy, comfort, social, environmental and urban are calculated according to methods and formulas described in section 2.1. As seen in the table interventions which are embedded in scenarios might have remarkable effects on sustainability indicators such as scenario 6 has a positive impact on the reduction of green house gas emissions nearly 50%. On the other hand, scenario 6 has no effect on achieved rent increase. Not all of the indicators which appear in the section 2.1. are calculated because of the lack of available data. On the other hand, some indicator results aren't included in table 4.1. because of the privacy of the project of R2cities and the residents.

Table 4.1 : Calculation Results of Indexes According to Scenarios

Section		SI	Units	Base Line	SCENARIOS					
					1	2	3	4	5	6
Energy Index	EN1	Density of final energy consumption	kWh/m²y	210	185	153	134	84	81	74
	EN2	Maximum and annual/monthly efficiency of energy supply units	kWh/kWh	0.85	0.85	0.85	0.85	4.95	4.95	2.97
	EN3	Maximum and annual/monthly power of energy supply units	kW/kW	0.85	0.85	0.85	0.85	0.91	0.91	0.91
	EN5	Peak load of thermal energy demand	kW	1,955	1,618	1,499	2,056	255	184	180
	EN6	Degree of accordance with national laws and standards	%	67	88	113	136	166	170	180
	EN8	Degree of energetic self-supply thermal	%	0	0	37	36	62	66	65
	EN9	Net fossil energy consumed	kWh/m²	629	555	358	294	125	112	103
Economy Index	ECO1	Investments	€/m²	0	36,83	63	83	97	100	125
	ECO3	Life cycle cost (20 years)	€/m²	717	767	736	539	540	534	515
	ECO4	Life cycle payback period	year	0	31.02	13.63	7.33	8.07	8.04	8.59
	ECO5	Total annual revenues discounted annual revenues and annuity	€/year	0	5	55	167	174	181	207
	ECO6	Energy production costs	€/kWh	0.04	0.04	0.04	0.02	0.03	0.02	0.01

Table 4.2 (continued): Calculation Results of Indexes According to Scenarios

Section	SI		Units	Base Line	SCENARIOS 1	2	3	4	5	6
Economy Index	ECO7	Internal rate of return	%.	0.0	2.4	10.4	19.1	17.7	17.8	16.8
	ECO8	Return of investment	%	0	-111.5	-8.2	98.4	124.3	125.5	105.5
	ECO9	Dynamic payback period	year	0	219.3	32.9	14	15.7	15.7	17
	ECO10	Achieved rents incl./excl. ancillary costs	€/m^{2}year	56.9	56.9	56.9	56.9	56.9	56.9	56.9
	ECO11	Achieved rent increase (excl. ancillary costs)	€/m^{2}year	10.7	10.7	10.7	10.7	10.7	10.7	10.7
Comfort Index	CO1	Predicted Mean Vote	n.a.	-0.8	-0.5	-0.5	-0.7	-0.7	-0.7	-0.7
	CO2	Predicted percentage of dissatisfied	%	17.7	11.5	11.4	14.9	14.9	14.9	14.9
	CO3	Comfort parameter average value	h/year	520	319	242	301	301	301	301
	CO4	Local thermal comfort	scale	C	B	B	C	C	C	C
	CO5	Percentage outside range	%	5.19	3.18	2.41	3.01	3.01	3.01	3.01
	CO6	Visual comfort	lux	472	472	472	619	619	619	619
	CO8	Indoor air quality	ppmCO	426	426	426	426	426	426	426
Social	SO11	Accessibility of users with physical impairments	n.a.	83	83	83	83	83	83	83
	SO12	Impact on energy poverty	%	101	95	86	54	74	73	65
Environmental Index	ENV1	Final energy demand and consumption	kWh/m^{2}year	629	555	459	403	354	345	325
	ENV2	Primary energy demand and consumption	kWh/m^{2}year	1116	1016	924	541	517	496	431
	ENV3	Greenhouse gas emissions	t/m^{2}year	0.17	0.15	0.13	0.1	0.11	0.1	0.09
	ENV4	Eco-efficiency of hybrid systems	%	0	34	102	196	153	184	228
	EN5	Ecological footprint	Ha*year/ m2y	0.02	0.02	0.02	0.01	0.02	0.02	0.02
Urban Index	UR1	Impact of the refurbished district: efficiency of the urban system	n.a.	9,392	8,546	7,769	4,547	4,350	4,174	3,622
	UR2	Urban complexity: Enterprises, civil organizations/associations	%	4.8	4.8	4.8	4.8	4.8	4.8	4.8
	UR3	Impact on pedestrian public spaces	%	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	UR4	Impact on transport	%	11.7	11.7	11.7	11.7	11.7	11.7	11.7

4.2 Results of the Classification of Sustainability Indexes at District Scale

The standards are determined in the section of 2.2 according to national and international norms. According to scenario 6, the scores are shown in table 4.2. The colours which are used to make the sustainability indicators to speak the same language, show the intervals for the standards. Therefore, in table 4.2. the achivements after interventions are indicated in the scope of standards.

Table 4.3 : Classification of Sustainability Indicators according to relevant standards.

Section	SI	Units	Result According to Standard
EN1	Density of final energy consumption	kWh/m^2y	A
EN5	Peak load of thermal energy demand	kW	A
EN6	Degree of accordance with national laws and standards	%	A
EN9	Net fossil energy consumed	kWh/m^2	A
EN11	Temporal predictability and controllability of energy supply	n.a.	2
EN12	Visibility of technology	n.a.	2
ECO1	Investments	$€/m^2$	moderate
ECO4	Life cycle payback period	year	acceptable
ECO7	Internal rate of return	%.	beneficient
ECO8	Return of investment	%	beneficient
ECO9	Dynamic payback period	year	beneficient
ECO11	Achieved rent increase (excl. ancillary costs)	$€/m^2year$	acceptable
CO1	Predicted Mean Vote	n.a.	C
CO2	Predicted percentage of dissatisfied	%	C
CO3	Comfort parameter average value	h/year	acceptable
CO4	Local thermal comfort	scale	C
CO5	Percentage outside range	%	acceptable
CO6	Visual comfort	lux	very good
CO8	Indoor air quality	ppmCO	acceptable
ENV1	Final energy demand and consumption	kWh/m^2year	B
ENV2	Primary energy demand and consumption	kWh/m^2year	A
ENV3	Greenhouse gas emissions	t/m^2year	B
ENV5	Ecological footprint	Ha/person	very good

4.3 The Effects of Building Retrofitting Interventions on Energy Consuming Parameters at Building Scale

Building retrofitting interventions such as thermal insulation, window change, LED (Light Emitting Diode) lighting, heat pump, solar thermal panels, automation &

monitoring systems, application of water saving systems and radiant heating have remarkable effects on energy consuming parameters such as lighting, miscellaneous equipment, space heating, space cooling, pumps, ventilation fan, domestic hot water. The methodology for that section is indicated in section 2.4.

4.3.1 Thermal insulation

4.3.1.1 Exterior wall insulation

In exterior wall insulation, the exterior wall of the building facade is covered with better insulating material called EPS. The old exterior wall U value was 0.6 W/m^{2}K. After the intervention the U value is decreased to 0.223 W/m^{2}K.

Table 4.3 shows that exterior wall insulation has no effect on lighting, miscellaneous equipment and domestic hot water parameters. However, it leads to dramatically decrease on space heating energy consumption and minor effects on space cooling, pumps, ventilation fan parameters. In other words, by preventing the heat loss to the outside of the building, exterior wall insulation provides 393,190 kWh and 10.7% energy saving for space heating.

This intervention has very little negative effect on space cooling. Better insulation hardens the air transfer through walls, it increases space cooling consumption by 0.9% 8140 kWh which is negligible when the total consumption of 904.417 kWh is considered.

On the other hand, exterior wall insulation decreased the pumps electricity consumption by 4.3% with an energy saving of 13255 kWh. For the ventilation fan, 5482 kWh energy saving occurs with the percentage of 1.2%. Figure 4.1 shows the level of effect that exterior wall insulation cause on energy consuming parameters.

Table 4.4 : Individual effect of exterior wall insulation on energy consuming parameters

Intervention/ Energy Consuming Parameters	Lights	Misc. Equip.	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water
Exterior Wall Insulation (U Value:0.223W/m2K)	0%	0%	10,70%	%-0,9%	4,30%	1,20%	0%

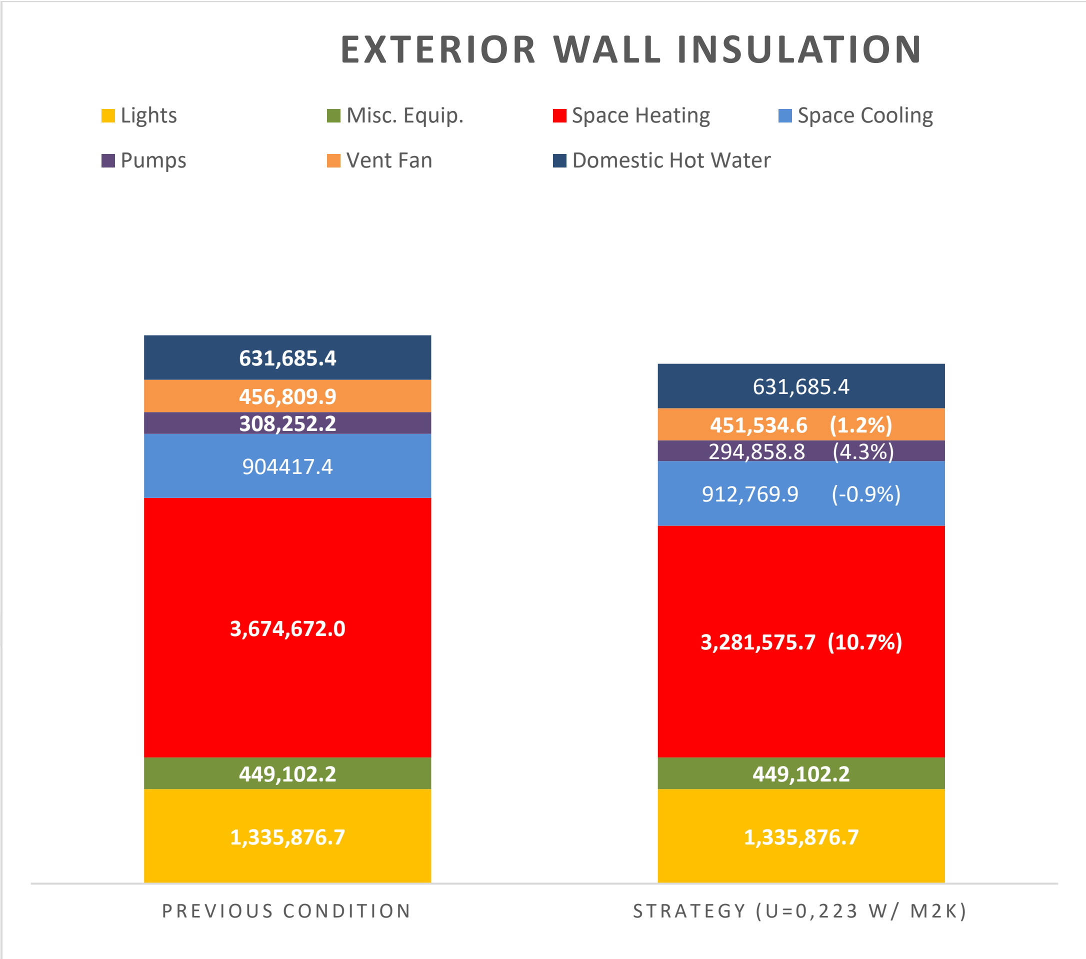


Figure 4.1 : Exterior wall insulation effect on energy consuming parameters.

4.3.1.2 Underground wall insulation

Underground Wall Insulation level in terms of U value is enhanced from 0.959 W/m^{2}K to 0.482 W/m^{2}K. Table 4.4 shows that this intervention has no effect on lighting, miscellaneous equipment. It leads to a sharp decrease on space heating values. By preventing the heat loss from ground floor, the energy saving in terms of natural gas is calculated as 330.720 kWh which is 9 % of total space heating consumption. It increases space cooling slightly because in summer time the ground is colder than atmosphere so that by decreasing heat transfer rate from ground floor, this intervention increases the consumption as 9.044 kWh which is 1 percent of total space cooling consumption. In addition, the pumps consumption is decreased by 3.1 percent which equals to 9.556 kWh. The percentage effect of this intervention to ventilation fan is 0.8 % which brings 3654 kWh gain. 0.5 percent gain from domestic hot water leads to 3.158 kWh energy saving. Figure 4.2 shows the level of effect that underground wall Insulation cause on energy consuming parameters.

Table 4.5 : Individual effect of underground wall insulation on energy consuming parameters.

Interventions/ Energy Consuming Parameters	Lights	Misc. Equip.	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water
Underground Wall Insulation (U value: 0.482 W/m^{2}K)	0	0	9	-1	3,1	0,8	0,5

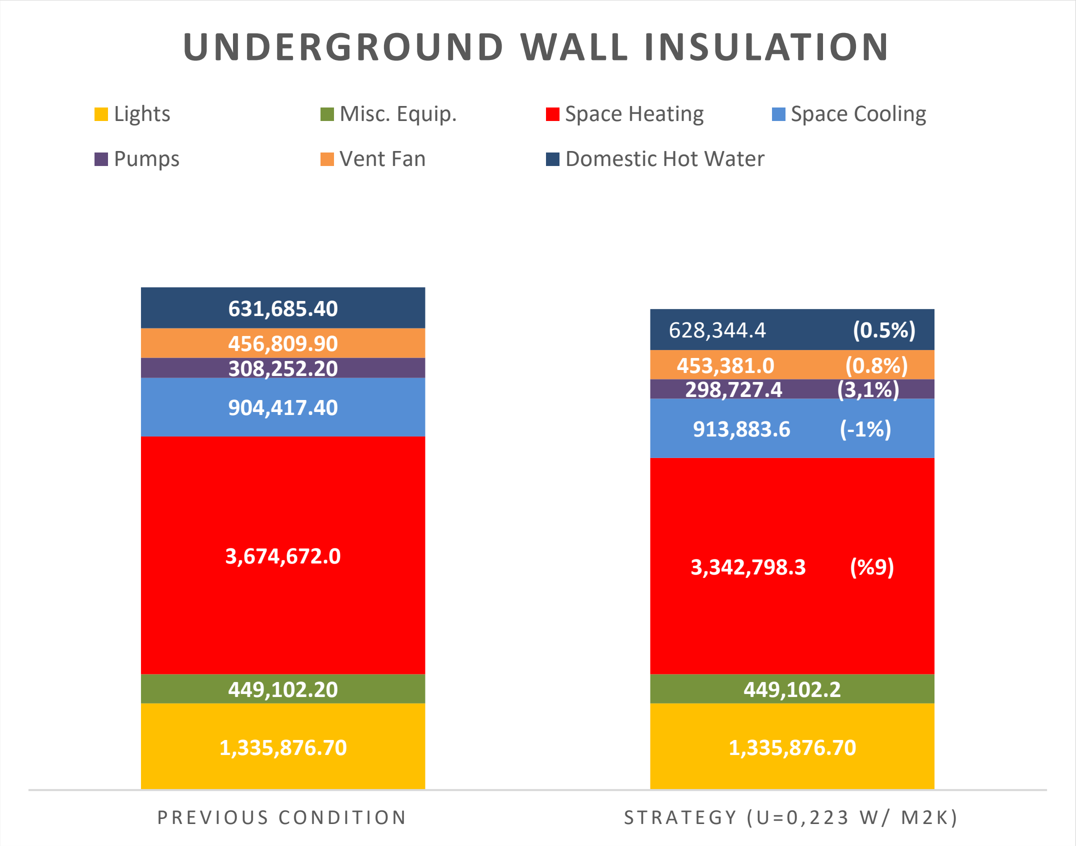


Figure 4.2 : Underground wall insulation effect on energy consuming parameters.

4.3.2 Window change

All windows of the building have been changed. Table 4.5 includes that the changing of windows has no effect on lights, miscellaneous equipment and domestic hot water consumption. Nevertheless, it changes space heating consumption by 13.2% and 485.057 kWh by inhibiting heat loss to the outside. For the same reason, it decreases the space cooling consumption by 219.773 kWh which is 24.3 percent of total space cooling consumption. The change of all windows effects pumps consumption by 30.8 percent resulting in 94.942 kWh energy saving. For the ventilation fan, 8.9 percent decrease has been obtained implying 40.656 kWh. Figure 4.3 shows the level of effect that all window change causes on energy consuming parameters.

Table 4.6 : Individual effect of window changes on energy consuming parameters.

Interventions/ Energy Consuming Parameters	Lights	Misc. Equip.	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water
All Window Change (U Value:1.6 W/m^{2}K)	0	0	13,2	24,3	30,8	8,9	0

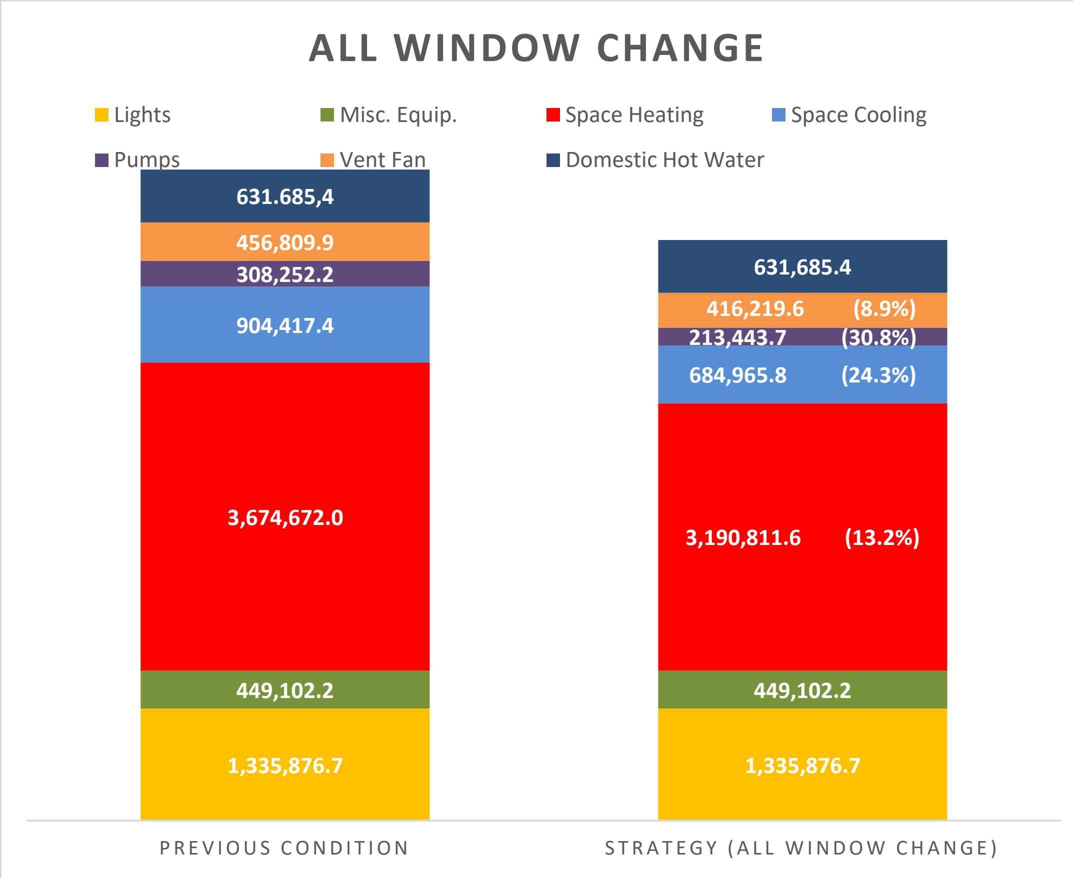


Figure 4.3 : Window Change Effect on Energy Consuming Parameters.

4.3.3 LED lighting with sensors

All of the incandescent lights have been changed with LED lighting. Also, motion sensitive and computer based controlled sensors are linked with LED lighting.

Table 4.6 summarizes that the insertion of LED lights and sensors has no energy saving effect on miscellaneous equipment. However, this intervention dramatically decreases the lighting energy consumption results in 1.048.663 kWh energy saving with 78.5%. Therefore, the LED technology and sensors decrease the electrical consumption in terms of watt per meter square. On the other hand, this intervention provides negative effect for space heating. The incandescent lights which are less efficient than LED lights in terms of energy efficiency luminous flux because incandescent lights lose their energy to the heat. That heat will help heating spaces approximately 12.9 percent results in 474.033 kWh extra energy load. Because of the same reason that LED lights have cooling technology for the waste heat in electricity circuit in the light, it has positive contribution to space cooling by 15.4 percent resulting in 139280 kWh saving. Pumps energy consumption is effected by LED lighting with sensors as 5.2 percent meaning 16029 kWh energy saving. For the ventilation fan consumption, this intervention has little effect about 1.7 percentage and 7766 kWh. LED lighting without sensors negatively effects domestic hot water energy consumption by 0.7 percent with an energy saving of 4422 kWh. Figure 4.4 shows the level of effect that LED lighting with sensors cause on energy consuming parameters.

Table 4.7 : Individual effect of LED lighting with sensors on energy consuming parameters

Interventions/ Energy Consuming Parameters	Lights	Misc. Equip.	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water
LED Lighting with sensors	78.5	0	-13,4	15,4	5,2	1,7	0

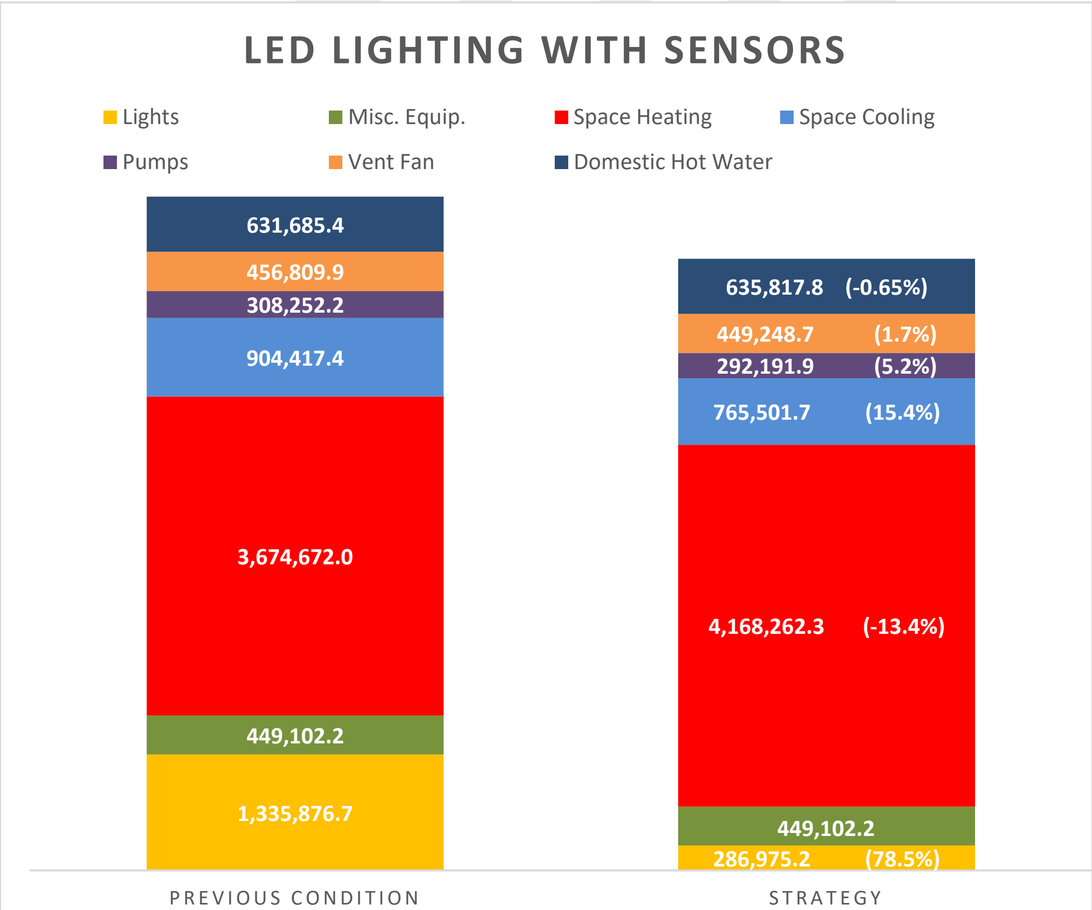


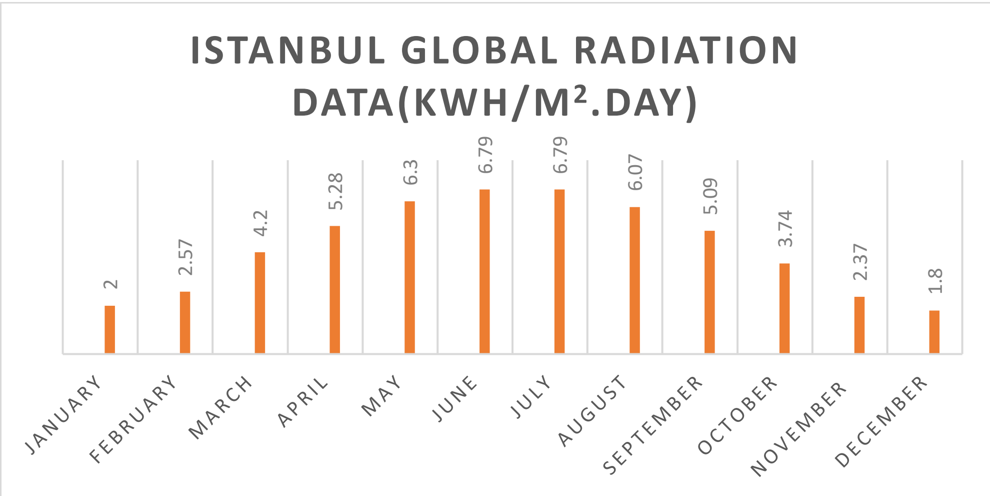
Figure 4.4 : LED Lighting with Sensors Effect on Energy Consuming Parameters

4.3.4 Solar thermal systems

Solar Thermal panels are placed on the flat roof of the building to heat the domestic water. Table 4.8 summarizes that all of the panels have been decreased domestic hot water energy consumption by 33.2 percent with an energy saving of 209.719 kWh. It has no effect on other energy consuming parameters as lighting, miscellaneous equipment, space heating, space cooling, pumps and ventilation fan.

Standard collector dimension is 1235x1935x10 mm. The area that absorbs sunlight is 2.4 m^2. The efficiency of the collector is 40%. Global radiation data for Istanbul is given on Table 4.7 Accordingly, average daily global solar radiation energy intensity for Istanbul is calculated with the equation below as 4.17 $kWh/m^2/day$. The roof area is the restricting factor for the number of panels. The panels are placed in the most efficient way that they do not put shade on each other even on 21st of December, when the length of shade is the longest over the year. To find the optimum energy that one panel produce to heat water is calculated as: Average daily global solar radiation energy intensity is multiplied by panel efficiency and panel area that absorbs sun radiation. The result is 4 kWh/day. The area gives oppurtunity to put just 150 solar thermal panels to the roof and 95% of the panels are able to emit sun radiation because there are junction points and optical losses on the surface of the panels. As a result total energy obtained from solar thermal panels are 219000 kWh/year, which is 5% bigger than 209.719 kWh that is calculated for this project. Figure 4.5 indicates the level of effect that solar thermal system cause on energy consuming parameters. As shown in equation x, average global radiation for the city of Istanbul is 4.17 $kWh/m^2/day$, which is the average value of 12 months in a year.

Table 4.8 : Istanbul Global Radiation Data(GEPA 2017)



$$\frac{2{,}00+2{,}57+4{,}20+5{,}28+6{,}30+6{,}79+6{,}79+6{,}07+5{,}09+3{,}74+2{,}37+1{,}8}{12}=4.17\text{kWh/m}^2/\text{day} \quad (4.1)$$

Table 4. 9: Individual effect of solar thermal systems on energy consuming parameters.

Interventions/ Energy Consuming Parameters	Lights	Misc. Equip.	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water
Solar Thermal Systems	0	0	0	0	0	0	33.2

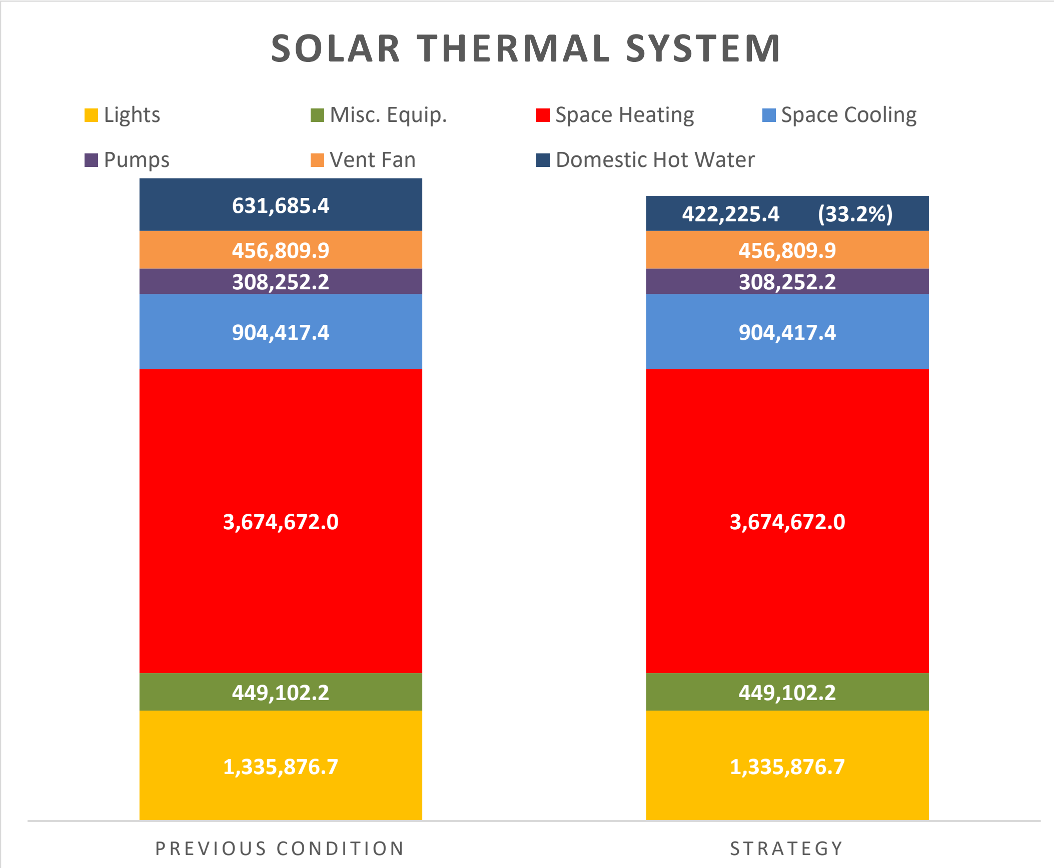


Figure 4. 5: Solar Thermal System Effect on Energy Consuming Parameters.

4.3.5 Automation and monitoring

Automation and monitoring systems are applied to observe energy consumption of mechanical systems, electrical systems and appliances to determine the system performances and possible maintenance problems. The system keeps the records of systems and gives warnings to building manager when there is any malfunction. Table 4.9 shows that automation and monitoring systems have no effect on lights and domestic hot water energy consumption. But it brings 10 percent decrease in miscellaneous equipment because it holds the daily work data of the equipment and provides correction chance for the user. The space heating is highly affected approximately 34 percent which equals to 1245714 kWh, the second biggest individual influence in this project. By tracing the data and performance of heating appliances, such as heat pumps and radiant systems and the rate of air in heat transfer areas, automation and monitoring provide energy efficient solutions to user. In addition to devices, the indoor air quality parameters are measured with the help of sensors and the data are compared to check the performance of the heaters. Because of the similar reasons, space cooling is decreased 45 percent meaning an energy savings of 406988 kWh. Cooling performance is also analyzed by putting trackers to the devices and indoor air quality sensors which measures indoor temperature and relative humidity. Figure 4.6 shows the level of effect that automation and monitoring cause on ECM.

Table 4. 10: Individual effect of automation& monitoring on ECM

Interventions/ Energy Consuming Parameters	Lights	Misc. Equip.	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water
Automation and Monitoring	0	10	33,9	45	39	45	0

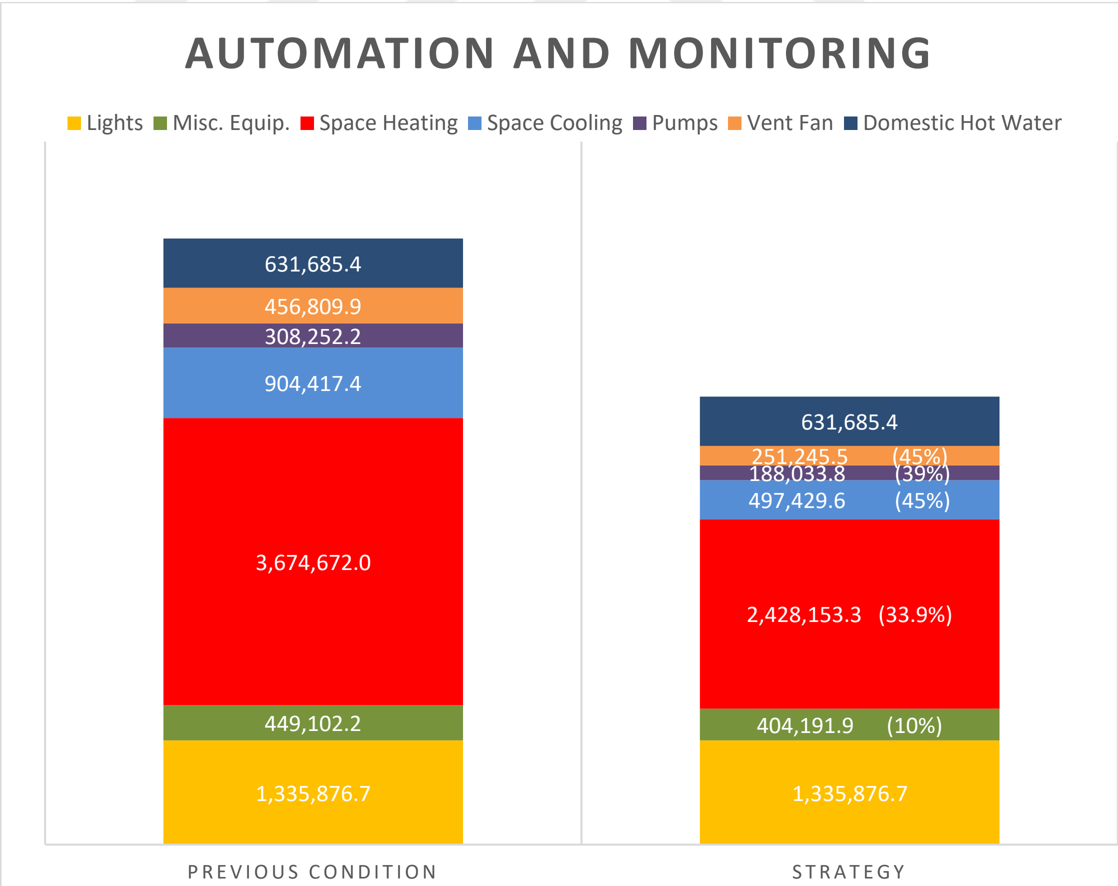


Figure 4.6 : Automation and Monitoring Effect on Energy Consuming Parameters.

4.3.6 Ground source heat pump

Ground source heat pumps are used to take advantage of thermal energy underground. It can absorb heat from warmer space under the ground, increase its temperature and release it to colder spaces in winter times as a space heating tool. In addition, it can draw colder temperatures under the floor, decrease its temperature and release it to inner spaces as colder air in summer times as space cooling. Table 4.11 shows that addition of heat pump has no effect on lighting, space cooling, pumps, ventilation fan and domestic hot water energy consumption. Ground source heat pump has very little effect on miscellaneous equipment because heat pump needs electricity to work but in this project it is negligible. However, it is one of the most effective intervention amongst others. Heat pump intervention has its major effect on space heating. It decreases space heating consumption by 34.7 percent meaning an energy savings of 1275111 kWh. Table 4.10 shows the technical specifications of the ground source heat pump. Figure 4.7 shows the level of effect that ground source heat pump cause on energy consuming parameters.

Table 4.11 : Details of ground source heat pump.

Heating Requirement	630,2	kW
Heat Pump COP	4,5	
Heat taken from ground	490	kW
Unit heat transfer from ground	80	W
Required well depth	6127	m
Depth of one well	125	m
Total number of wells	49	

Table 4.12 : Individual effect of heat pumps on energy consuming parameters.

Interventions/ Energy Consuming Parameters	Lights	Misc. Equip.	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water
Heat Pump	0	0	34,7	0	0	0	0

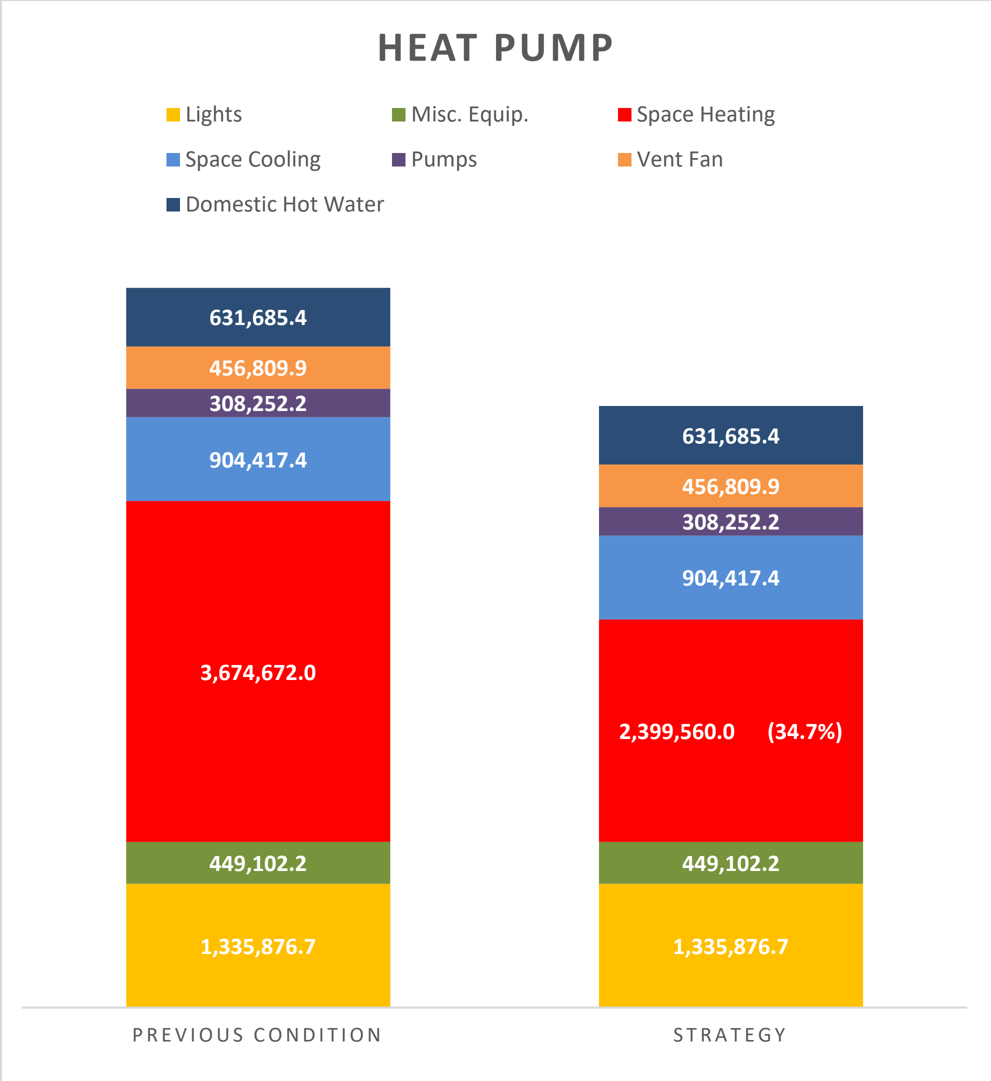


Figure 4. 7: Heat Pump Effect on Energy Consuming Parameters.

The effects of each intervention on energy consuming parameters are investigated and important points are determined. In addition, this section represents the sustainability performances numerically which includes calculations of effects of interventions to the energy consuming parameters. Specifically, intervention of exterior wall insulation and underground wall insulation has considerable positive impact on space heating but it has negative effect on space cooling.

Another important point is that LED lighting with sensors have great influence on energy decrease on lights and space cooling energy consumption but it has negative effect on space heating because LED lights give less waste heat to the environment than incandescent lighting. Similarly, LED lighting has very little negative effect on domestic hot water for the same reason.

Table 4.13 : Prepared matrix for contribution of energy consuming parameters in total consumption.

Interventions / Energy Consuming Parameters	Lights	Misc. Equip	Space Heating	Space Cooling	Pumps	Ventilation fan	Domestic Hot Water	Cumulative Total
Exterior Wall Insulation (U Value:0.223W/m^2K)	0	0	5,07	-0,1	0,17	0,07	0	5,21
Underground Wall Insulation (U value: 0.482 W/m2K)	0	0	6,26	-0,12	0,12	0,05	0,04	6,35
All Window Change (U Value:1.6 W/m^2K)	0	0	4,25	2,83	1,22	0,52	0	8,83
LED Lighting with sensors	13,5	0	-6,34	1,79	0,21	0,1	0	9,26
Solar Thermal Systems	0	0	0	0	0	0	2,7	2,7
Automation and Monitoring	0	0,58	16,05	5,24	1,55	2,65	0	26,07
Heat Pump	0	0	16,43	0	0	0	0	16,43

Table 4.14 : Meaning of Colours in Table 4.12.

Colours	
	Extra load of the intervention to the energy consumption (side effect)
	Top beneficial individual performances that decreases energy consumption most
	Positive effects of interventions on energy consumption
	No effect
	Top beneficial effects of interventions as cumulative total including the sum of negative and positive effects of interventions on energy consumption

When overall effects of interventions on energy efficiency are considered, it is also valued to precisely identify not only the individual effect of each intervention but also their effect on each other. Specifically, as given on the table 3.2 nearly half of the consumption belongs to space heating before interventions. If an intervention, such as ground source heat pumps affects the space heating in 34.7 percent it means it has 16.43 percent effect on total consumption which is the biggest individual effect on the project. Second biggest individual decrease is seen in automation and monitoring's effect on space heating as 33.9 percent meaning an energy savings of total 16.05 percent in total energy consumption. LED Lighting with sensors intervention takes the 3rd place by decreasing lights consumption 78.5 percent. It seems as the best percentage decrease but in total space heating consumption is much bigger than lights. At first, all interventions and energy consuming parameters are taken in equal weight amongst themselves. After calculation of total loads for energy consuming parameters and the effects on interventions, the weight scheme is formed according to their contribution and ranked accordingly. When total effects of the interventions are considered automation and monitoring takes the first place with the percentage of

26.07 % and heat pump takes the second place with 16.43%. LED lighting with sensors enhances total energy demand by 9.26 percent. The percentages are the key points to form indexes for the interventions.

It is clearly shown in table 4.12 that 0 percent scored interventions will be called none sensitive. The percentages less than 3 percent are classified as partly sensitive by not looking at the sum of the effects.

On the other hand, the interventions that have percentages between 3 percent and 7 percent are accepted as reasonably sensitive, such as all window change or underground wall change on space heating. There are 4 highly sensitive applications: automation and monitoring on space heating, ground source heat pump on space heating, LED lighting with sensors on lighting and LED lighting on lighting, respectively which have more than 7 percent effect on energy consuming parameters individually.

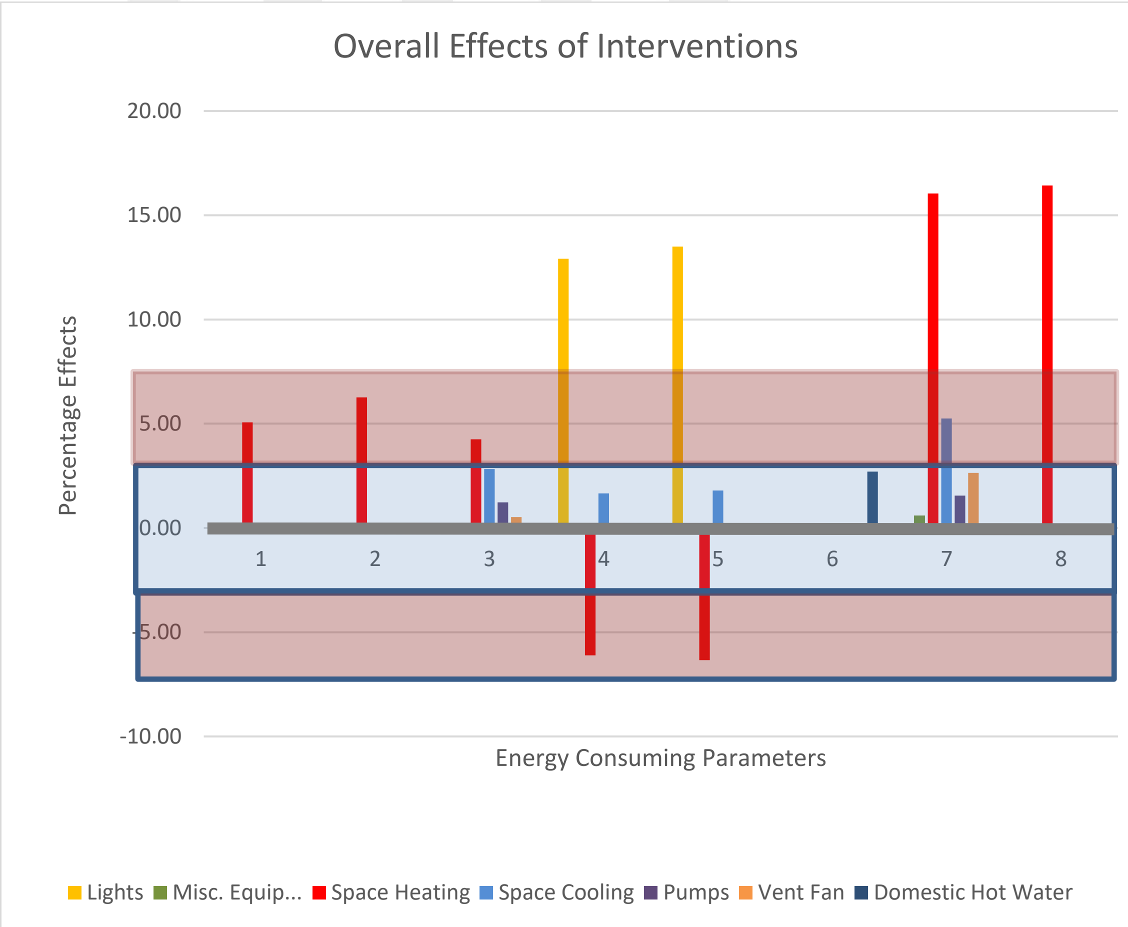


Figure 4.8 : Percentage Effects of Interventions

Table 4.15 : Percentage Effects and Sensitivity Level of Interventions.

Percantage Effects of Interventions	Sensitivity Level
0	No Sensitivity
Between -3%-0% and 0%-3%	Partly Sensitive
Between -7%and -3% & 3% and 7%	Reasonably Sensitive
< -7% and > 7%	Highly Sensitive

the main purposes of exterior wall Insulation and underground wall insulation are to improve space heating by minimizing heat loss through facade and through ground. However, as seen in Table 4.12, these two interventions have negative effects on space cooling. In addition, thermal Insulation leads to small improvement on pumps and ventilation fan. The small effect of underground wall insulation on domestic hot water is also an unintended result. The target of window change is to enhance thermal performance of the building, such as space heating and space cooling but pumps and ventilation fan are positively affected from the change. LED lighting with sensors directly aims to decrease lighting consumption but it considerably increases space heating loads which is the biggest negative effect in this study. For the same reason, relatively small side effects are indicated table 4.12 on pumps and ventilation fan consumption.

Automation and monitoring system is applied to track HVAC and non HVAC systems even it does not decrease the energy consumption of parameters. So, the changes related with automation and monitoring helps building managers or users to understand their system components and help them to take related precautions, which surely decrease energy consumption especially space heating and space cooling. Unlike other interventions heat pump just affects the thermal performance of the building and has no side effects. Like heat pump, solar thermal system just decreases DHW consumption and has no side effects.

4.4 The Effects of Building Retrofitting Interventions on Sustainability Indexes at District Scale

The below table 4.15 indicates the percentage effects of each individual buiding retrofitting intervention on the defined sustainability indexes.

Table 4.16: The effects of Applied Interventions on Sustainability Indexes.

	Thermal Insulation	LED Lighting	Heat Pump	Automation Monitoring	Solar Thermal Panels	Windows Replacement
EN1	-11.74	-12.15	-39.94	-8.58	-3.61	-13.70
EN2	0.00	0.00	482.35	-40.00	0.00	0.00
EN3	0.00	0.00	7.06	0.00	0.00	0.00
EN5	-17.24	37.15	-91.03	-2.20	-27.54	20.19
EN6	20.59	23.10	33.28	10.48	3.69	21.71
EN8	0.00	-0.39	29.71	-1.21	4.07	32.76
EN9	-11.74	-17.77	-61.97	-7.82	-10.33	-25.18
ECO1	36.83	19.94	17.69	24.53	3.45	22.48
ECO3	6.97	-26.77	-0.93	-3.56	-1.11	-2.93
ECO4	100.00	-46.22	9.69	6.84	-0.37	-55.69
ECO6	0.00	-63.41	60.00	-45.83	-7.69	0.87
ECO7	2.39	8.71	-1.35	-0.95	0.06	7.97
ECO8	-111.53	107.08	27.06	20.00	1.16	101.84
ECO9	100.00	-57.45	12.14	8.28	0.00	-85.00
CO1	-37.5	40	0	0	0	0
CO2	-35.12	31.40	0.00	0.00	0.00	-1.22
CO3	-38.67	24.72	0.00	0.00	0.00	-24.20
CO5	-2.01	0.60	0.00	0.00	0.00	-0.77
CO6	0.00	31.06	0.00	0.00	0.00	0.00
SO12	-6	-32	19	-8	-1	-8
ENV1	-11.74	-12.15	-14.39	-6.02	-2.55	-14.75
ENV2	-9.00	-41.48	-8.20	-13.22	-4.04	-5.04
ENV3	-9.00	-26.30	6.46	-9.92	-4.16	-8.63
ENV4	33.94	93.43	-11.25	43.29	31.74	36.62
ENV5	10.19	-51.03	143.81	-13.63	-0.73	-6.86
UR1	-9.01	-41.47	-8.20	-13.22	-4.05	-5.05

The methodology of that measurements are included in section 2.5. The influences of interventions such as thermal insulation, LED lighting, heat pump, automation and monitoring (ICT) system, solar thermal panels and enhanced windows are determined according to configuration of scenarios. The red coloured effects are negative side effects, which are not intended effects for improvements of the interventions on the sustainability indicators. Some sustainability indicators that are described in the previous sections are not affected by interventions. Therefore, they are not included in the above table 4.15. The effects of application of water saving systems and radiant heating are negligible in the scope of that part.

For instance, improving only thermal insulation without any other intervention provides 17.24% enhancement for the index of “peak load of thermal energy demand”

(EN4). On the other hand, LED lighting causes negative side effect that increases 10.45 percent of peak load of thermal energy demand (EN4).

4.5 Relationship Examples of Relevant Indicators from R Studio at District Scale

The usage of R Studio software is described in section 2.6. According to statistical changes of the indexes within the scenarios below results are obtained.

- 1 unit change in Density of final energy demand (EN1)
  leads to 0.43 unit difference in Life cycle cost (ECO3)
- 1 unit change in Energy production costs (ECO6
  leads to 0.5 unit difference in Impact on energy poverty (SO12)
- 1 unit change in Final energy consumption (ENV 1)
  leads to 1.84 unit difference in Dynamic payback period (ECO9)
- 1 unit change in Net fossil energy consumed (EN9)
  leads to 1.054 unit difference in Internal rate of return (ECO7)
- 1 unit change in Greenhouse gas emissions (ENV3)
  leads to 2.51 unit difference in Level of energetic self-supply (EN8)

5. DISCUSSION

Energy efficiency is a significant subdivision of urban sustainability. This thesis points out comparison methods in energy efficiency in order to initiate urban and local public actions in the context of sustainability. The thesis describes and discusses tools and methodologies to evaluate energy efficiency and sustainability.

The cities and urban regions play an important role on the energy component of sustainability concept. Therefore, cities should be promoted by appropriate and impellent policies. Furthermore, cities have to benefit from the monitoring of the results of the interventions about energy efficiency in order to reach GHG emission reduction targets. The measured or monitored indicators should be selected carefully for reporting which may then help standardization of that indicators.

Building retrofitting is a major concern in terms of energy efficiency that need to be considered more seriously from economical, social and environmental perspectives. Examining energy saving strategies in detail is significant for constructing common retrofit guidelines. The consequences derived from the study should be examined for different refurbishment situations considering climate change and energy supply scenarios at different locations.

This study takes advantage of indicators and the assesment of literature review to constitute an analytical point of view to support policy uses of indicators.

Developing sustainability indexes is an important aspect to assess regional sustainability degree. The approach formed in this study is to indicate the real situation of local sustainability performance in all directions without limiting it into one complex indicator thus, each aspect of various sub indexes is clearly presented. It is important that different weight of indicators might bring subjective approach to sustainability assesment. Therefore, this study recommends equal weighing of selected indicators. One of the main purposes of this study is to exhibit linkages between indicators and standardization in order to form a framework to guide emprical further search.

The sustainability plans of numerous countries depend on examination of case studies relating individual buildings that are representative of specific archetypes and retrofitting technologies. The elements of sustainability should be improved according to main actors in order to conduct the constituents more applicable. Defining sustainability indexes at local level may be an initiative for authorities or policy makers to form standards towards national level. Even though, every place has its own peculiarities, the guidelines for sustainability help different places to provide their own sustainability evaluation.

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CURRICULUM VITAE

Name Surname: Doruk Takmaz

E-Mail: doruktakmaz@hotmail.com

EDUCATION:

- **B.Sc.:** Istanbul Technical University Environmental Engineering Department

PROFESSIONAL EXPERIENCE AND REWARDS:

- Worked in the Energy Institute of Istanbul Technical University as a project supported research assistant between the years of 2016-2018.
- Working in the Department of Transportation and Infrastructure of Tekfen Engineering as a project engineer since April, 2019.

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

- Sözer, H., & Takmaz, D. (2019). Calculation of the Sensitivity factors within the Defined Indexes in a Building Level. Journal of Sustainable Development of Energy, Water and Environment Systems. doi: 10.13044/j.sdewes.d7.0265