ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

MICROCLIMATIC EFFECTS OF GREEN ROOF APPLICATIONS IN DENSE URBAN AREAS

M.Sc. THESIS

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Thesis Advisor: Prof. Dr. Fatih TERZI

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

YOĞUN KENTSEL ALANLARDA YEŞİL ÇATI UYGULAMALARININ MİKRO-İKLİMSEL ETKİLERİ

YÜKSEK LİSANS TEZİ

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Tannaz Sabamehr, a M.Sc. student of İTU Graduate School of Science Engineering and Technology student ID 502151840, successfully defended the thesis entitled MICROCLIMATIC EFFECTS OF GREEN ROOF APPLICATIONS IN DENSE URBAN AREAS”**,** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my father,

FOREWORD

I would like to thank my supervisor Dr. Fatih Terzi at Istanbul Technical University for his valuable contributions to my thesis studies. He has always supported and motivated me in this challenging period. I am grateful for his solidarity and cooperation that he has shown in this process.

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May 2019

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ABBREVIATIONS

UFORE **:** Urban Forest Effects Model
GISP **:** Green Infrastructure Spatial Planning
GIS **:** Geographic Information System
UGI **:** Urban Green Infrastructure
GIS **:** Geographic Information Systems
SWAT **:** Soil and Water Assessment Tool

SYMBOLS

° C	**:** Centigrade
PPM	**:** Parts per Million
M/S	**:** Meter per Second
t	**:** Time

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MICROCLIMATIC EFFECTS OF GREEN ROOF APPLICATIONS IN DENSE URBAN AREAS

SUMMARY

This study aims to examine the role of green roof applications in terms of urban sustainability. Due to the intensive urban growth, the undeveloped lands have been transformed into developed lands and the forest areas and urban green areas have decreased. The lack of enough green space in urban areas is also one of the main reasons for some essential problems such as increasing of global warming, excessive CO2 emission, increasing of mental problems in people, and urban warm island effect. In other words, inadequate vegetation in urban areas causes environmental, economic and social problems in general. In this context, green roof applications, which are still a new idea in the world, seem to be as an alternative solution.

In this thesis, the microclimatic effects of green roofs on dense urban areas were examined via ENVI-meet. In order to use the ENVI-met tool, some data such as the size of the area, the building floor condition and location are needed. The Envi-met software uses the values regarding the vegetation, building, ground surfaces, soil, and climate conditions as inputs and then simulates the selected building. This software considers all kinds of solar radiation (direct, reflected and distributed). In addition, the average radiant temperature can be calculated by this software. The grid resolution of the model is 10 seconds at 0.5-10 meters and can analyze the situation up to 24-48 hours.

Two scenarios were developed within the scope of the examination. The location, zone size, building floors, road arrangement and materials used in both scenarios were the same. The difference between the two scenarios was the roof materials and measurements made at different times. In this regard, dense urban areas were chosen for the research. In the first scenario, it was used the terracotta roof. In the second scenario, the green roof was implemented. For both scenarios, CO2 levels, air temperature, and wind speed changes, which could be considered as the microclimate elements, were measured at specific times (10.00 AM, 12.00 PM, and 21.00 PM) and then compared each other. After measuring the temperature changes in both scenarios, it was observed that the green roof reduced the air temperature to 0.5 °C. Co2 levels for the two scenarios were also measured. The green roof reduced Co2 emissions by up to 1.04 PPM and decreased the atmospheric Co2 value to 3.65 PPM. The second scenario in which the green roof was implemented was evaluated in terms of wind speed, and then it was observed that the grass did not have any impact on the wind speed change and the wind speed was the same for both scenarios.

The case study reveals that the air temperature values differences in the range of 23–24 ℃ for the roof without vegetation at 10.00 AM and the differences in the range of 23-23.75 ℃ for the green roofs. The differences at 12.00 pm, it was the range of 22.25–24.25 ℃ for the roof without vegetation and the range of 22.25-24 ℃ for the green roof. At 21.00 PM, 21.77–above 22.25 ℃ for the green roof and in the range of 22–above 22.25 ℃ for the roof without vegetation. That means that the mass of the building with green roof led to decrease of 0.25 ℃ in surrounding air temperature at 21.00 pm.

Co2 value differences at 10.00 AM were in the range of 401.25–402.65 PPM for the roof without vegetation and in the range of below 400.20–401.25 PPM for the green roof. The differences were in the range of 403.69–406.82 PPM for the roof without vegetation and in the range of below 402.65–403.7 PPM for the green roof. That means that the mass of the building with green roof decreased surrounding air CO2 amount at 12.00 pm. Looking at the differences at 21.00 pm, it was found that the differences were in the range of 396.58.5–397.71 PPM for the roof without vegetation and in the range of below 393.75–396.58 PPM for the green roof. It mean after sunset CO2 amount increase.

Green roof applications are developing every day and their many benefits are coming out. As a result, it was found out that green roofs have the capacity to decrease the ambient temperature, decrease the CO2 level in the environment, and thus contribute to improving the wellbeing and quality of people.

YOĞUN KENTSEL ALANLARDA YEŞİL ÇATI UYGULAMALARININ MİKROİKLİMSEL ETKİLERİ

ÖZET

Son dönemde dünyada yaşanan hızlı nüfus artışı ve kentleşme ile birlikte, açık araziler kentsel alanlara dönüştürülmekte ve yeşil alanlar her geçen gün azalmaktadır. Teknolojik gelişmelerdeki baş döndüren gelişmeler, buna paralel olarak insan ihtiyaçlarında da bir takım değişikliklere neden olmuş ve bu ihtiyaçların giderilmesi istenirken bazı ekolojik sorunlar ortaya çıkmıştır.

İnsanların yaşam kalitesini artırabilmek için bir taraftan yüksek ticari binalar, konut, alışveriş merkezleri ve sosyal yaşam alanları gibi yapılar inşa edilirken, diğer taraftan insan yaşamına birçok yönden olumsuz etki yaptığı herkes tarafından bilinen ormanların ve yeşil alanların azalmasına neden olunmaktadır. Bu çelişkiyi giderebilmek için, kentleşme ve refah arasındaki dengeyi gözetmek ve insan yaşamı açısından hayati öneme sahip kentsel sürdürülebilirliğin sağlanabilmesi önem arz etmektedir.

Kentsel alanlardaki yetersiz yeşil alan ve bitki örtüsü, genel olarak çevresel, ekonomik ve sosyal sorunlara neden olmaktadır. Yaşam bölgelerindeki yeşil alan eksikliği, sadece küresel ısınmanın artması, CO2 emisyonunun yoğunlaşması gibi çevresel sorunların değil, aynı zamanda insan sağlığını olumsuz etkilemesi (insanlarda zihinsel sorunların artması vb.) ve kentsel ısı ada etkisi dediğimiz sıcaklık artışına neden olması açısından, insan refahını ve yaşam kalitesini olumsuz etkileyen temel sorunlardan biridir. Bu bağlamda, dünyada hâlâ yeni diye kabul edebileceğimiz yeşil çatı uygulamaları, söz konusu bu temel soruna alternatif bir çözüm olarak karşımıza çıkmaktadır.

Bu çerçevede, özellikle peyzajın çevreye olan etkisinin araştırılması üzerinde durulmuştur. Yeşil alanlar doğal çevreyi ve biyolojik çeşitliliği korumakta ve kent ısı adalarının etkilerinin azaltılmasına yardımcı olmakta, havadan savrulan parçacıkların filtre edilmesini kolaylaştırmakta, ortamdaki oksijen-karbondioksit dengesini sağlamakta, özellikle şehirlerdeki gürültünün azalmasında adeta bir gürültü emici gibi vazife görmekte ve genel olarak da insan sağlığı açısından birçok fayda sağlamaktadır. Bu nedenle, yeşil alanlara olan ihtiyacın her geçen gün artması yadsınamaz bir gerçeklik olarak karşımıza çıkmaktadır.

Bu çalışmanın temel amacı, dünyada kullanımı gittikçe yaygınlaşan yeşil çatı uygulamalarının kentsel sürdürülebilirlik açısından üstlendiği rolü ortaya koymaktır. Bu kapsamda bu tez çalışmasında, yeşil çatıların yoğun kentsel alanlar üzerindeki mikro iklimsel etkileri incelenmiştir.

Şehirlerde artık yeterince boş alan olmaması nedeniyle, binaların çatılarının boş kısımlarının yeşil alanlarla kaplanması, son dönemde revaçta olan yeni bir uygulamadır. Bu maksatla özellikle dünyanın dört bir yanında uygulanan bu yaklaşım irdelenirken, maliyet-getiri dengesi gözetilerek çalışmalar yapılmaktadır. Yeşil çatıların çevreye sağladığı pozitif etkiler bu bağlamda uygulayıcı ülkeler tarafından değerlendirilmekte ve özellikle üç tip yeşil çatı üzerinde durulmaktadır. Bunlar geniş (extensive) yeşil çatılar, yoğun (intensive) yeşil çatılar ve yarı geniş (semi-extensive) yeşil çatılardır. Bu çeşitler arasından bazı parametreler dikkate alınarak bir tercih yapılabilmektedir. Bunlar arasında; enerji performansını artırmaları, yağmur suyunu bir seviyeye kadar toplayabilmeleri (sonrasında bu sulama maksadıyla da kullanılabilmekte), sel baskını zararlarını minimize edebilmeleri, estetik bir konfor sağlamaları ve özellikle de farklı canlı türlerinin yetiştirilmesine sağladıkları olanaklar sayılabilir.

Bu yeşil çatı türlerinin kullanım maksatları birbirinden tamamen farklıdır. Geniş (extensive) yeşil çatılar, ekolojik bir çatı türüdür ve bu çatılarda ekim için daha çok sedum bitkisi tercih edilir. Çünkü sedum, susuzluğa ve sert iklim koşullarına dayanıklı bir bitki türüdür. Bu tarz çatılar gezmek için tercih edilmez, sadece estetik güzellik sağlaması açısından ön plandadır. Diğer çatı türlerine göre katmanları daha hafiftir ve binaya fazla ağırlık yapmazlar. Yoğun (intensive) çatılarda ise park, bahçe ve seralar vardır. Bu çatılar insanların peyzaj ihtiyaçlarına yöneliktir. Bu tip yeşil çatılar ağırdır ve binaların kuvvetli olmasını gerektir. Ayrıca bu çatılarda, sulama imkânı olması ve toprak katmanlarının elverişli olması nedeniyle ağaçlar, çiçekler yetiştirilebilmekte ve hatta havuzlar yerleştirilebilmektedir.

Yeşil çatı uygulamaları ilk olarak Almanya'da yapılmıştır, sonrasında tüm dünyaya yayılmıştır. Bu çalışma kapsamında dünyanın farklı bölgelerinde uygulanan yeşil çatı uygulamalarına değinilmiştir. Yeşil çatı uygulamalarının kullanım maksatlarına baktığımızda, Avrupa'da daha çok çevre sürdürülebilirliğine katkı sağlaması bağlamında tercih edildiğini görmekteyiz. Örneğin yeşil çatılar İngiltere'de özellikle, biyolojik çeşitliliği artırmak ve insan sağlığına sağladığı faydalar ve kent ısı adalarının etkilerinin azaltılmasına katkıları bakımından yaygın olarak kullanılmaktadır.

Bu çalışmada bir araştırma aracı olarak, yeşil çatıların yoğun kentsel alanlar üzerindeki mikro iklimsel etkilerini incelemek maksadıyla ENVI-met bilgisayar yazılımı kullanılmıştır. Bu yazılımı kullanabilmek için, araştırma yapılan alanın büyüklüğü, binaların kat durumu ve konumu gibi bazı parametrelere ihtiyaç duyulmaktadır. Ayrıca ENVI-met yazılımı; bitki örtüsü, bina durumu, zemin yüzeyi özellikleri, toprak, iklim koşulları gibi değerleri girdi olarak kullanmakta, müteakiben üzerinde çalışılması hedeflenen bina simüle edilerek sonuçlar elde edilmektedir. Bu yazılım, her türlü güneş ışınımını (direkt, yansıtılmış ve yayılmış) dikkate almakta ve çevredeki ortalama radyan sıcaklığını hesaplayabilmektedir. Grid

çözünürlüğü 0.5-10 metrede 10 saniye olan bu yazılım sayesinde ve çalışma 24-48 saate kadar analiz edilebilmektedir.

Bu kapsamında, yeşil çatıların kentsel sürdürülebilirlik açısından mikroiklimsel etkilerini ortaya koyabilmek maksadıyla, iki farklı senaryo geliştirilmiş ve yoğun bir kentsel alan olan Çeliktepe'de bir alt bölge araştırma bölgesi olarak seçilmiştir. Her iki senaryoda; kullanılan konum, araştırma alanı büyüklüğü, bina kat durumu, yol inşa malzemelerine ilişkin bilgiler aynı olmalarına karşın, fark çatı malzemeleri kullanılarak ve farklı zaman dilimlerinde yapılan ölçümlerle simülasyon uygulaması gerçekleştirilmiştir. Bu çerçevede ilk senaryoda, standart çatı uygulaması, ikinci senaryoda ise yeşil çatı uygulaması yapılmıştır. Her iki senaryoda da mikro iklimlendirme parametreleri olarak ortam hava sıcaklığı, CO2 miktarı ve rüzgar hızı değişiklikleri incelenmiştir. Bu parametrelere ilişkin değerler standart ve yeşil çatı uygulamasının her ikisi içinde güneş ışınlarının en yoğun olduğu belirli zaman dilimlerinde (Saat 10.00, 12.00 ve 21.00) ölçülmüş ve müteakiben bu değerler karşılaştırılmıştır. Her iki senaryoda sıcaklık değişim değerlerinin ölçülmesi neticesinde sabah saat 10.00 da standart çatı uygulamasında hava sıcaklığı 23_24°C aralığındadır ve yeşil çatı uygulamasında hava sıcaklığı 23_23.75 aralığında bulunmuştur. Yani yeşil çatının hava sıcaklığını 0,25°C düşürdüğü gözlenmiştir, öğlen saat 12.00' de standart çatı uygulamasında hava sıcaklığı 22.25_24.25°C aralığında iken, yeşil çatının uygulamasında hava sıcaklığı 22.25_24°C aralığında bulunmuş, yeşil çatının hava sıcaklığını 0,25°C düşürdüğü gözlemlenmiştir. Akşam saat 21.00' de yeşil çatı uygulaması hava sıcaklığını bazı bölgelerde 0,25°C düşürdüğü bazi bölgelerde ise 0,25°C artırdığı gözlenmiştir.

CO2 seviyeleri de ölçüldüğünde, sabah saat 10.00' de standard çatının CO2 seviyesi 401.25_402.65 PPM, yeşil çatı uygulamasında ise 400.20_401.25 PPM aralığında; öğlen saat 12.00' de standart çatı uygulamasında 403.69_406.82 PPM, yeşil çatı uygulamasında 402.65_403.7 PPM aralığında; akşam saat 21.00' de yeşil çatı uygulamasında 393.75_396.58 PPM, yeşil çatı uygulamasında 396.58_397.71 PPM aralığında bulunmuştur. Yeşil çatı uygulamasının, akşam gün batıktan sonra atmosferik CO2 değerini 1,08 PPM artirdığı tespit edilmiştir. Yeşil çatının rüzgar hızı değerleri üzerinde herhangi değerlendirildiğinde ise, çatıda uygulanan çimlerin rüzgar hızı değişikliği üzerinde herhangi bir etkisinin olmadığı ve rüzgar hızının her iki senaryoda da aynı olduğu tespit edilmiştir.

Sonuç olarak, dünya çapında her geçen gün kullanımı yaygınlaşan yeşil çatı uygulamalarının kentsel sürdürülebilirlik açısından sağladığı faydalara yönelik araştırma ve çalışmalar halen sürmektedir. Bu çalışma sonucunda da, yeşil çatıların özellikle ortam sıcaklığını düşürme ve çevreye salınan CO2 miktarının sabah saatlerinde düşürülmesinde önemli bir etken olduğu ve bu sayede insanların refah seviyesi ve yaşam kalitesinin iyileştirilmesine kaydadeğer bir katkıda bulunduğu ortaya çıkmıştır.

1. INTRODUCTION

In recent years, rapid economic growth and urbanization in the world have caused the population to intensify especially in certain regions, and hence, there has been a substantial increase in the construction of tall buildings. The increase in population and construction has led to a decrease in green areas, leading to increased temperatures and reduced air humidity, and ultimately to climate change (Vijayarajhavan, 2012). The US Green Building Council (USGBC) has estimated that 30% of greenhouse gas emissions and 65% of electricity consumption in the US stem from commercial building and residential construction (Bianchini, 2012). It has been repeatedly reported that around 40% of the world's energy use is stemmed from building construction and maintenance, and the greenhouse emissions from these buildings account for 33% of the greenhouse gas emissions in the world. (Berardi et al., 2013). In addition, recent studies emphasize the importance of four types of urban green infrastructure (UGI) available: Green open areas such as parks, green roofs and walls, shade trees, and façades (Norton et al. 2015).

Green areas can improve ecosystem services since they are eco-friendly, and using green infrastructure contributes to energy saving. Green structures can reduce domestic energy use, in addition, thanks to their ability to cool air and mitigate flooding; green areas provide the protection of wildlife (Cameron et al., 2012). The best way to increase green areas, which are of crucial importance in urban life, is to use them in different structures such as green roofs and transform the bare roof of the building into eco-friendly green roofs which are classified into two main types: Extensive and Intensive green roofs. However, since each country has diverse climatic conditions and building features, it is necessary to conduct local research to determine the correct components for the successful installation of green roofs (Vijayarajhavan, 2016).

1.1 Purpose of Thesis

The purpose of the thesis is to develop green areas in buildings with bare roofs and to calculate the effects of green roofs on urban climate changes including factors such as urban temperature changes, air pollution, and urban heat island.

1.2 Scope

In order to have sustainable cities, it is important to take into account the ecology and social aspects of cities and to have an adequate economy. In recent years, industrialization and population have increased rapidly, and some of the undeveloped land areas have been transformed into hard and impervious areas such as roadways and rooftops. These hard and developed surfaces mean less green space and therefore cause some economic, ecological and social problems in the cities. The buildings in our environment are in a way related to the energy and water consumption in the world and CO2 emissions and the majority of waste production (Nelson et al., 2010). Vegetated areas, such as green roofs, are closely related to urban planning, as they positively affect microclimate. Since green roofs create many advantages in urban life, it seems like a good idea to use bare rooftops in dealing with the lack of green space. Green roofs in urban areas, especially by maintaining rainwater flow, reduce the urban heat island effect. Thus, it contributes to increase the quality of urban life of people.

1.3 Methodology

This thesis has been prepared for Istanbul Technical University Urban Planning Master Program. It has been decided to analyze the micro-climatic effects of green roof applications in the dense urban area, such as reducing urban temperature and decreasing CO2 levels in the environment. Green roofs are one of the methods of green field application, which has been widely used recently in cities. Because of the fact that Istanbul contains excessive buildings and populations in terms of urbanization, Çeliktepe, which is one of the densest neighborhoods of Istanbul, has been taken as an example. As online accessible resources on the internet, Geographic Information System (GIS), for collecting data on building floors and ENVI-met holistic microclimate model are available. ENVI-met has specifically been designed

to simulate mutual effects between surface, plant, and air. ENVI-met is a three-dimensional software model. It is widely used in urban climate forecasting, urban planning, architectural activities, and the design of buildings, and it has been able to attract more than 1500 registered users since 1998 when it was available for use (Huttner, 2009). ENVI-met is used in urban environments with a distinctive resolution up to 0.5 m in space and up to 1-5 seconds in time. The model includes the simulation of the wind flow between and around buildings, the change of processes on the floor surface and building walls, the effect of vegetation on the local microclimate, and the dispersion of pollutants. ENVI-met tool needs a base map taken from Google Earth in order to simulate the area. First, the place where the case study was carried out, and then the neighborhood satellite image from Google Earth was determined. The image format was converted to bitmap format and used in ENVI-met tool. The building structures of the neighborhood were taken online via GIS and this information was used on the ENVI-met to initiate the simulation.

ENVI-met tool collected information about the neighborhood via climatology online resources from the selected base map location. The output files give information about air temperatures, CO2 value, humidity, vegetation, wind speed, and direct solar radiant. The format of these output files are EDX/EDT.

Two scenarios were created for measuring the impact of green roofs on microclimate. First scenario, is taken on neighborhood existing situation this scenarios is located in Istanbul district. All the roofs material and buildings wall material, roads structure is same as current situation. Roads material is asphalt and flagstone, roofs structure is terracotta. Second scenario is also located in Çeliktepe neighborhood in Istanbul district. All the buildings, wall material, roads structure is same as current situation just terracotta roofs converted to green extensive roofs. Roads material is asphalt and flagstone, roofs structure is plant. The scenarios results were analyzed with the ENVI-met software tool, Leonardo, which brought about plenty of illustration facilities. The ENVI-met database provides a wide variety of different vegetation and material for walls, roofs, and surfaces. Concerning the ENVI-met features, the research started with two different scenarios. The location and the building mass of both two scenarios are the same. However, roofing materials are different in both scenarios.

Scenario information is entered in ENVI-met. After the simulation, the results of both scenarios were analyzed. Finally, all the results were compared. Below methodology mentioned as a flowchart:

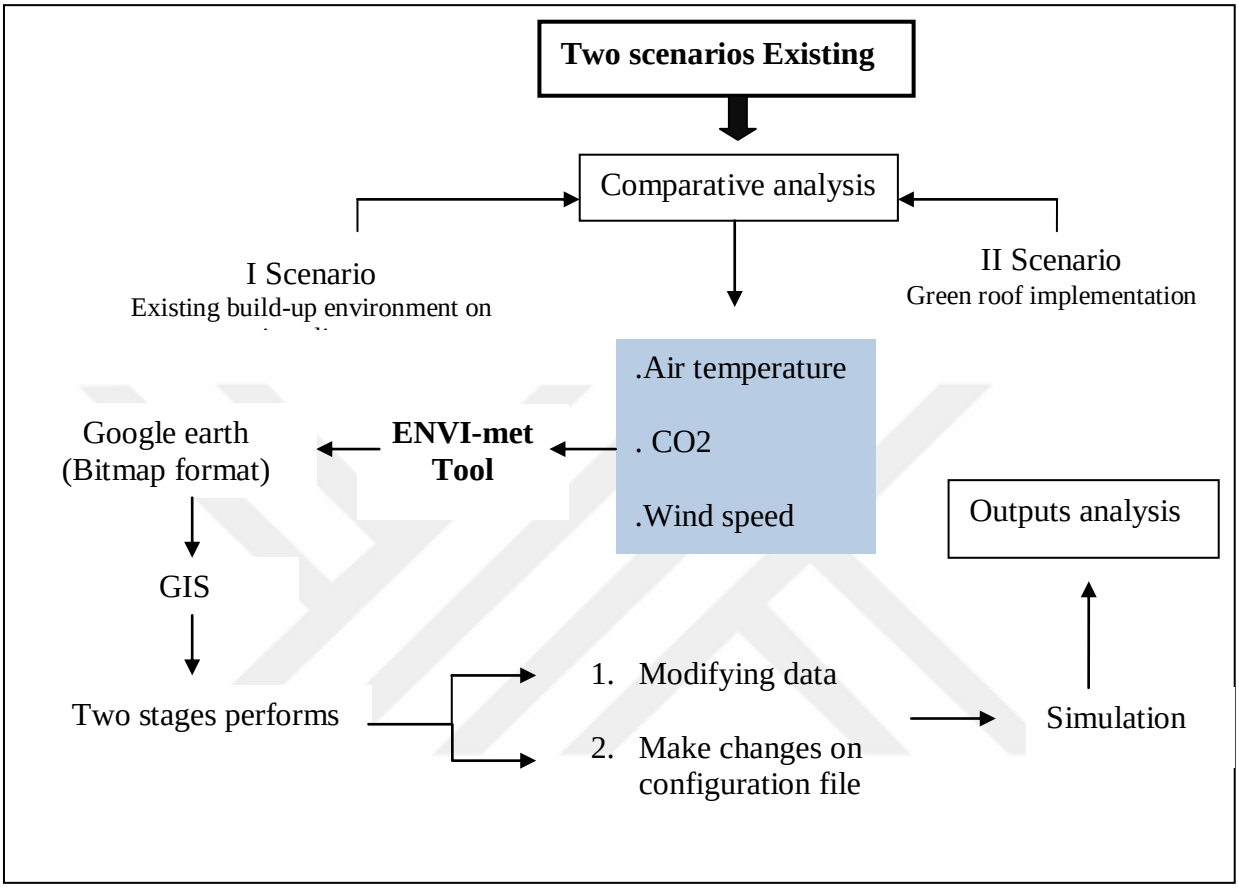

Figure 1.1 : Flow chart of the methodology

2. LITERATURE REVIEW ON GREEN ROOFS

2.1 Definition and Concept of Green Roof

The green areas (Mentens et al., 2006), where water can infiltrate and evaporate, are also known as eco-roofs around the world. Green roofs, which are called "living roofs" or "roof gardens", have been used since the 1960s, however, according to some sources, these spaces have been used for more than 100 years (Li WC, 2014). The green roofs, which have been used for a long time, seem to provide some benefits from many aspects. First, it is a suitable solution for meeting even partially the lack of green space in urban areas. Secondly, green roof applications are an important factor in the solution of many environmental problems such as urban hot island effect, overflowing and unused groundwater, reduction of air and water quality, damage to habitat and reduction of biodiversity (Nyuk Hein Wong, 2002; Umberto Berardi, 2014).

The existing literature shows the various styles of green roofs used in different climatic conditions worldwide. It seems that the implementations of the green roof systems are especially common in the US and European countries, and has become widespread worldwide. Green areas have environmental, recreational, emotional and aesthetic benefits (Ong, 2003; Li WC, 2014). Green roofs are more common in European countries, especially in Germany, Norway, France, Switzerland, and Austria. Many people see only the aesthetic aspect of green roofs. But the green roofs have many benefits. In addition to its aesthetic aspects, it provides benefits not only ecologically but also economically. Green roof systems are not just a typical roof garden covered with vegetation, but also the areas directly planted on the roof (McIntyre, L, 2010). Green roof systems are different from traditional gray or white roofs and the application of these roof systems is expensive compared to others. However, they have more valuable benefits than traditional roofs. Therefore, green roof systems are recommend for sustainable buildings in many countries having different climates (Berardi et al., 2013).

People think that the installation of green roof systems is expensive because of the time and effort they require. In fact, these systems bring an additional financial burden in terms of collecting necessary data during the implementation phase, but in the long term, it can be said that they are efficient structures. Green roof systems implemented by applying vegetation on a roof have some functions such as reducing roof temperatures, absorbing rainfall, improving air quality and increasing urban living spaces (Carter, 2008). Green roofs are also called "eco-roofs", "living roofs" or "roof gardens". They photosynthesize and thus provide clean air and absorb rainwater thanks to the vegetation they have (Berardi et al., 2013). Green roofs mean that plants grow on roofs. Thanks to the green roofs, the negative effects of pollution in cities can be reduced. For example, the leaves absorb air pollution and improve the quality of life of people.

The environmental and economic benefits of green roofs are undeniable (Berardi et al., 2013). Green roofs (vegetative, “eco or living roofs”) are roofs covered with vegetation (Vijahayarajhavan, 2016). Green roofs mean that the vegetation can be grown on the roof floors with a thinner layer because the cities are growing day by day and the green areas are diminishing (Braaker, 2014). Roof vegetation, or green roofs, is a roof design approach that includes various plant species, either spontaneously or later installed purposely. In general, we can divide green roofs into two types, such as “extensive, intensive and semi-intensive” (Lagstrom, 2004).

2.2 Green Roof Types and Their Features

Green roofs generally classified as “Extensive, Intensive” and some examples of “Semi-intensive green roofs” (Banting et al., 2005; Vijayarajhavan, 2016). As seen on all kinds of roofs, the green roof layers must provide drainage and protect the existing structure by a waterproof membrane. Green roof plants layer, planted over waterproofing system. Each green roof is different. Depth of the layers and the number of layers, vegetation varieties are choose by several factors for example roof’s slope, height, sun direction, wind speed, building weight, and budget. On the one hand, the roofs should be built as light as possible; on the other hand, they must have enough space for growing the plant, ease the watering and contain enough barrier to protect the plant roots. Figure showed the several types of green roofs on different types of buildings.

Figure 2.1: Different types of Green roof: residential (1, 2); commercial (3, 4); institutional (5, 6) (URL-1).

According to the purposes of the users, one of the roof types is preferred. According to the green roof type, the cost of installation of the roof, the time and cost required for the maintenance, and the time required for installation vary. The green roofs are building with different layers, in which different types require the use of different plants. In addition, in terms of the growing environment, different depth and soil thicknesses are need according to the roof types (Bianchini, 2012).

"Extensive green roofs are the simplest form of green roofs," making it much faster and more practical to build. This type of green roofs can be implemented to large areas. Construction and maintenance costs are lower. A further advantage is that the

weight of the green roof is less due to the minimum thickness and depth of the soil layer. These kind of green roofs usually do not require water and do not need additional artificial watering. The vegetation used on wide green roofs is natural or self-growing. These are drought-resistant plants and limited in number. This type of plants, which are becoming more common day by day, have shallow roots. Recently, especially sedum species have been used extensively on large green roofs. However, recent research shows that broadleaf plants performance is better than sedum-type plants (Banting et al., 2005; Umberto Berari, 2014; Li W.C, 2014). The "extensive green roofs", which are generally used as an ecological roof, can be implemented to "both flat and sloped roofs". In this case, the inclination angle can be as high as 45◦C. (Nyuk, 2002; Mentens, 2006).

Figure 2.2 : Extensive green roof on sloped roof (URL-2)

The main characteristic of "intensive green roofs" is that they have higher installation and maintenance costs than other roof types, having a thick soil layer (20 - 200 cm). "Intensive green roofs" are generally preferred in park or garden construction. There are many vegetation and plant varieties to be used for this purpose such as garden trees, shrubs, grasses, and perennial grasses. The soil layers on the intensive green roofs are thicker and require regular watering and maintenance. The maintenance and management service of such roofs require skilled labor. Furthermore, the intensive green roofs require additional time to prevent and remove the formation of undesirable plant species. On the other hand, when compared to "intensive green roofs", "extensive green roofs" do not require additional watering, and just rainwater is sufficient. "Intensive green roofs" have the ability to better isolate the roof and better manage rainwater and energy performance (Berardi et al., 2013). "Intensive green roof" systems make roofs heavier because they require intensive soil use. For this reason, they can be constructed in structures

having a strong architectural structure that can carry extra weight (Umberto Berari, 2014; Nyuk, 2002; Dunnett N, 2008; Vijayarajhavan, 2016). On deeper green roofs, heat loss is lower and this saves energy. They usually have "better thermal performance". "A 10 cm rise in soil thickness increases the thermal resistance of dry clay soils by 0.4 m2 K/W". "Intensive green roofs" are usually installed on roofs with slopes of less than 10 degrees (Mentens et al, 2006).

"Semi-intensive green roofs are a combination of extensive and intensive green roof systems (Fabricio, 2012)". In terms of installation and maintenance, they are more expensive than "extensive green roofs".

Figure 2.3: Intensive green roof installation on sloped roof area (URL-3)

2.3 Benefits of green roof in terms of sustainability components

Green roof systems have a long history and have been becoming widespread in recent years. Looking at the historical background, we see that the first use of vegetation in roofs began in Mesopotamia. Especially, the "Hanging Gardens of Babylon", which were implemented on terraced bare roofs, have been considered as the most famous roof gardens (Miaomiao, 2011). Because of the population density and the increase in the number of buildings in cities, the temperature of the cities is increasing day by day, and consequently, the green areas and open spaces have decreased and the heat island phenomenon has emerged. Buildings cause 33% of greenhouse emissions in cities, which necessitates taking measures immediately. In this context, it is important to change the traditional energy consumption trend in

urban areas and to introduce new green space concepts in the light of various environmental technologies developed in the world.

Just at this point, the benefits of the green roof systems are coming into prominence. Green roofs are now considered a rich strategy to make the city sustainable, and their cooling function plays a crucial role in dealing with the challenge of temperature rise as well as energy consumption in cities. (M. Santamoris, 2012; Berardi, 2014).

Green roofs have environmental, economic, social, and environmental benefits, depending on vegetation types, roof types and ground depth, and climate. The most important benefits of the green roof include storm water management, reduction in energy costs, decreasing "urban heat island effect", protection of urban natural habitats and aesthetics, increasing the lifetime of roof membrane (Castleton, 2010), reflecting of solar radiation by 20% to 30%, and absorbing up to 60% of it through photosynthesis (Berardi et al., 20130). These are the advantages of green roof systems compared to the traditional cheap roof implementations. Kristen and his colleagues emphasize the "economic and environmental aspects of green roofs" as their most important benefits. In this context, they touch upon the benefits of green roof systems such as rainwater management of green roofs, energy conservation, the reduction of "urban heat island effect" and increasing the roof membrane lifetime. They also state that these structures create job opportunities in the field of landscape architecture as a positive effect of its aesthetic advantage (Getter, 2006).

2.3.1 Environmental benefits

Environmental benefits related to the types of roofs such as "soil depth and vegetation type, and the climate" (Berardi et al, 2013) and Jensen et al said the environmental benefits of green spaces are surface runoff infiltration, recycling organic waste and improvement urban biodiversity as well as Snodgrass focused on the green areas high effect on cooling buildings, and mentioned that the Ancient Greek and Roman both used roof gardens for cooling buildings inside because buildings materials absorb heat and maintain it so these "hard surfaces become as much as 10°C higher" that atmosphere temperature but plants on surfaces by transpiration decrease surface temperature sometimes cooler than atmosphere and sometimes don't rise more than 4-5 C above the atmosphere temperature (Snodgrass & Snodgrass, 2006. Ong, 2003). Due to the fact that there is not enough vegetation in

urban areas, impervious surfaces are formed which cause rainwater runoff. These surfaces absorb solar radiation during the day, and in the evening they emit solar radiation. Thus, the urban air temperature may be 5.6 °C higher than in rural areas or underdeveloped environments. For example, the urban temperatures of Berlin are 9 °C higher than the rural areas (Von, 1990). According to some sources, the temperature of hard surfaces can be 2 °C hotter in summer and the increase of urban green surfaces can reduce the air temperature by 1-3 °C (Meerow, 2017). Research has shown that, if 50% of the roofs in New York City are covered with plants, the temperature difference between the city and the suburbs can be reduced by 0.8 °C (Bianchini, 2012).

- **Urban heat island effect**

The relationship between green areas and the reduction of urban heat island, in other words, the relationship between the types of vegetation and its effect on cooling, is still being investigated. Trees in urban areas provide shadow and evapotranspiration and have a great effect in terms of cooling. Research shows that thanks to the transport of trees, about 270 kWh of cooling can be achieved per tree. It has been found that approximately one-fourth of the cooling effect provided by trees in urban areas in the US is provided by green areas and street trees. However, considering the architectural types and size of the trees and plants, the cooling effect on the buildings is thought to be different (Rose W.F, 2012).

Urbanization is increasing especially in developed countries and this causes “urban heat island effect”. In this context, green roofs can help to improve this phenomenon in buildings in cities (Amberto, 2018). Santamouris states that the important reason for the “urban heat island” is due to the lack of vegetative areas in urban areas, and this led to climate change in the world. Because of this phenomenon, he also mentions that the temperatures are lower in the suburbs compared to urban areas. In addition, he says that the urban high temperature led to an increase in demand for consuming energy to use the cooling systems and this is another reason for the increased temperature. From that point of view, Matheieu says that, with the urbanization, finding suitable areas on the ground is difficult and thus green roof systems are suitable for that purpose, especially in terms of decreasing “urban heat island effect”. In this regard, both Santamouris and Matheieu mention about two types of technologies such as reflective and vegetation roofs. Both types of roofs

help reducing environmental temperature. However, in green roof applications, they determined that the percentage of the cooling effect required for the environment should be calculated. They showed that this was related to many environmental conditions such as building characteristics, watering, wind speed, and different climate. For example, in windy areas, they found that green roof systems helped to cool the environment more quickly, since it helps to the evapotranspiration through wind, soil, and plants, and this is a way of lowering environmental temperature (Santamouris, 2014).

Some sources show that green roofs in hot and arid regions have a temperature-attenuating effect. Smith and Roeber studied the effects of green roofs in Chicago on the ability to mitigate climate temperature and the urban heat island. They argued that the large green roofs, through increased albedo and evaporation, reduced the temperature by 3 ℃ and thus, the city temperature decreased by 2 to 3 ° C from 7 pm to 11 pm (Smith et al, 2011). Wong and his colleagues focused on finding the thermal benefits of the green roof. For example, they measured an "extensive green roof" surface within 22 days, with and without vegetation. They found that the temperature of the roof containing the vegetation was lower than the original roof and the maximum temperature. They also found that the temperature difference between vegetated and conventional roof was 18 ℃. However, they were expecting more temperature differences between the two roofs. They investigated why. As a result, as a first reason, they found that the soil layer was thin in extensive green roofs. The second reason was because of the fact that evapotranspiration was lower in thin soils due to the type of vegetation. If they planted vegetation with high density and high-lying ground cover-type, the temperature differences would be higher between these two types of roof (Hein, 2007).

Onmura et al. examined "the evaporative cooling effect of rooftop gardens" in 2001 during the extremely hot weather time in Japan and confirmed that the temperature of surface of the roof fell from 60 ℃ to 30 ℃ during the day. This means a 50% decrease in heat flow into the building. They found that soil moisturizing had really an impact on cooling the surface of the roof. Because, when solar radiation is absorbed by moist soil, evaporation takes place through plants and soil, and as a result, that cools the environment, and the wind accelerates the evaporation and increases the cooling effect (Onmura, 2001). Liu and Minor said that heat flow

reduction was realized “by 70%–90% in summer and 10%–30% in winter” (Berardi et al., 2013). Niachou et al. and Berardi emphasize on the measurement of energy behavior of green roofs, and green areas affect the reduction of temperature. They stated that there was a difference between the green roofs and the “conventional roofs”, and they always found that the air temperature under the plants was related to the leaf thickness and the temperature was lower on the lower side than the upper side. They focused on the performance of green roofs in terms of their energy-saving performance, and the microclimate environment inside and outside the building.

They carried out this experiment on a green roof in a hotel near Athens and recorded surface and air temperatures between June and August many times. At first, they measured the temperature of the two roof types (green, conventional or bare roofs) and found that the lowest temperature was 26 °C. While the temperature in the area with thick vegetation was measured at 29 °C, the highest value in the bare roof area (soil) was measured at 40 °C. Peck said that when the environmental temperature was 30 C, the green roofs reduced the indoor temperature of the building by 3 to 4 °C. Alexandri and Jones used a one-dimensional model to study on green roofs effect on the urban climate. In other words, they investigated the impact of green roofs in reducing the urban temperature. For this purpose, they used a mathematical model. In this model, they found that the vegetation areas helped to shade and acted as if it were an umbrella. From a thermal modeling point of view, they said that four components on a green roof should be distinguished: building material, soil, vegetation cover leaf, and the air above the roof. They decided to calculate the heat transfer by using these components. For this purpose, an experiment was carried out on “the roof of Welsh School of Architecture for 5 days”. They did this experiment with two different models. However, the layers and size were the same in both models. One of the roofs was bare (it was only concrete), the other was covered with vegetation and soil. In this experiment, they found that the heat exchange in the green roof is smaller than the bare roof because of the redistribution of radiation in the vegetated roof. That means vegetation in the green roof keep radiation and use the heat for transpiration and make the air milder. If it was implemented in the urban areas, it would act as a natural cooling and decrease the urban temperature eventually. As a result, the researchers concluded that the air coming from the green roof is severe in hot and arid climates, but can benefit from this natural air-cooling in

very humid areas such as Istanbul (Alexandri, 2007). Feng et al. reported that within 24 hours of a classic summer day when the groundwater was filled with 600 W / m2 of latent heat, the heat was released with the use of an extensive green roof (Feng, 2010).

- **Storm water runoff management**

In parallel to urban developments, the number of hard surfaces in cities increases, resulting in a reduction in storm water infiltration. Green areas play an essential role in the absorption of rainwater. Keeping rainwater in green areas is lower in winter than in summer. Here, water quality is also an important factor (Mentens et al, 2006). Some research suggests that roofing materials are effective on water runoff quality and that most of the roof system add some chemicals to the water runoff (Bianchini, 2012). Berndtsson points out that many factors such as green roof type and geometric characteristics (especially the slope) are effective in the effect of green roofs on the water runoff management. For example; soil moisture properties, season, weather and rainfall and rain characteristics, green roof year of production, and vegetation are closely related to each other. On the other hand, the runoff water quality is related to the green roof material, the construction of the roof by using the heavy materials, the phosphorus and nitrogen concentration (Berndtsson, 2010). Many researchers have pointed out that one of the most important environmental benefits of green areas is to reduce storm water runoff. Plants and soil absorb rainwater, and this led to water runoff to decrease.

In recent years, Urban Green Infrastructure (UGI) has been playing a significant role in coping with the environmental challenges in cities. The type of Urban Green Infrastructure (UGI) is green roofs so green roofs plants and growing medium layer filter the water and capture the rain water and using water for growing or evapotranspiration as well as the “reduction in runoff generally ranges from 50% to 100% depending on the type of green roof system, substrate depth, roof slope, plant variety” (plant variety play essential role on water runoff management because each plants have different capacity for “water interception, water retention and transpiration”) and duration of the rainfall (Rowe, 2011; Vijayarajhavan, 2016; Ong, 2002). Green areas can absorb water through plants, vegetation, especially trees. By doing the following, they can contribute to decreasing the water peak flow rate: (i) To reduce water flow time with absorption of water in the green roof system. (ii) To

maintain the amount of rainfall that reduces the total runoff. (iii) To ensure that the extra water spreads over a long period of time with the slow release of the water runoff by taking advantage of the water retention feature of the roof slope. (Cameron et al, 2012; Binachin, 2012; Mentens et al, 2006). The control of storm water runoff is one of the most important environmental advantages of green roof systems and many researchers draw attention to this benefit. In the forests, the soil absorbs 95% of the precipitation. But with the urbanization in recent years, this rate falls to 25% in the hard and watertight regions. This is one of the most important reasons for the rain flow in the cities and the extensive green roofs that have thick sub-layers can be taken into account as a solution. In terms of reducing the runoff, the use of extensive green roofs is more effective (Mentens, 2006).

Pauleit and Dume stated that the houses with a garden had three times less rainwater than compact buildings and that the vegetation-covered roofs had water regulating effect, indicating the amount of rainwater absorbed by plants and soil (Lagstrom, 2004). Green roofs allow absorbing rainwater to some extent and reducing water runoff in "extensive green roofs" to 60% and in "intensive green roofs" up to 100% (Denardo, 2005). Runoff water also has a negative impact on the ecosystem and human health because it contains contaminants (Scholz, 2001). Similarly, Kolb stated that 45% of this water can be reused with recycling and that the green roofs can manage rainwater. Pollutants are poured into rivers and streams with the rainwater runoff. "Conventional roofs" in cities, which are full of buildings, do not have the ability to absorb water. This is, in a way, a cause of the water runoff containing pollutants. The soils in the vegetated and undeveloped areas can absorb water easily, or at least, they allow storm water runoff slowly to pour into firstly rough and vegetated surfaces, then towards rivers and streams and, some quantity of this water is absorbed by the leaves and evaporated into the atmosphere. In traditional building roofs, the water flow is more rapid, so managing runoff in developed areas is an urgent and priority issue (Kolb, 2002). The roof slope is also a factor affecting the water flow level (Getter, 2007).

Similarly, VanWoert et al. say that urban areas such as roads, buildings, industrial areas increase the storm water runoff, unlike natural areas, since hard surfaces are impervious and so do not absorb water through the soil. However, natural areas, in other words, undeveloped areas (rural areas, vegetated areas) decrease storm water

runoff. And they say that creating green spaces in urban regions in order to deal with the challenge of water runoff is essential, and that's why they conducted two types of experiments to examine the water flow rate in the applications of different types of roof. First one was related to the sandy roof, the second one was regarding the green roof without vegetation (green roofs have layers for keeping extra water) and the third one was about the green roof with vegetation. In this experiment, they used extensive green roof (VanWoert, 2009) and add a certain amount of water for all types of roof. As a result, rainfall retention was observed by 48% for the sandy roof, 82% for the vegetated roof and 60% for the vegetated green roof layers. The second study was carried out on 3 sloping roofs types, such as sandy roofing, a green roof without vegetation, and a green roof with the vegetated layer. The slope was between 2% and 6.5%. In this test, it was observed that the water runoff increased in all three cases. However, when they decreased the slope level and increased the quantity of soil and layers depth, they observed that the water retention decreased. The researchers concluded that green roof systems not only decrease storm water runoff but also decrease the duration of extra water retention, and this was beyond the actual rainfall. The soil and the leaves of the vegetation hold the water between the soil and the plant and use this water. Extra water, because of the vegetation, moved slowly over the soil and transpiration took place and some of the water flowed (VanWoert et al, 2005). For an extensive green roof, the rate of storm water retention is increased by 82.8% (Berardi et al., 2013).

During small storms, the water flow from the green roof was less than the water flow from a bare roof. However, in the case of larger storms, this effect was gradually reduced. Green roofs delayed the water runoff more than traditional roofs. On a green roof, “57% of the peaking water flow was delayed up to 10 minutes compared to a bare roof (Berndtsson, 2010)”. Also, Simmons et al. (2008) observed that “green roofs generally delayed water runoff by 10 minutes”. Kristin L and his friends applied many varieties of slope options on the green roofs to calculate water runoff for each roof type. Then, water runoff implemented on the 12 extensive green roofs was analyzed. There were four types of slope (2%, 7%, 15%, and 25%) and this experiment was conducted for three different amount of water (light, medium, and heavy). They did this experiment because they thought that the impervious areas today cause most of the water flow and the increasing of floods. Looking at the other

problems in cities, they indicated that increased air temperature and noise, especially that the air quality was lowered. One of the main benefits of green areas is storm water management. In green roof systems, most precipitation is kept in the soil or in vegetation, and then the evaporation from the soil or plant surface is realized or with transpiration, it is released into the atmosphere again. In this regard, they tried to test the slope effect on water runoff. They implemented this experiment by using 12 different platforms of green roofs and these roofs were tested with four different slope levels (2%, 7%, 15%, and 25%), then rainfall and water runoff for each roof were recorded. Subsequently, they analyzed the data they obtained on rainy days throughout the year and calculated the water flow rate for each slope. They determined the effect of slope on water retention. In this context, they concluded that the minimum water retention was at the slope of 25% and the highest water retention was at the slope of 2%. The differences among the different sloping roofs were just about 9 %. However, they found that the water runoff was much delayed for all sloping green roofs compared to the conventional roofs (Krisrin, 2007).

Similarly, Roehr and Kong selected three case studies, Vancouver, Shanghai, and Kelowna, and compared all three to each other. These three case studies were conducted in different climate conditions. They calculated water gain and loss on a green roof for a year. The result of the study showed that the typical green roof is able to reduce rooftop water runoff by 27% in Vancouver, 100% in Kelowna and 55% in Shanghai. For this reason, it was understood that plant type and soil properties such as soil depth play an important role in water runoff management (Roeher, 2010). In addition to the impact of green roofs on storm water runoff, they have also an impact on water run-off quality (Stovin, 2012). Vijayaraghavan stated that green roof components of the water had an impact on the quality of water. After the application of the green roof, it was observed that the nutrients in the water flow decreased. However, it was found that runoff components were largely dependent on the nature of the substrates used in the green roof and the volume of precipitation. This suggests that the concentration of nitrate and phosphate in green roofs may be at high levels. (Vijayaraghavan, 2012).

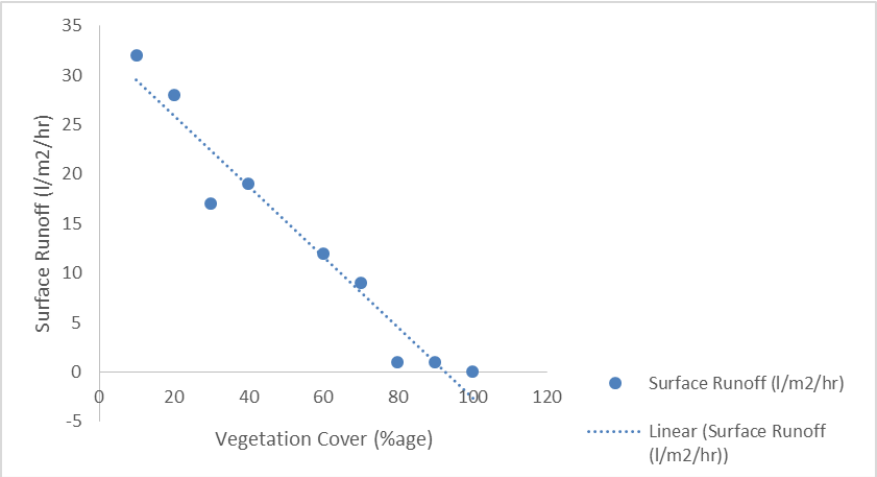

Figure 2.4: Relationship between surface runoff and precentage vegetation cover (Ong, 2003)

- **Air quality**

Urban areas often have higher levels of toxins in the air, and this polluted air is directly related to the deterioration of human health (Bianchini, 2012). In addition, trees in the cities have the ability to destroy air pollutants (Cameron et al., 2012). These green infrastructures reduce the levels of nitrogen dioxide and ozone in the air, thus improving air quality (Meerow, 2017). In regards to this ability, green roofs can help to decrease air pollution in two ways: Firstly, they control the temperature in the summer and winter and decrease "heating and air conditioning demand, and thus, less carbon dioxide is released". Secondly, thanks to green roof systems, the amount of carbon dioxide in the air is intercepted by photosynthesis (Getter et al., 2010). Bianchini et al. compared "the emissions of NO2, SO2, O3 and PM10 in the green roof material manufacturing process" in their study. New technologies make it possible to use low-density polyethylene and polymers to reduce the weight of a green roof. In this way, green roofs can balance air pollution because of the production of polymers in 13-32 years. However, low-density polymers manufacturing has a real negative effect on the environment. For this reason, it is essential to explore some other materials that can replace polymers. The result of the research has shown that the installation of a green roof system has more advantages than disadvantages in terms of reducing air pollution (Bianchi et al., 2009).

Currie and Bass in Toronto created six types of vegetation based on 7 scenarios and then they compared the effect of these different types of vegetation on air pollutants. Scenarios were conducted on the community scale, not on the building scale. They

divided Toronto's avenues into several plots. With a radius of 11.287 m, these plots were circular. Total areas provided for these plots were 0.04 ha per plot. Each plot was defined as "a low, medium, and high residential, commercial, industrial, institutional, and open spaces". They used GIS and UFOR model and a computer model for finding out air pollution in the different areas (NO2 remove, O3, PM10, SO2 removal) such as vegetated areas, extensive roofs, intensive roofs, green walls residential. They recorded this data for one year at the beginning of each hour. "Pollution removal was calculated for 03, SO2, NO2, C0 and PM10". They showed the results of each scenario by graphics. They reported that green roofs, whether they were intensive or extensive, improved urban air quality. Especially the improvements that trees on the intensive green roofs provided were significant in this regard. And the intensive green roofs were effective for the removal of PM10. They concluded that trees are the most important element in decreasing air pollution and stated that nearly "109 ha of green roofs remove 7,87 metric tons of air pollution per year" (Currie, 2008).

Similarly, Tan and Sia evaluated the environmental advantages of green roof systems and compared the buildings with and without green roofs. They installed four types of green roof systems on multi-story car parks of public buildings and measured the SO2 and NO2. They selected drought-tolerant planet and evaluated the temperature of the roof surface before and after installation. They measured the ambient air temperature of the green roof, bare surface, roof surface, and the soil after installation. The results showed that the temperature of the vegetation surface was 15 - 20 C lower than the bare surfaces on the roof. Their evaluations showed that the temperature depended on substrate moisture on green roofs and if it were not provided enough water for the green roofs, the temperature would go up. The other result was regarding air quality. The green roofs had an impact on air gaseous pollutants. They absorbed these pollutants and improved air quality. Then, they measured air quality through MSCP for a gaseous pollutant. It was found that the level of SO2 was reduced by 6- 37% after the implementation of the green roof system and NO2 level was reduced by 20%, and nitric acid level increased by 48% (Tan, 2005).

Deutsch et al. used the "urban forest effect model for Washington DC" and stated that "green roofs are capable of reducing air pollution" (Deutsch, 2005). Also, Yung

et al. studied the effect of green roofs on air quality, and this study took place in Chicago. In a total of 19.8 hectares of green roof area, 71 green roofs were used. Absorption of SO2, NO2, O3, OM10 by green roof was calculated. In these experiments, particularly intensive / semi-extensive type green roofs were used. O3 was the most effective air pollutant seen in Chicago, then PM10, SO2, and in winter NO2 reached a peak. They measured these pollutants through several formulae and found that 19.8-hectare green roof absorbed 52% of O3, 27% of NO2, 14% of OM10, and 7% of SO2. And they concluded that green roofs have the potential for reducing air pollution (Yang, 2008).

2.3.2 Economy benefits

In the long run, the green roofs are really more economical than the bare roof in many aspects. The cost of applying traditional bare roof is cheaper than green roofs. In other words, the cost of green roof systems is roughly twice that of traditional roofs. However, planting vegetation on the roof provides an economic benefit for the owners. Owners with a bare roof should replace the building roof waterproofing layers every 10 years, while green roof life spans can be up to 90 years (Porche et al., 2009). Wong et al, in their study conducted in Singapore, tried to highlight green roofs' economic benefits and they compared green roofs with “conventional roofs” in terms of their initial and life-cycle costs. As a methodology, in the first step, they started to ask some questions about the case study and processing data. Then, they found the initial costs of a green roof, their replacement and maintenance costs. After, they determined that the maintenance cost of an extensive green roof is minimal, but “intensive green roof” maintenance cost was higher than both extensive and bare roof. They calculated the cost of each tree on “intensive green roofs”. They found that although the “extensive green roofs” had a high initial cost, they had lower life-cycle cost compared with “intensive green roofs”. The result of the study showed that the extensive green roofs could decrease building energy consumption. While net energy saving for the extensive green roof was by 14.6%, it was found by 4% for the “intensive green roof”. As a result, in terms of the lifespan, energy consumption, and maintenance costs, an “extensive green roof” is more affordable than a conventional flat roof (Wong, 2003).

- **Energy cost**

Green roofs reduce the energy consumption of buildings in both hot and cold climates and decrease the indoor temperature in summer. Simmons et al. showed that "extensive green roofs" have the ability to reduce surface and building indoor temperature in subtropical regions. "They compared the performance of six different extensive green roof designs." As a result, they concluded that green roofs can decrease roof surface by 38 C and can cool the inside of building up to 18 C (Simmon's et al, 2008). Intensive green roofs provide shading by trees by blocking the direct effect of sunlight (Berardi et al., 2013).

In another study, it was revealed that green roofs in Greece reduce the indoor temperature of the building to 4K and green roofs for the enclosed area can reduce "the energy consumption between 2% and 48% for cooling" (Niachou A et al, 2001). A study in Singapore found that the temperature change in the bare roof was very high compared to the green roofs. Analysis conducted on summer days showed that green roofs reduced surface temperature and positively affected soil temperature (Qin X et al, 2012). Jim analyzed the role of the green roofs in Hong Kong. In the hot and humid climate, they examined three vegetated plots covered with grass. During the analysis, soil-covered plants and shrubs, biomass structure, type (species) and plant form appeared to play the most important role in energy saving (Jim C, 2012).

Getter et al in their study in the Midwestern of U.S with hot and humid summer days and cold and snowy winters found that in fall temperature 5 c lower that bare roof temperature and during cold and humid condition the heat flux leaving the building was lower, the temperature on top of the bare and green roof is variable in winter without snow than on snowy days so they said extensive green roofs decrease buildings "heat flux by 13% in winter and 167% in summer days" (Getter K et al, 2012). Olivieri et al. said in Mediterranean coastal climate in summer the density of plants in a green roof is increased so the roof structure appreciably insulated so green roof can decreased cooling consumption up to 60% in comparison to a bare roof In one study, the researchers compared two rooms with different roof structures, the bare roof and the green roof, and concluded that the temperature change and heat flow in the roof were low on the green roofs (Berardi et al., 2013).

The green roof helps lower energy costs. Because it has the ability to reduce the heat flow entering the building in the summer months. Green roofs can reduce the cost of heating in winter, especially in older buildings. In fact, green roofs act like insulators in some conditions, such as summer, absorb the heat in the plant and release this heat slowly throughout the day. In winter, it keeps the heat inside the building. Two basic dimensions are taken into account when building a house. The first is the aspect of the economy and the other is the aspect of "the effect of the urban heat island". The temperature of cities is higher than suburban in summer because cities are full of buildings, roads, and absorb the sun's rays and become warm air. At night, the city releases slowly the air known as the heat island effect. In his research, Theodosiou focused mainly on the development of green roof technology and the energy consumption of green roof buildings for decades. He emphasized that the benefits of a green roof are qualitative rather than quantitative. First of all, he stated that the most important reason for using green roof systems is to contribute to keeping building indoor temperature in winter. Because, the green roof layers provide insulation for the roof of the building in winter and maintains the heat, while in the summer it acts as an isolator and protects the building against overheating (heat absorption) due to the sunlight. In addition to reducing the impact of the urban heat island, he also touched upon the benefits of green roof systems such as reducing air pollution, increasing roof life, preventing local floods, providing visual attraction, creating habitat for urban natural life and reducing urban noise and providing social benefits (Theodosiou, 2008).

- **Green roofs and agriculture production**

Today, many manufacturers are interested in producing food in urban areas. Although there are many manufacturers in urban areas, there is not enough free space to produce in cities. In this case, the production on roofs is an alternative to be considered (Rowe, 2011). Colla et al. did their research in Newyork University, Toronto, Ontario, and Canada. They aimed to investigate the condition of bees in six different places. For this purpose, they used two extensive green roofs and four non-green roofs. These roofs were two or three storey building roofs. They did research on these bees for two years and gathered bees two years later. They found some differences between the bee species "in the building with a green roof and the bees in the building without the green roof." They found many different types of bees on the

green roofs, and some of these species were not native. The results obtained from the analyses showed that the two green roofs support the same bee species. Therefore, this research reveals that green roofs provide living space for many bee species (Colla, 2009).

- **Increase roof membrane life**

A green roof increases roof membrane life of the building, especially during the hot summer days. Traditional roof temperatures can be increased up to 60 ° C when the roof covering is not protected by ballast insulation. This brings an additional economic burden since it must be replaced within fifteen or twenty years. Replacing the roof membrane is costly. When roof temperature increases and absorption occurs, roofs release this heat to the atmosphere and this is one of the reasons for urban warming. The components of the green roof make the temperature moderate and protect the roof from excessive heat and sunlight. Thus, the heat of the sun is absorbed by the roof vegetation and the roofs serve as insulation and extend the life of the roof up to 50 years. In Toronto, the temperature of the traditional roofs reached 70 °C, while the temperature of the green roofs was 25 °C (Liu, 2003). In summer days, the temperature of the roof surface reaches approximately 80-100°C, while it reaches -20°C in the cold winter nights. These temperature changes on the roofs affect the lifespan of roof, ultimately damaging the structure of roof, and these extremely high and low temperatures shorten the lifespan of roof. However, the green roofs do not allow the temperature to fall below -5 ° C in winter and to exceed 25 °C in summer. In this way, they provide economic benefits by contributing to the lifespan of roof. (Lagstrom, 2004).

2.3.3 Social Benefits of Green Roof Systems

Modern cities are overcome by the built environment, which completely different with the primary habitats it changes via its mass of hard surfaces. This shape of the built environment can have some ecological effects. Urban habitats are too dry for vegetation because of surface or nonexistent soil also they maybe overmuch moist because of insufficient drainage affected through the impermeability of hard surfaces (Lundholm, 2006).

- **Protecting urban habitat and providing aesthetic attraction**

Public access to extensive green roofs is not free. Because, in such environments, there can be many species of birds, insects, and microorganisms. In Switzerland, for example, some researchers have shown that, in addition to many bird species, 9 species of orchids have been identified in Germany.

Some researchers investigated "green roof systems installed at the Ford Motor Company's River Rouge assembly plant in Dearborn, Michigan". They examined insects and bird species of this type of roof. As a result of 4-week monitoring, they found many different types of birds and insects on the roof, including spiders, bees, and flies (Coffman, 2005) Similarly, a comprehensive study was conducted in the UK and gathered information on insect species in the Leicester garden. They have observed all insect species for 30 years. They focused on one family of insects for three years. As a result of this study in England, 15 species were identified as new and it was concluded that the gardens contribute to increasing the urban habitat (Azmeh et al., 1998).

Stephan Brenneisen stated that extensive green roofs could improve urban biodiversity and create habitats for rare and widespread wildlife. He also mentioned that, while new flat roof buildings are being built in Switzerland, the construction of green roofs is compulsory. He stated that the use of natural soil in such roofs could be beneficial in terms of contributing to the diversity of biodiversity in the region. Unlike the natural habitats, the soil on the green roof system ground is not deep and the animal species living under the ground will move to the outer surface of the soil especially in arid conditions (Brenneisen, 2006). Green roofs are capable of providing an aesthetic green area to places where the green space on the ground is not enough or not at all. (Berndtsson, 2010). The vegetation and the appearance of the plants have positive effects such as reducing stress, controlling tension, making people feel pleasant and improving human mental health (Urich, 1991). Although the gardens and green areas affect the well-being of the people and facilitate the control of blood pressure, heart rate and cholesterol levels, some sources emphasize that green infrastructure has no impact on the health of the individual (Ross W.F, 2012).

Green areas can provide a healthy environment, pleasant aesthetic, physical and psychological benefits. Payne et al. found that people who went to the park had a

healthier mindset and that these people could relax with active rest (Tzoluas, 2007). Madre F and his friends said that green roofs could increase urban wildlife by providing new areas on the roof tops. They worked on 115 large green roofs in northern France, focusing on wild plants and identified 176 plant species. 86% of these species were domestic and they found that green roofs could provide living space for many species. In this study, they concluded that green roofs could play an important role in increasing urban biodiversity and if we these types of roof became widespread in cities, many rare and different plants could be grown in these buildings (Madre, 2014).

- **Noise reduction**

The noise caused by high sound waves originating from rail, road, and air can cause health problems. It has been determined that the roofs having plant combination play a more effective role in absorbing high sound waves compared to the bare roofs with a hard surface (Rowe, 2011).

Green roofs are also effective in reducing noise pollution. Green roofs increase transmission loses from 5dB to 13dB at low and mid and high frequencies (Van, 2011; Connely, 2008). Noise pollution affects the social and economic life of the population. From a social point of view, the noise makes a negative impact on people's resting. From an economic point of view, it can reduce employers' productivity (Lagstrom, 2004). The conventional roof reduces noise by 33 dB, while green roofs can reduce noise by 41dB when they were dry and 51dB when they were wet. This shows that the green roofs have the ability to reduce noise by more than 8dB compared to the conventional roof. Green roofs with lower substrate depth can provide noise reduction up to 15-20 cm depth (Rowe, 2011).

Van et al. used the Sound Propagation Model and parameters to calculate the noise reduction effect of two types of green roof (extensive, intense). They found that thicker green roofs did not have much effect on reducing noise, and both extensive and intensive green roofs reduced sound waves on the building. It was observed that extensive and intensive green roofs reduced noise around 10 dB at high frequencies and low frequencies were not affected much by extensive or intense green roofs (VanWoert, 2005). Similarly, Lagstrom used Schroeder method to calculate sound impulses in bare and green roofs. This method was not expensive and could result

very quickly. While the green roof layers gave less noise to the building, it was observed that the bare roofs with waterproof membranes gave more noise to the buildings. In this study, firstly sound measurement was made, then green and bare roofs were established, then two types of roofs sound level were compared to each other. The sound signal was sent from the computer to the speaker via the amplifier. When the first sound reached the microphone, the signal strength was increased and the sound passing through the roof of the building was recorded on the computer. The noise level results were repeated 16 times. The noise reduction on the green roof was found to be between 5 and 20 dB. It was concluded that there was a difference in the sound pressure of the two studies and the noise reduction effect of the green roofs (Lagstrom, 2004). Yang et al. also stated that green roofs reduce the noise in urban areas because the vegetation in the green roof is capable of absorbing sound (Van, 2011; Connelly, 2012). In this context, it is considered that green roofs have a positive effect on buildings in airports, industrial zones, and urban environments (Rowe, 2011).

3. GREEN ROOF EXPERIENCES FROM SELECTED COUNTRIES

When we look at the history of green roofs, we must go to "Babylon's hanging gardens" in the fifth century, which we can call the first green roof application. Subsequently, we see similar roof applications in "the ziggurats of ancient Mesopotamia." Green roofs are expected to play an important role in the urban design of the future and play a key role in the construction of cities with high living conditions. Bare roofs with almost no economic value-added can be transformed into green roof areas such as green parks, vegetable gardens, and aesthetically pleasing environments, and this means a great gain in terms of both economic and human welfare. In recent years, green roof applications have become widespread at an unprecedented level. The use of green roofs on all kinds of buildings, from private houses and schools to public institutions and enterprises, is becoming widespread. Such structures are widely used in the US and Canada, particularly in Europe and Asia. In particular, Germany is the first in Europe in green roof application. There are hundreds of roof gardens in this country, Berlin is the one popular example of German green roof implementation .In Asia, Japan is considered the leading country in this regard. Japan has even become the center of roof garden technologies worldwide. There is even legal regulation in Tokyo regarding the green roof systems and 20% of the newly constructed building roofs need to be built in the form of a green roof in Tokyo (Grant et al., 2019). Northern European countries, where weather conditions are relatively colder, have used green roofs to improve thermal insulation. Japan has identified green roofs as the first start-up technology to reduce "urban heat island" and promote sustainable buildings (Berardi et al., 2013).

Green roof system applications in the world attract the attention of every country because of some issues came to fore such as the climate change problem, the reduction of green areas day by day, the need to improve the city climate and biodiversity, the rainwater runoff, and providing an aesthetic architecture in the city.

The changing living conditions in the cities also changed people's lifestyles by changing their lifestyles, which in turn led to a decrease in green spaces. The green

areas that should be in the cities were converted into concrete areas due to excessive building construction and intense human migration to urban areas. This has encouraged the emergence of projects to take measures to the lack of enough green areas in cities. Thus, many projects were initiated. The most striking and perhaps most ergonomic of these projects is the green roof applications that aim to regain the destroyed plant areas (Beyhan et al., 2013).

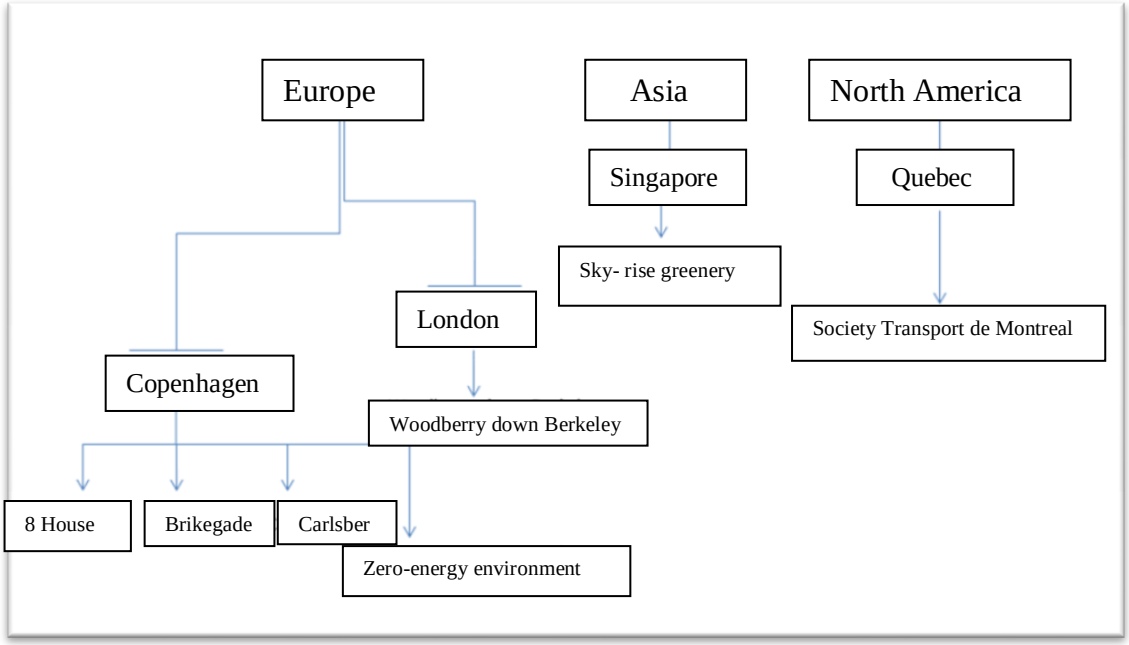

Figure 3.1 : The figure represent green roof experiences from selected country.

3.1 Europe

Green roofs have several of benefits. They act like an isolator, consumption energy reducing energy, decreasing costs also they absorb amount of rain water. The green roofs are a pleasure place of many insects (such as bees) and birds. In southern Europe, requesting for implementation of green roofs increased in modern day building infrastructures. Green roof depends on Europe's water supply and because of the temperature, raising it has become an issue that has plagued the region. European countries emphasize on the benefits of green roof about captivating a bit of CO2 from the air. It means green roofs plants fighting with climate change (European Federation of Green Roof Associations – EFB)

3.1.1 Berlin

The Green Roofs implementation in Germany goes back to the early 1980s. The main purpose was to convert the bare roof to green living roofs, first extensive green roof implemented in Germany and the main focus was about the economical benefits of this types of roofs then the intensive green roofs became famous and used for many purposes.

the popular example of Germany green roofs project is located in Berlin city, the main purpose of the green roof projects implementation in Berlin is decreasing the negative effects of storm water in urban areas and reducing the air temperature. One of the famous green roof projects in Berlin is The ufa-Fabrik Berlin is an "International Center for Culture and Ecology this project located in southern of Berlin the roofs of this projects isn't bare there are 4,000 square meters of green roof planted and used native plants in this project. They used green roofs for improving buildings insulation and reducing air pollution, this project showed that the green roofs per year absorb approximately 2000 kilograms of dust.

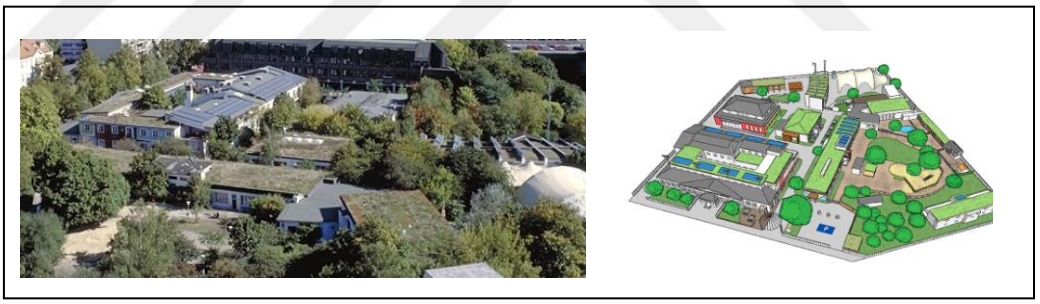

Figure 3.2 : Berlin Ufa-Fabrik green roof project (URL-4)

3.1.2 Copenhagen

In Europe, Copenhagen is the capital and most crowded city of Denmark. In Copenhagen, it has focused on the implementations of a green roof as a part of urban development since 2008. Green roof systems have been used in Copenhagen since 2010 and constructors have been building green roofs at all sizes. In the beginning, the purpose of the implementation of green roof systems in Copenhagen was storm water runoff management. Then the authorities realized that they could reduce the effect of urban heat island by building green roofs. Today, the city of Copenhagen has at least 40 green roofs including residential, commercial and public buildings. It has been developed three main projects in Copenhagen in this regard mainly focused

on reducing the impact of the urban heat island, they built two sloping green roofs in a total of 1,700 m² in 8 houses.

One of the famous green roof applications in Denmark, **"Eight House (Tallet in Danish)"** is a "mixed-use bowtie-shaped" building, with three different types of residences, 10,000 m2 of retail and office, the largest private development of Denmark. In the beginning, two sloping green roofs were placed in total 1,700 m2 to reduce the impact of the urban heat island. The terraces along the road around the building were built with hundreds of half-dense 1 square meters of gardens. These terraces also have slopes, so the vegetation can be easily seen from the interior windows.

Figure 3.3 : Copenhagen 8 house green roof project (URL-5)

As the second project, the Birkegade Rooftop has been built. The area of this roof covers 900 m². The last project regarding the green roof system implementations in Copenhagen is called Warehouse Toldbod. The purpose of this project is to create a new recreation area and to improve the urban climate. Ware House roof area is 1900 m².

Figure 3.4 : Brikegade green roof in Copenhagen city (URL-6).

There is a local planning for Carlsberg district of Copenhagen. In the old industrial zone of the district, 6500 houses will be built. When building these residents, it will be considered that they have a modern and sustainable architectural structure. "The development plan is based on the classical block structure, which includes small streets, squares and plazas." The urban zone area will include cultural and commercial buildings and facilities and residences that will provide active urban living. In these structures, rainwater management and utilization will be provided through roofs. The flat roofs to be built in new buildings will cover an area of 30 hectares.

Figure 3.5 : The local area plan for Carlsberg city(Copenhagen Municipality 2007-2009**).**

There is also the "**Zero-Energy Environmental Center"** located by the harbor to the North of Copenhagen. The aim of this project is to contribute to the sustainable development of North Harbour. Solar panels and photovoltaic cells have been used in order to provide zero energy need in a building. Another object is to collect rainwater through the roof. Its roof area covers1600 m2.

Figure 3.6 : Zero-energy environmental center (Copenhagen Municipality).

3.1.2 London

The Mayor of London, "Boris Johnson's Climate Change Adaptation Strategy", has introduced some conditions for green roofs in new buildings in the "Central Activities Area of London". The aim was to create a new green roof area of at least 100,000 m² in 2012. The aim of the green roof installation in London is to provide aesthetically pleasing roofs, natural habitats, building insulation, rainwater management, and air temperatures, and to reduce "the urban heat island effect". Two projects explained below implemented as developed sustainable buildings.

Woodberry down Berkeley North East London

Woodberry Down is a unique place and close to the Woodberry Down Wetlands, and there are links between these two. Here, the number of buildings intended to provide biodiversity increases and projects are developed with the understanding that buildings create a space for nature. The size of the project in this region is 25.8 hectares. The roof type, which is planned to be constructed, is "extensive green roofs."

Figure 3.7: Woodberry Down Berkeley green roof in London (URL-7).

3.2 Asia

The Larg-cities of Asia are concern about environmental problems like air pollution, water flooding, run-off, and lack of recreational green space and they Residents worry increasingly about food security and climate change so green roofs can overcome with all these issues (Mathews, 2013).

3.2.1 Singapore

The authorities have been working on a greening blueprint of the city since 1992 to turn the city of Singapore into a garden town with 148 acres of covered roofs. When 1986 was compared to present-day Singapore, only 36% were green. Singapore introduced the Skyrise Greenery Incentive Scheme (SGIS) in the period of 2009 - 2015. The first purpose of introducing SGIS to support Skyrise greenery installations on the existing buildings of Singapore. The Second one is to create a specific image of the city in the tropical climate through extensive green facades and Skyrise green gardens. The third one is to promote environmental benefits, such as reducing the Urban Heat Island effect and improving air quality through plants. In this city, Parkroyal Hotel is the densest example of green roofs and vegetation. The hotel's roof is covered with 15,000 m² of vegetation.

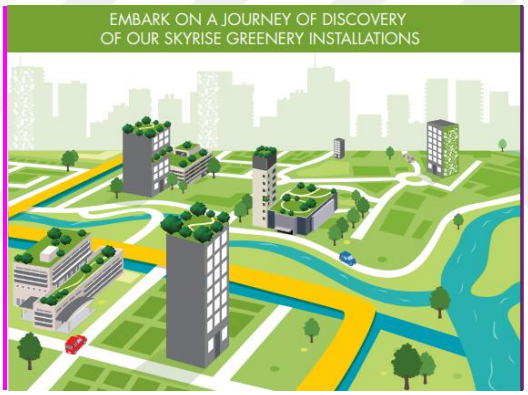

Figure 3.8: Skyrise greenery installation Singapore (URL-8)

The benefits of skyrise greenery are widely explained. Mitigating urban heat island effects, decreasing energy consumption, reducing noise pollution, skyrise greenery also creates an aesthetically attractive environment for public to live, work and plays in, and creates habitats to increase biodiversity in urban areas. Green roof can help to promote community interaction among residents by developing a sense of ownership also it help to improve mental problems.

3.3 Canada

Each cities of Canada using green roofs for different purposes. In 2009, Toronto became the first city in North America to pass a bylaw requiring all new construction with a footprint of more than 2,000 square meters to incorporate a green roof. In city of Monteral, the municipality implement green roofs for energy efficiency and urban

agriculture. The Torento city the most important reason for using green roof is controlling storm water management and air pollution. The main reason of green roof implementation in Waterloo is using them in storm water controlling and improves air quality (Lawlor, 2006).

3.3.1 Quebec

The Societe Transport de Montreal building was opened on January 6, 2014. This building is new Stinson garage using for bus in Quebec. The building has the capability for 300 normal and electric buses and over the building is two storey and very big. The project is plan according to the law of sustainable development. A plan is very large project rely on sustainability it is comes from STM's massive green roof. Green roof company implemented over 80,000 square feet of HYDROPACK to converted the building to the biggest green roof in Quebec in October 2013.

The building feature component is as a fifth façade and composed of strips of green space and major skylights in the form of belts. Building is covered by a 35,000 square meter (37.6736 ft2) roof.

Figure 3.9: The green roof application on Societe Transport de Montreal building roof in Quebec (URL-9).

The selected countries green roof projects showed that different countries with different weather and location used green roofs for different purposes, for example European countries because of the cold weather focused on buildings insulation and rain water management also Asian countries have used green roofs mostly for mitigating urban heat island effect and aesthetic attraction.

4. CASE STUDY: ANALYSIS OF MICROCLIMATE EFFECTS OF GREEN ROOF IN ÇELIKTEPE NEIGHBORHOOD

This section contains general information about the district of Çeliktepe. Its location in Istanbul. After revealing the purpose of the subject, the district problems were identified and analyzed.

In order to understand the effects of green areas on environment and ecology, areas with large constructions and areas with low green areas should be considered. Istanbul is the most crowded cities in Turkey, there are too many buildings here, and green areas are not enough for a sustainable city, so it is better to choose this neighborhood as an example to find out the effect of green roofs on climate. In addition, very dense areas in terms of buildings and the areas with very little green spaces were randomly chosen.

4.1 Background Information

Çeliktepe is located in Kagithane district, in Istanbul, Turkey. The neighborhood of Çeliktepe is located on the European side. Sariyer is located in the north of the district, Besiktas is located in the northeast and Sisli is located in the southeast of the district. The population of Çeliktepe is 32.935 in 2016.

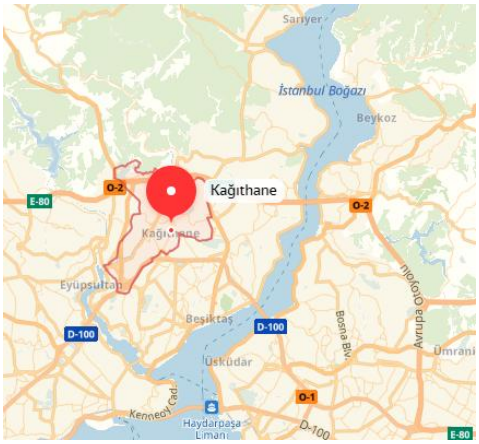

Figure 4.1: Kagithane location on Istanbul (URL-10)

Çeliktepe is one of the crowded neighborhoods in Istanbul city. The neighborhood total areas are 5340585,11 m² and just 953 m² of the whole neighborhood reserved

for open spaces and parks. The neighborhood includes high dense building mass with different floors. The main street name is Ismet Inonu Caddesi and the street width is about 11 m this street is the broadest street in the area, other roads is very narrow also these roads pedestrian roads are really narrow or they organized without pedestrian road. The Çeliktepe is sloppy area some streets slope is over the 25%.The renovation projects started in Çeliktepe because of unorganized building mass. For Çeliktepe chosen for simulating the effects of green roof on urban areas because this neighborhood is problematic area like high population, lack of green and open spaces, each person need at least 9 $m^2$of green space for healthy life, mass buildings area and this is main reason for urban heat island effect and air pollution.

Table 4.1 : General information about Çeliktepe neighborhood (Kagithane Muniipality 2018).

Location	Neighborhood total are (m^2)	Population	Open space area(m^2)	% Slope	Roads width (m)
Çeliktepe	534.584,11	32.935	935	Up to 30%	11 m

4.2 Data and Methodology

In this research, a particular tool and some microclimate data were utilized. It cannot be said that the case study was large enough in terms of scope. In the context of this case study, a neighborhood of approximately 32,000 inhabitants was chosen.

Figure 4.2: Çeliktepe satellite image (URL-11)

As a source of simulation of the neighborhood microclimate, microclimate geo-resources which can be used online on the internet have been used. The basic map used in simulation is Bitmap (BMP). Bitmap is actually an image file format on a computer. It is used to create and store charts. The image here is a grid of rows and columns. Thanks to these grids, images could be obtained from the data. Satellite imagery of the neighborhood was obtained through Google earth. These images were

then converted to a bitmap. GIS is an efficient means of data collection and analysis. information about the buildings location, floor number, areas in the neighborhood was compiled using Geographical Information System (GIS). Data on the building walls and roofs of the neighborhood were taken from Google Earth.

ENVI-met® is a modeling tool. Thanks to ENVI-met, the interaction between building-air-vegetation can be modeled in three dimensions. ENVI-met is commonly used to estimate weather conditions or future climatic conditions in particular. In terms of our research, this software analyzes micro-scale thermal interactions in urban environments. The grid resolution of the model is 10 seconds at 0.5-10 meters. Thanks to this model, the analysis process can be made up to 24-48 hours. In the realization of simulation by Envi-met, data such as vegetation, ground surfaces, building, soil, and climatic conditions provide input to the software. The building can be simulated according to these inputs. This software considers all types of solar radiation (direct, reflected and diffused) and calculates the average radiant temperature. In terms of predicting values for some future parameters, some key variables that can be calculated by Envi-met are air and soil temperature, wind speed and direction, air and soil moisture, turbulence, radiation flows, gas and particle diffusion. ENVI-MET, first of all, performs two stages before starting a simulation. As a first stage, it regulates the input data for the urban area. In this context, especially horizontal and vertical dimensions regarding some features such as surface materials, ground cover, vegetation size and coverage, buildings form and so on. The building can be simulated according to these inputs. The data within the scope of the input is designed in a three-dimensional environment. With three dimensions, trees, buildings, surfaces are shown in various sizes of grid cells from 0.5 meters to 10 meters. The second step is to make some changes to the configuration file. For example, information on site location, temperature, wind speed, humidity, PMV parameters, and soil types and vegetation variables are entered into the database. As a result of using ENVI-met, output in binary file format (.EDI / .EDT) is obtained and these outputs can be converted to visual data later in the LEONARDO 3.0 program. Each output file contains a large number of different information. There are three types of layers to create the output. These are the data layer, the special layer, and the vector layer. The data layer contains sequential data such as temperature. The special layer represents a single data such as building and vegetation. The vector

layer represents vector information such as wind forecast. First, environmental and physical information on the case study is collected by means of online tools such as GIS. ENVI-Met® software can be used for micro-climatic data. The problem here is the ability of people to change these microclimatic data. As the most popular example here, we can give the effect of the Urban Heat Island which was widely mentioned in the literature. The best way for urban planners working to reveal the issues affecting the urban micro-climate is to simulate using the ENVI-met modeling tool. In order to be able to use ENVI-met software, data inputs related to climatic conditions should be made. Data on these climatic inputs were collected in the field and used in lieu of the normal meteorological year data.

Table 4.2 : Scenario's condition when starting simulation

Simulation	I. Scenario	II. Scenario
Location	Çeliktepe	Çeliktepe
Time	10 AM, 12 PM, 21 PM	10 AM, 12 PM, 21 PM
Roads material	Flagstone, Asphalt	Flagstone, Asphalt
Roof material	Terracotta	Extensive Green roof

This studies data was collected in July 2018, the climate stations collected the data such as temperature, humidity, solar radiation, wind speed, and globe temperature. The measurements were started at 8:00 am. The buildings block of the neighborhood was tested with and without extensive green roofs, extensive green roofs chosen because the implementation is cheaper than intensive green roofs and for using intensive green roof building should be strong enough because intensive green roofs are heavy, so based on the effect of the green roof on temperature, CO_2 and airflow value and wind speed in two different scenarios. Wind is an important resource in cooling the urban environment and it is one of the contributing factors in increasing UHI effect. In this project, the simulation started by two scenarios in Çeliktepe neighborhood. Çeliktepe has mass buildings with different storey blocks and narrow roads. In order to gain an understanding of which type of building roofs (green, bare) and open spaces (Vegetation, hard surfaces like asphalt) effect on orientation,

temperature, urban heat island in Çeliktepe neighborhood, most of the neighborhood land areas were discovered and it was found that over 90% of them were constructed.

4.3 Scenarios

The specific purpose of this chapter is comparing outdoor microclimate conditions in two different roof types, first one is bare roof and second one is green roof. Implemented green roof on buildings and analyzing the effect of neighborhood building's roof material on atmosphere temperature, CO2, wind speed so two scenarios located; in both scenarios the location, buildings arrangement, roads, climate condition is same, the difference between these two scenarios is building's roof material. First scenario is a building with bare roofs the roofs material is terracotta. Second scenario is located in same neighborhood with same road material and arrangement, same climate and same building mass but the building's roof material is different, the Second scenario roofs were converted to ecological green roofs. Regarding to (Table, 4.2) the neighborhood roads are narrow and it is covered up with building mass also, we are faced with lack of green spaces in Çeliktepe neighborhood. The approximately 90% of the land covered with buildings**.**

4.3.1 First Scenario

Both scenarios are located in Çeliktepe neighborhood in Istanbul district. In first scenario, simulation is taken on existing situation. All the roofs material and buildings wall material, roads structure is same as current situation. Roads material is asphalt and flagstone, roofs structure is terracotta. Existing situation microclimatic simulation is done with Envi-met tool; microclimate is the suite of climatic conditions measured in localized areas near the earth surface also microclimatic conditions depend on such factors as temperature, humidity, wind and turbulence. The microclimate condition in existing situation tested in three different hours (10 AM, 12 PM, 21 PM). First Scenario air temperature, CO2 and wind speed of existing situation measured. First and Second Photos below are indicates case study location in satellite and buildings arrangement, also main and auxiliary roads, zone form and open spaces size. Third photo's simulated by ENVI-met tool this is existing situation of neighborhood and building's roof material specifically mentioned in photo. The case study divided to four part (a, b, c, d) for detail analyzing, each part has different

character. Part a the buildings are sticked together, the minimum open spaces belongs to part a and one small park is located in this part, some of the buildings have been renovated in this section. Part b, buildings are close to each other but roads are wider than the part a this part is out of green spaces, the renewal projects is started in this part too. Part c is like part b but the roads are too sloppy in this section. Part d is the most instructed part one small park is located in this section, the neighborhood main road is located in this part and most of the buildings are old.

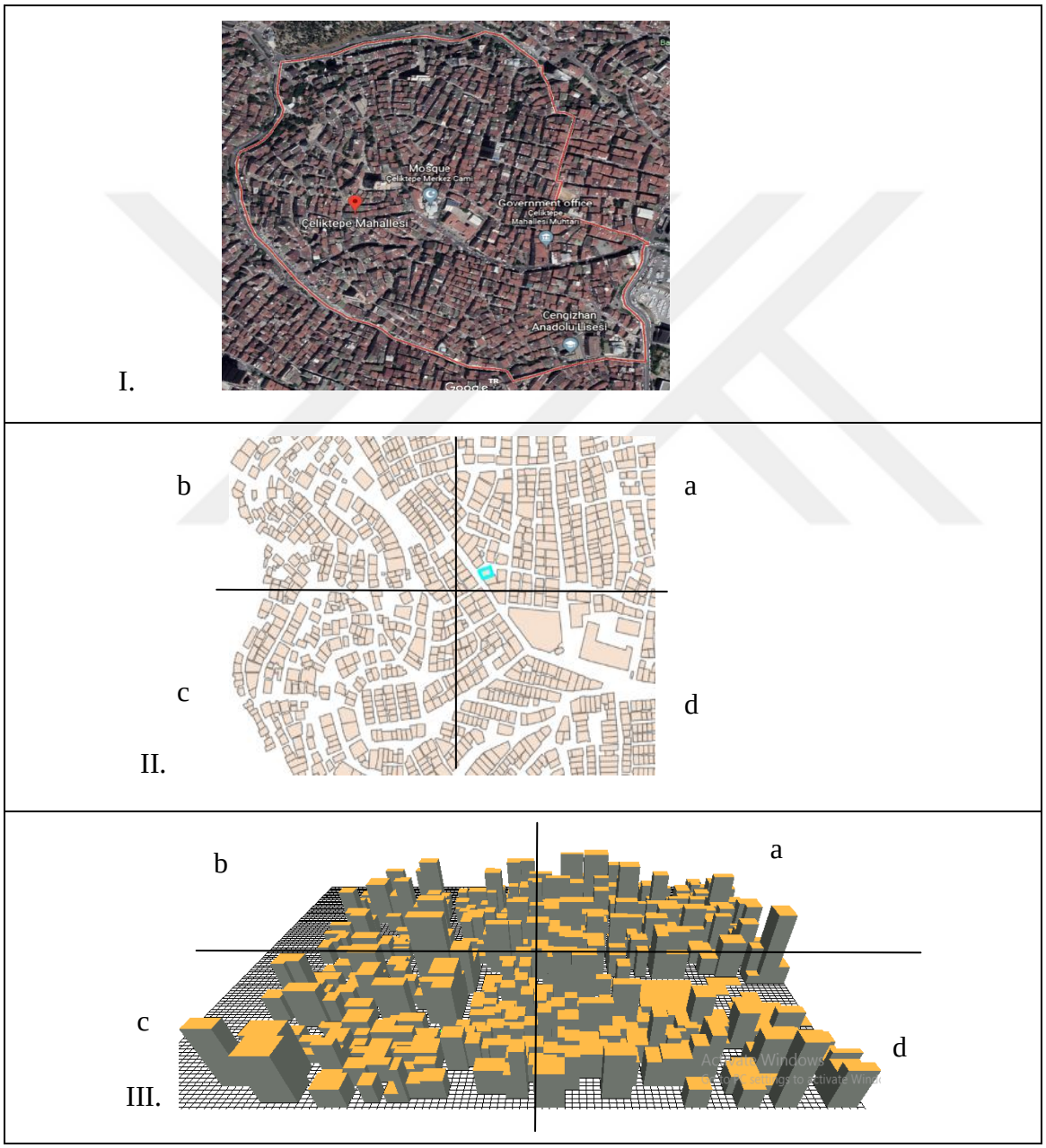

Figure 4.3: I case study satellite image. II. Case study building information taken from GIS. III. Çeliktepe existing situation simulated in ENVI-met tool

4.3.2 Second Scenario

Second scenario is located in Çeliktepe neighborhood in Istanbul district. Simulation is taken after green roof implementation. All the buildings, wall material, roads structure is same as current situation just terracotta roofs converted to green extensive roofs. Roads material is asphalt and flagstone, roofs structure is plant. Green roof microclimatic simulation is done with Envi-met tool; The microclimate condition in green roof tested in three different hours (10 AM, 12 PM, 21 PM). II. Scenario's CO2, air temperature, wind speed measured.

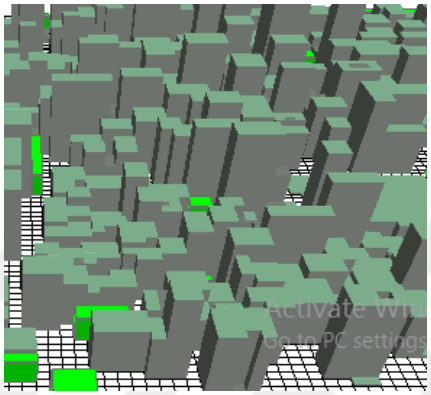

Figure 4.4 : Green roof simulation via ENVI-met tool

4.4 Analysis

The both scenarios simulated done in ENVI-met tool for 24 hours at 23.06.2018.

Table 4.3 : Information about scenario-I

Scenario	Date	Scale	Time	Location	Climate
I	23.06.2018	150000 sqm	10 AM 12 PM 21 PM	Çeliktepe Istanbul	Warm and humid

Table 4.4 : Information about scenario-II

Scenario	Date	Scale	Time	Location	Climate
II	23.06.2018	150000 sqm	10 AM. 12 PM 21 PM	Çeliktepe Istanbul	Warm and humid

4.4.1 Temperature change

The urban temperature in that date is hot and regarding to literature review's hot dry or humid is good time to observing green roofs performance on atmosphere. The air temperature analysis result showed below: Temperature changes are indicate with 10 different colors, the colors change from every 0.25 ° C.

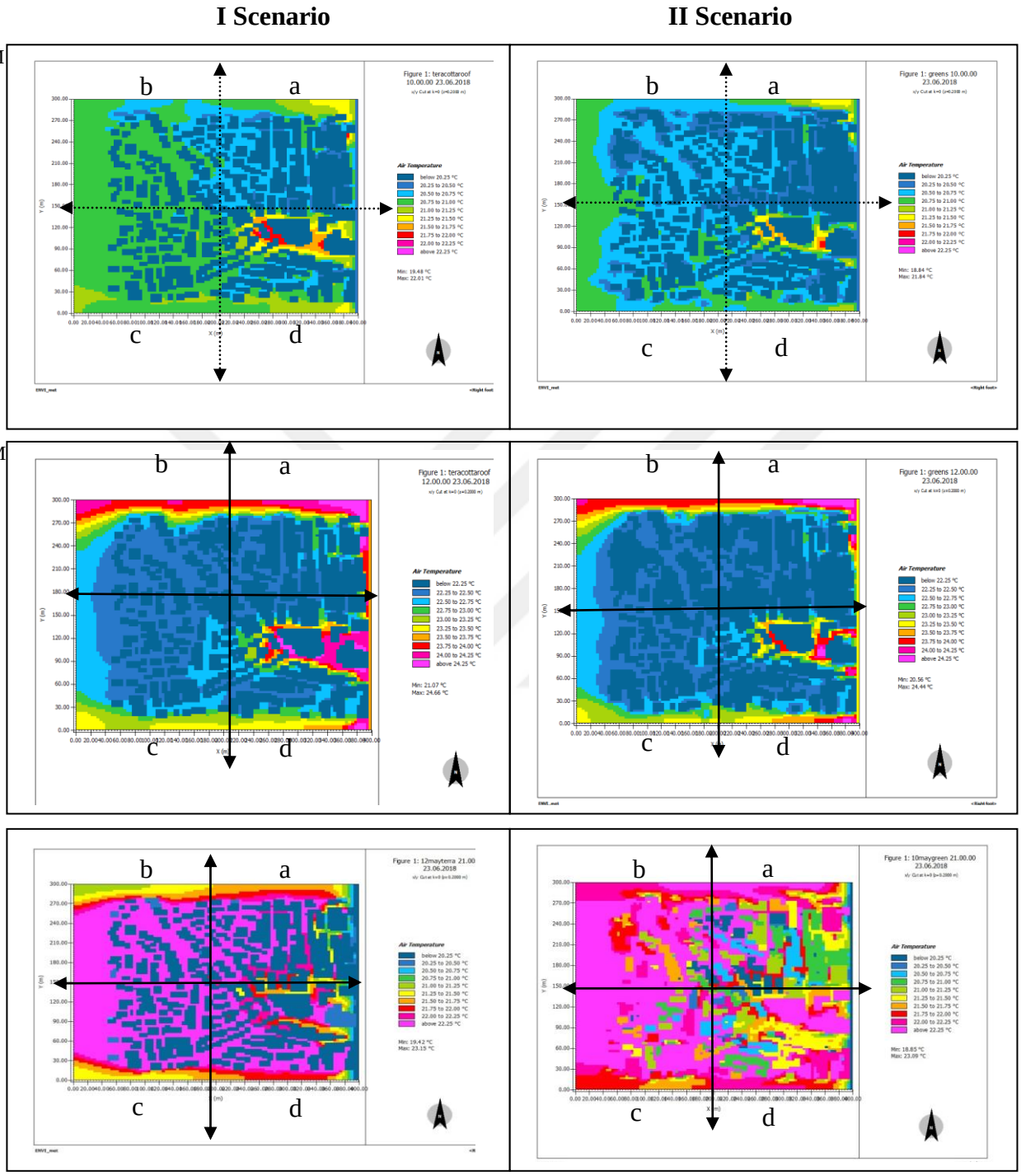

Figure 4.5 : Both scenarios air temperature simulation result explained in three different times in Çeliktepe

4.4.2 Wind speed change

The wind speed analysis result showed below. Wind Speed indicated with 10 different colors, the color changes from every 0.25 m/s. Wind speed unit is meters per second or kilometers per hour.

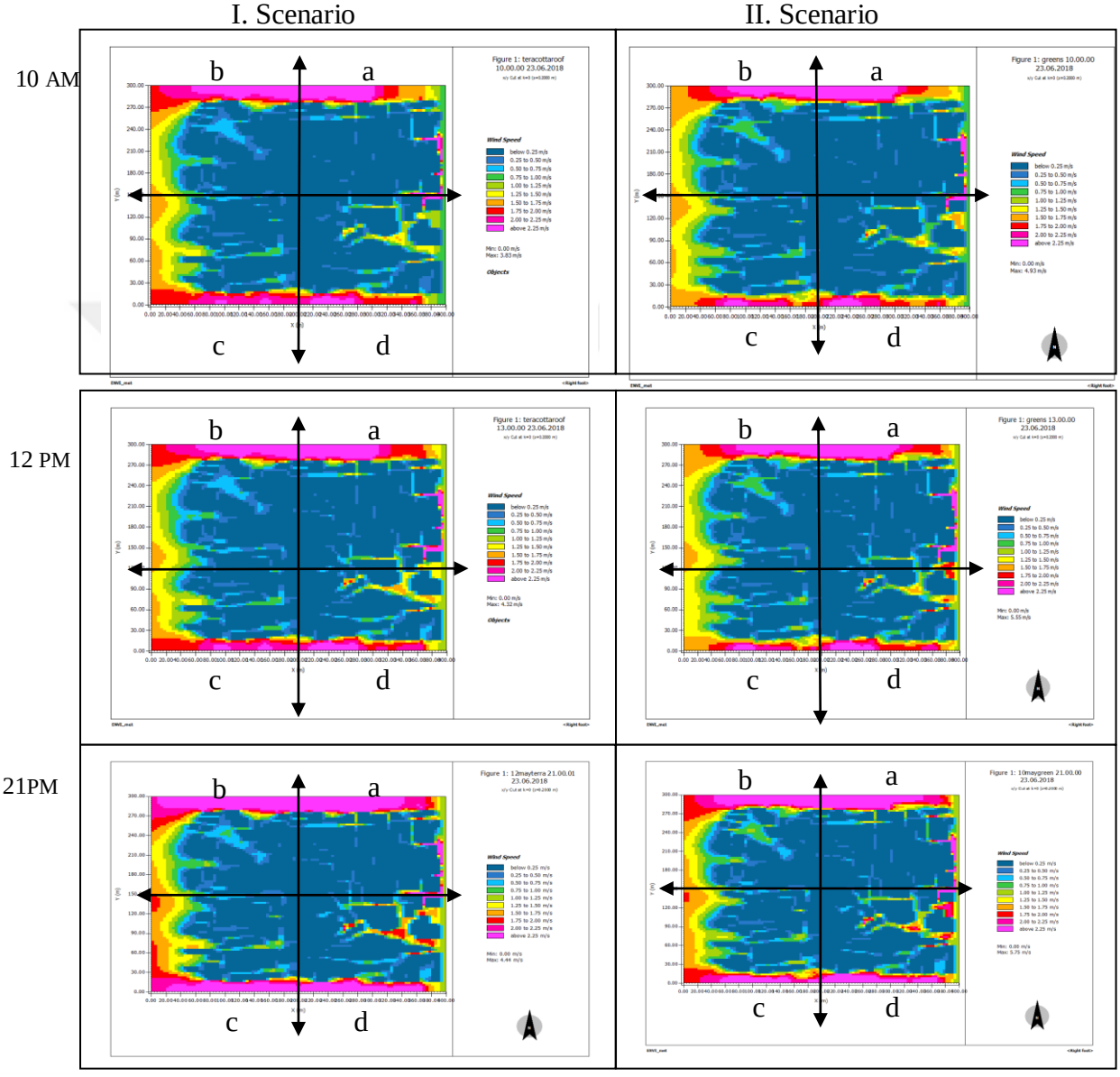

Figure 4.6 : Both scenarios wind change simulation result explained in three different times in Çeliktepe

4.4.3 CO2 value

The CO2 value analysis results are showed below

I Scenario **II Scenario**

10 AM

12 PM

21 PM

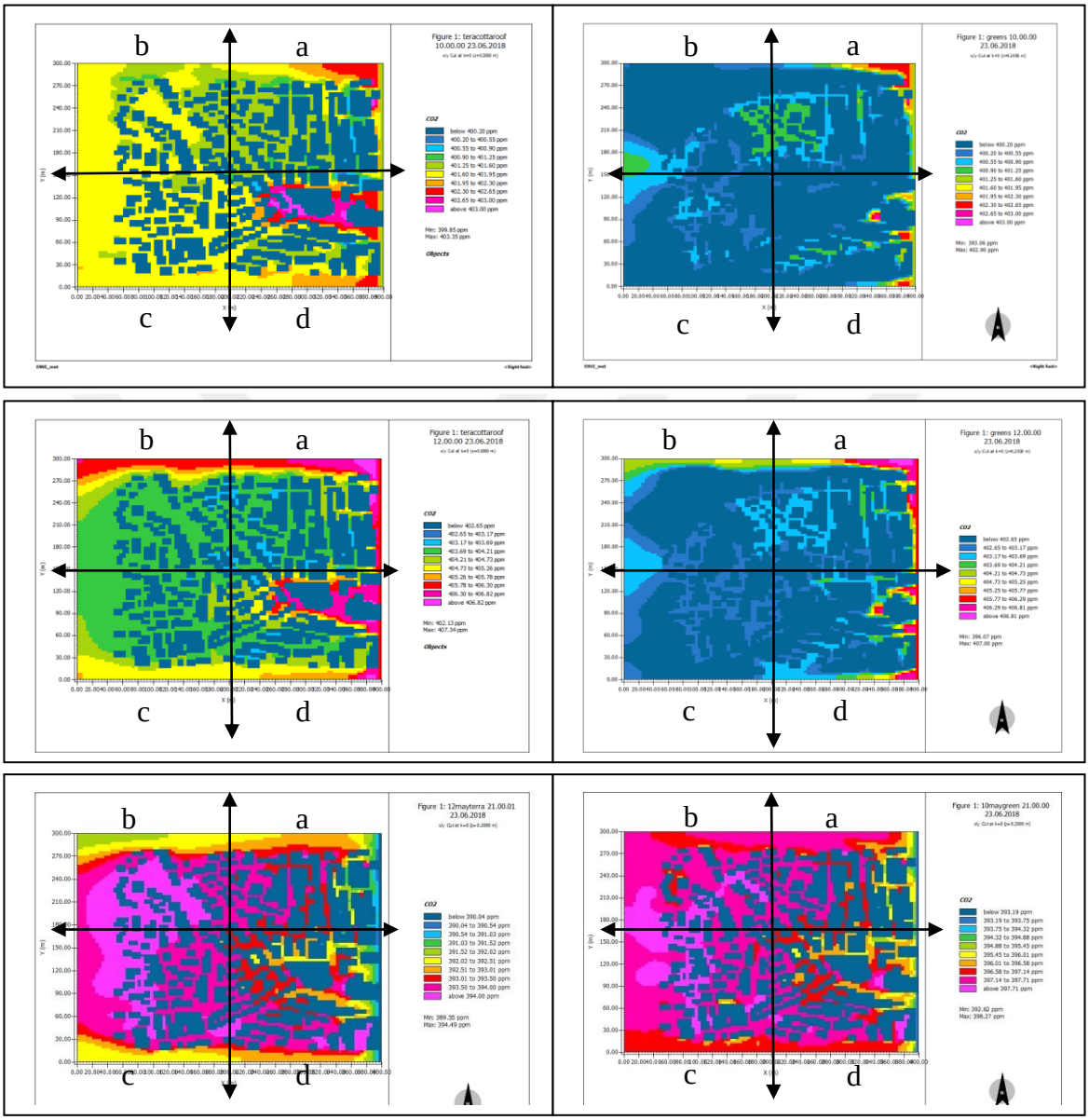

Figure 4.7 : CO2 changes in three different times in Çeliktepe.

4.5 Findings

Air temperature at 10 AM

Two different scenarios air temperature simulation result at 10 AM are divided to four part (a, b, c, d) then each part temperature in two scenarios were compared and findings written in the table 22.

Table 4.5: Comparing two scenarios air temperature result at 10 A.M

Air Temperature changes at 10 AM	a	b	c	d
I Scenario	20.5-20.75 20.75-21 21-21.25	20.75-21	20.75-21	20.75-21 21.25-21.5 21.5-21.75 21.75-22
II Scenario	20.25-20.5 20.5-20.75	20.5-20.75	20.5-20.75	20.5-21.75 21.25-21.5

Temperature changes in both scenarios mentioned on Table 22. First scenario's **part a** temperature is among 20.5-20.75° C, 20.75-21° C, 21-21.25° C, II scenario's temperature changes different from first one, the difference between two **a parts** in II scenario compared to the first scenario decreasing air temperature. It mean in second scenario's **part a** approximately temperature decrease up to 0.25 ° C in some areas.

Part b air temperature digits are different in two different scenario's. II scenario temperature is 0.25 ° C cooler than first scenario.

Part c air temperature digits are different in two different scenario's. II scenario temperature is 0.25 ° C cooler than first scenario.

Part d air temperature is different in both two scenarios I scenario air temperature is among 20.75-21 ° C and 21.75-22 ° C, II scenario air temperature is among 20.5-21.5 so in second scenario approximately temperature decreased up to 0.25 ° C.

Air temperature at 12 PM

Two different scenarios air temperature simulation result at 12 P.M are divided to four part (a, b, c, d) then each part temperature in two scenarios were compared and findings written in the table 1.2

Table 4.6 : Comparing two scenarios air temperature result at 12 P.M

Air Temperature changes at 12 P.M	a	b	c	d
I Scenario	22.25-22.5 22.5-22.75 22.75-23	22.25-22.5 22.5-22.75 22.75-23	22.25-22.5 22.5-22.75	23.75-24 24-24.25
II Scenario	22.25-22.5 22.5-22.75 22.75-23	Below<22.25 22.25-22.5 22.5-22.75 22.75-23	22.25-22.5 22.5-22.75	23.25-23.5 23.75-24

Temperature changes in both scenarios mentioned on Table 22. First scenario's **part a** temperature is among 22.25-22.5° C, 22.5-22.75° C, 22.75-23° C, II scenario's temperature like first one but the difference between two **a parts** is: 22.5-22.75 temperature in II scenario compared to the first scenario increased and 22.75-23° C decreased it mean in second scenario's **part a** approximately temperature decrease up to 0.25 ° C in some areas.

Part b air temperature digits is same in two different scenario's but in II scenario temperature in some areas is Below<22.25° C it mean just in some areas approximately temperature decrease up to 0.25 ° C in second scenario.

Part c air temperature digit is same in most of the areas in two different scenario's but in II scenario temperature in some areas changed from 22.5-22.75° C to 22.25-22.5° C it mean just in some areas approximately temperature decrease up to 0.25 ° C in second scenario.

Part d air temperature generally different from each other in two scenarios I scenario air temperature is 24-24.25° C and 23.75-24 ° C, II scenario air temperature is 23.25-23.5 and 23.75-24 In this part approximately temperature decreased up to 0.5 ° C.

Air temperature at 21 P.M

Two different scenarios air temperature simulation result at 21 P.M are divided to four part (a, b, c, d) then each part temperature in two scenarios were compared and findings written in the table 1.3

Table 4.7 : Comparing two scenarios air temperature result at 21 P.M

Air Temperature changes at 21 P.M	a(° C)	b(° C)	c(° C)	d(° C)
I Scenario	22-22.25 21-21.25	21.75-22 Above 22.25	Above 22.25	21.25-21.5 21.5-21.75
II Scenario	21.75-22 20.50-20.75	21.25-21.5 22-22.25	Above 22.25	21-22.25 21.25-21.5 21.5-21.75

Temperature changes in both scenarios mentioned on Table 22. First scenario's **part a** temperature is among 21.75-22° C, 20.5-20.75 ° C, I scenario's temperature is among 22-22.25° C, 21-21.25° C.

Part b air temperature changes is different in two scenario's, I scenario temperature compared with II scenario increased up to 0.5 ° C .

Part c air temperature digit is same in two different scenario's.

Part d air temperature generally different from each other in two scenarios II scenario air temperature is 21-22.25° C, 21.25-21.5° C, 21.5-21.75° C. I scenario air temperature is among 21.25-21.5° C and 21.5-21.75 ° C In this part some parts of I. scenario is cooler or warmer than II scenario.

Wind speed change

I, II Scenarios wind speed change is same at 10 AM, 12 PM and 21 PM, terracotta roof and extensive green roof don’t have much influence on wind speed because grass which used in second scenario (extensive green roofs) don’t have effect on wind speed.

CO2 changes in terracotta and green roofs at 10 A.M

Two different scenarios air temperature simulation result at 12 P.M are divided to four part (a, b, c, d) then each part temperature in two scenarios were compared and findings written in the table 1.3

Table 4.8: Comparing two scenarios CO2 result at 10 A.M

CO2 changes at 10 A.M	a(PPM)	b(PPM)	c(PPM)	d(PPM)
I Scenario	401.25-401.60 401.60-401.95 401.95-402.30	401.25-401.60 401.60-401.95	401.60-401.95	402.65-403 402.30-402.65 401.95-402.30 401.60-401.95
II Scenario	Below 400.20 400.55-400.90 400.90-401.25	Below 400.20	Below 400.20	Below 400.20

CO2 change in both scenarios mentioned on Table 24.

First scenario's **part a** CO2 measure in several areas is among 401.25-402.30 ppm. II scenario's CO2 volume at least 2.10 ppm lower than first scenario.

Part b CO2 measure is change in different two scenario's, II scenario CO2 is at least 1.75 ppm lower than first scenario.

Part c CO2 measure is change in different two scenario's, II scenario CO2 is at least 1.75 ppm lower than first scenario.

Part d CO2 measure is change in different two scenario's, II scenario CO2 is at least 2.70 ppm lower than first scenario.

CO2 changes in terracotta and green roofs at 12 P.M

Two different scenarios air temperature simulation result at 12 P.M are divided to four part (a, b, c, d) then each part temperature in two scenarios were compared and findings written in the table 1.3

Table 4.9 : Comparing two scenarios CO2 result at 12 P.M

CO2 changes at 12 P.M	a(PPM)	b(PPM)	c(PPM)	d(PPM)
I Scenario	403.69-404.21 404.21-404.73	403.69-404.21	404.73-405.26 403.69- 404.21	403.69-404.21 404.73-405.26 406.30-406.82
II Scenario	Below 402.65 402.65-403.70 403.17-403.69	Below 402.65	402.65-403.17 Below 402.65	402.65- 403.17 Below 402.65

CO2 changes in both scenarios mentioned on Table 24.

First scenario's **part a** CO2 measure in several areas the result showed us that CO2 volume is among 403.69-404.73 ppm. II scenario's CO2 volume at least 1.06 ppm lower than first scenario.

Part b CO2 measure is change in different two scenario's, II scenario CO2 is at least 1.56 ppm lower than first scenario.

Part c CO2 measure is change in different two scenario's, II scenario CO2 is at least 2.08 ppm lower than first scenario.

Part d CO2 measure is change in different two scenario's, II scenario CO2 is at least 5.65 ppm lower than first scenario.

CO2 changes in terracotta and green roofs at 21 P.M

Two different scenarios air temperature simulation result at 21 P.M are divided to four part (a, b, c, d) then each part temperature in two scenarios were compared and findings written in the table 1.3

Table 4.10 : Comparing two scenarios CO2 result at 21 P.M

CO2 changes at 21 P.M	a(PPM)	b(PPM)	c(PPM)	d(PPM)
I Scenario	396.01-396.58 395.45-396.01	391.52-392.92	395.45-396.01	393.75-394.32 396.01-396.58
II Scenario	397.14-397.71	397.14-397.71	396.58-397.14	394.88-395.45 396.58-397.14

CO2 changes in both scenarios mentioned on Table 24.

First scenario's **part a** CO2 measured in several areas the result showed that I. Scenario CO2 1.7- 4.9 ppm lower than II scenario.

Part b CO2 measure is change in different two scenario's, I scenario CO2 5.62 ppm lower than II. Scenario.

Part c CO2 measure is change in different two scenario's, I scenario CO2 is at least 1.13 ppm lower than II. Scenario.

Part d CO2 measure is change in different two scenario's, II scenario CO2 is at least 2.83 ppm lower than first scenario.

Result showed that the second scenarios CO2 increase up to 5.62 ppm. Because plants for photosynthesis using co2 during the day and after sunset give up CO2 and takes o2.

5. CONCLUSIONS

In urban areas, the effects of urban temperature and CO2 emissions must be taken into account in order to be able to build an environment that contributes to the happiness and healthy living of people. In this study, a method for modeling and simulating the effects of factors such as outdoor comfort, air temperature, roof material and vegetation on the microclimate of cities has been introduced. The software was used to simulate and evaluate the effects of roofing materials on outdoor temperature and welfare. Thanks to the method proposed in this study, the results obtained from the comparison of the outputs have given us the opportunity to see the effects of building roof materials and vegetation on outdoor comfort. Within the scope of this research, air temperature, CO2 and wind speed, amount were analyzed. For the two different scenarios, maps were developed which included the measured air temperature, CO2 amount and wind speed at certain times of the hot day (10.00 am, 12.00 pm, and 21 pm). For both scenarios, the hourly results recorded from ENVI-met and simulations were compared by focusing on air temperature, CO2 emissions and wind speed values.

Regarding air temperature values obtained from ENVI-met simulations, it was found the differences in the range of 23–24 ℃ for the roof without vegetation at 10.00 am and the differences in the range of 23-23.75 ℃ for the green roofs. That means that the mass of the building with green roof led to a decrease of 0.25 ℃ in air temperature at 10.00 am. Looking at the differences at 12.00 pm, it was the range of 22.25–24.25 ℃ for the roof without vegetation and the range of 22.25-24 ℃ for the green roof. That means that the mass of the building with green roof led to a decrease of 0.25 ℃ in surrounding air temperature at 12.00 pm. When it comes to the differences at 21.00 pm, it was in the range of 21.77- above 22.25 ℃ for the green roof and in the range of 22-above 22.25 ℃ for the roof without vegetation. That means that the mass of the building with green roof led to decrease of 0.25 ℃ in surrounding air temperature at 21.00 pm.

ENVI-met simulation in the two scenarios showed that the impact of green roof vegetation (the grass was used in this research, but normally the popular plant for extensive green roofs is Sedum) at certain times was about 0,25 °C.

As stated in the literature review, because there is not enough vegetation in urban areas, impermeable surfaces have been formed, these surfaces absorb sunlight during the day and spread the sunlight in the evening, thus increasing the air temperature in the areas of the buildings. Therefore, the urban air temperature may be 5.6 ° C higher than in rural areas or underdeveloped environments. This simulation showed that the green roof kept the radiation and used heat for transpiration and makes the air milder. If it is implemented in the urban areas, it could act as a natural cooling and decrease the urban temperature. In doing so, it not only decreases air temperature but also reduces the urban heat island effect. One of the most important impacts of the urban heat island effect phenomenon is also damaging human health.

Since air temperature is considered as one of the most influential parameters of thermal comfort, other researchers have focused on this issue too. For example, Ragheb et al. used ENVI-met tool for evaluating thermal comfort at street level in an ancient area. The particular aim of this study was to improve the outdoor thermal conditions with the help of the design such as having enough open space, vegetation, building arrangements, and pedestrian roads. This study proved that the microclimatic situations in an ancient area showed a close relationship between human comfort and urban design (Ragheb et al., 2016). In addition, while using the SOLWEIG radiation model in order to assess the average radiant temperature during the night, Jänicke et al. realized that absorbing of daytime temperatures by buildings and impermeable bare surfaces and then releasing it to the environment at night should not be underestimated. Thanks to long-wave radiation that is very effective at night and recorded with TRNSYS, building facades, and road materials are evaluated at a very detailed level.

Second parameter was used to simulate CO2 value obtained from ENVI-met simulations. CO2 value differences at 10.00 am. The difference at 10 am was in the range of 401.25–402.65 PPM for the roof without vegetation and in the range of below 400.20- 401.25 PPM for the green roof. That means that the mass of the building with green roof decreased CO2 amount in the air at 10.00 am. The differences were in the range of 403.69–406.82 PPM for the roof without vegetation

and in the range of below 402.65–403.7 PPM for the green roof. That means that the mass of the building with green roof decreased surrounding air CO2 amount at 12.00 pm. looking at the differences at 21.00 pm, it was found that the differences were in the range of 396.01–396.58 PPM for the roof without vegetation and in the range of below 397.14–397.71 PPM for the green roof. That means that the mass of the building with green roof increase surrounding air CO2 amount at 21.00 pm.

Carbon dioxide occurs naturally in the atmosphere. In this process, plants produce nutrients and energy. Since Co2 levels have risen due to burning fossil fuels since the industrial revolution, high amounts of CO2 cause environmental risks. The main reason for air pollution is the increase in CO2 levels. Carbon dioxide plays an important role in terms of the greenhouse effect, it traps solar radiation at ground level, creating ground-level ozone and permitting to cool earth at night. One consequence of this is the increase in temperature in the oceans; because the oceans capture the carbon dioxide in the atmosphere; therefore, the water temperature rises abnormally, causing the ability of the oceans to absorb carbon dioxide. Also, the phenomenon of climate change is a result of high carbon dioxide in the environment. Carbon dioxide emissions affect human health by reducing oxygen in the atmosphere because breathing becomes difficult. As the levels of carbon dioxide increase, global warming occurs. In this regard, considering the damages associated with high CO2 emissions, green roofs that reduce the level of CO2 in the atmosphere help to improve the environmental quality of life. Green roof applications are developing every day and their many benefits are coming out.

As a result of this study, it has been determined that green roofs have the ability to decrease the ambient temperature and decrease the CO2 level in the environment and thus contribute to improving the quality of life of people. Some sources estimates that the cost of installing a extensive green roof starts at around £500 per 8 m² (Url-18). Considering the size of Çeliktepe which is about 534.585 m² it might be evaluated as expensive to implement green roof on all buildings, but the benefits of green roof that are essential for the high dense urban areas, urban renewal project could be an opportunity to implement.

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