URBAN SYMBIOSIS THROUGH BUILDING INTEGRATED AGRICULTURE: TRANSFORMING VACANT AREAS OF A MULTI-STOREY CARPARK INTO AN URBAN FARM

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KAYA EMRE GÖNENÇEN

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submitted by **KAYA EMRE GÖNENÇEN** in partial fulfillment of the requirements for the degree of **Master of Science** in **Building Science in Architecture, Middle East Technical University** by,

Prof. Dr. Naci Emre Altun
Dean, Graduate School of **Natural and Applied Sciences**

Assoc. Prof. Dr. Ayşem Berrin Çakmaklı
Head of the Department, **Architecture**

Prof. Dr. Soofia Tahira Elias Ozkan
Supervisor, **Architecture, METU**

Examining Committee Members:

Assoc. Prof. Dr. Ayşem Berrin Çakmaklı
Architecture, METU

Prof. Dr. Soofia Tahira Elias Ozkan
Architecture, METU

Prof. Dr. Meltem Yılmaz
Architecture, Hacettepe University

Date: 05.07.2024

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Last name : Kaya Emre Gönençen

Signature :

ABSTRACT

URBAN SYMBIOSIS THROUGH BUILDING INTEGRATED AGRICULTURE: TRANSFORMING VACANT AREAS OF A MULTI-STOREY CARPARK INTO AN URBAN FARM

Gönençen, Kaya Emre
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Supervisor: Prof. Dr. Soofia Tahira Elias Ozkan

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Demands of increasing population cause not only rapid urbanization and the absence of greenery in the urban context but also insufficiency and infertility of conventional agricultural spaces. Both the built environment and agriculture become major consumers of energy and resources to fulfill the needs, while urban agriculture (UA) and building-integrated agriculture (BIA) have started to emerge as possible remedies towards revitalizing their ancient bond. This study aims to indicate conventional problems of agriculture and the built environment regarding environmental loads and to investigate possible symbiotic relationships between them to enhance resource use efficiency and local self-sufficiency.

This research investigates the impacts of agricultural methods and conducts circular scenario analysis of a proposal to transform a multi-storey carpark in Ankara into an urban farm with BIA methods and urban symbiosis options. As methodology, quantitative data about agricultural methods is gathered for meta-analysis comparison from producers in Turkey and literature review among 156 reference sources. Moreover, the scenario is analyzed for capturing surrounding CO_2, utilizing water sources, and producing renewable energy.

In summary, this study outlines the potential, limitations, and impacts of BIA methods from environmental, economic, and social perspectives. The analysis indicates that while BIA techniques, especially the controlled environment agriculture (CEA) method used in the proposed transformation, are costly, energy-dependent, and complex to operate, they offer considerable potentials for food production, resource use efficiency, and mitigating environmental loads of logistics, irrigation, and waste management. With symbiotic urban opportunities, BIA methods can benefit the local built environment and enhance local self-sufficiency.

Keywords: Building-integrated Agriculture (BIA), Urban Agriculture (UA), Controlled Environment Agriculture (CEA), Urban Symbiosis, Environmental Load

ÖZ

YAPIYLA BÜTÜNLEŞİK TARIM İLE KENTSEL SİMBİYOZ: ATIL ÇOK KATLI OTOPARK ALANLARININ KENTSEL TARIM ALANINA DÖNÜŞTÜRÜLMESİ

Gönençen, Kaya Emre
Yüksek Lisans, Yapı Bilimleri, Mimarlık
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Artan küresel nüfus talepleri, yalnızca kentleşmenin hızlanmasına ve kentsel bağlamda yeşil alanların yok olmasına neden olmamış, aynı zamanda geleneksel tarım alanlarının yetersizliğine ve verimsiz hale gelmesine de yol açmıştır. Bu talepleri karşılamak amacıyla, yapılaşmış çevre ve tarım, enerji ve hammadde kaynaklarının en büyük tüketicileri haline gelirken, kentsel tarım (KT) ve yapıyla bütünleşik tarım (YBT), iki kavram arasındaki kadim bağın yeniden canlandırılmasına yönelik olası çözümler olarak ortaya çıkmıştır. Bu çalışma, geleneksel tarımın ve yapılaşmış çevrenin çevresel yükler açısından sorunlarını ele alırken, kaynak kullanım verimliliğini ve yerel kendine yeterliliği artırmak için tarım ve kentsel bağlamın olası simbiyotik ilişkilerini araştırmayı amaçlamaktadır.

Bu araştırma, tarımsal yöntemlerin etkilerini ve YBT yöntemleri ve kentsel simbiyoz seçenekleri ile kentsel tarım alanına dönüştürülmesi önerilen Ankara'daki çok katlı otopark yapısının döngüsel senaryo analizini incelemektedir. Araştırma yöntemi olarak, 156 referans kaynak arasında yapılan literatür taramasından, ve Türkiye'deki üreticilerden meta-analiz karşılaştırması için tarımsal yöntemler hakkında nicel veriler toplanmıştır. Ayrıca, dönüşüm senaryosu için seçilen yapı, çevredeki CO_2'nin yakalanması, su kaynaklarının kullanılması ve yenilenebilir enerji üretimi konularına yönelik analiz edilmiştir.

Özetle, bu çalışma YBT yöntemlerinin çevresel, ekonomik ve sosyal perspektifler açısından potansiyelini, sınırlamalarını ve etkilerini açıklamaktadır. Analizlerin sonuçları, YBT tekniklerinin, özellikle dönüşüm önerisinde kullanılan kontrollü ortam tarımı (KOT) metotlarının, maliyetli, enerjiye bağımlı ve işletilmesinin karmaşık olduğunu, ancak gıda üretimi ve kaynak kullanım verimliliği için önemli potansiyeller sunduğunu ve lojistik, sulama ve atık yönetimi gibi çeşitli aşamalarda çevresel yüklerin azalttığını göstermektedir. Simbiyotik kentsel fırsatlarla birlikte, YBT yöntemleri yerel yapılaşmış çevreye fayda sağlayabilir ve yerel kendine yeterliliği artırabilir.

Anahtar Kelimeler: Yapıya Bütünleşik Tarım (YBT), Kentsel Tarım (KT), Kontrollü Ortam Tarımı (KOT), Kentsel Simbiyoz, Çevresel Yük

Dedicated to those who believed in me and paved the way

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LIST OF ABBREVIATIONS

ABBREVIATIONS

BIA : building-integrated agriculture

BIM : building information modelling

CEA : controlled environment agriculture

CPUL : continuous productive urban landscape

ETFE : ethylene tetra fluoro ethylene

HVAC : heating, ventilation, and air conditioning

LED : light-emitting diode

PF : plant factory

PFAL : plant factory with artificial lighting

PV : photovoltaic

RH : relative humidity

UA : urban agriculture

UAA : urban agriculture architecture

UPA : peri-urban agriculture

VF : vertical farming

VIG : vertically integrated greenhouse

VOC : volatile organic compound

LIST OF SYMBOLS

SYMBOLS

cap : capita

CO_2 : carbon dioxide

ha : hectare

$kgCO_2eq$: kilogram equivalent of CO_2

kWh : kilowatt hour

lx : lux

O_2 : oxygen

Ppm : parts per million

pH : potential of hydrogen

λ : wavelength

μmole : micromole

CHAPTER 1

INTRODUCTION

This chapter has been structured under six subsections which give background information and motivation behind the research with the research problem, research objectives, questions, hypotheses, procedure, and the disposition to explain the flow of the research.

1.1 Background, Motivation, and Research Problem

The growing population is increasing the demand for food and shelter, making energy, water, and other resources more vital than ever. To meet these demands, new buildings are being constructed, and new agricultural lands are prepared. However, to make those actions possible, green areas are razed to clear lands for new sites, which leads to habitats and biodiversity loss. Many forests are cleared for new agricultural land because the existing ones are no longer sufficient and not as fertile as in the past due to the use of pesticides, artificial fertilizers, and harmful chemicals on soil with improper mass agricultural methods. Meanwhile, the expanding built environment consumes more energy, water, and resources for the ever-growing demands. This expansion also necessitates the clearing of green areas for new construction sites. Buildings become more impactful with their consumption; at the same time, their performance and indoor conditions are getting poorer owing to the urban context, which is devoid of greenery. In addition, agricultural land contamination, expansion of the cities, and modern transportation means widen the gap between agricultural lands and urban areas. It means harder access to food and increased food miles that cause poorer conditions of the food supply chain. Therefore, unplanned expansion of the built environment, loss of green areas, inadequate infrastructure, and lack of fertile lands are triggering factors for environmental, economic, and social issues such as global warming, resource depletion, economic inequalities, famine, and climate change.

After a search for the integration of the two major energy and resource consuming sectors, i.e. agriculture and the built environment, adopting urban agricultural methods such as building-integrated agriculture (BIA) becomes a possible remedy for providing urban facilities, mitigating the need for fertile lands, and saving resources and water. In other words, a mutual relationship between those major sectors is possible via BIA to reduce the environmental impacts of both while also considering their economic and social impacts. However, those applications of integration are rare in today's urban context due to high investment costs, energy dependence, lack of acceptance due to conventional mindsets, and ignorance of the benefits of BIA food production and the building's environmental performance. According to De Wilt and Dobbelaar (2005), the lack of acceptance of BIA systems is about consumer preferences, who consider plants cultivated via BIA systems as not naturally grown and not healthy to eat.

This study is a result of the search for the re-integration of the built environment, green areas, and agriculture via BIA methods to mitigate their environmental loads while enhancing resource efficiency and local self-sufficiency via circularity scenarios with urban symbiosis options. Thus, transformation of a multi-storey carpark into an urban farm with the use of building-integrated agricultural (BIA) methods, circularity concept, and symbiotic relationships between local sources will be investigated via different research methods. There will be qualitative and quantitative comparisons between conventional agriculture and different BIA methods with case studies from the literature and Turkey as meta-analysis. Moreover, a designed scenario for Sıhhiye Multistorey Car Parking Building will be investigated in terms of its impacts on three pillars of sustainability as environment, economy, and society. Environmental potentials and loads of the symbiotic system between the built environment and BIA systems will especially be the focus of the study and proposed project scenario.

1.2 Research Objectives

The objectives of this research are:

- to determine the weaknesses and problematic issues of the existing built environment and conventional agricultural systems for searching potential mutual remedies with an architectural approach
- to indicate the potentials as well as the limitations regarding environmental, economic, and social impacts of UA and BIA methods as solutions to the lack of local food supply, the lack of green urban areas, and resource depletion
- to check differences between the crop yields, resource consumptions, and energy consumptions of conventional agriculture, UA, and BIA methods for comparing their environmental loads
- to analyze Sıhhiye Multistorey Car Parking Building, its users, its surrounding, and its vacant floors for potential BIA integration as a possible solution to combat local problems, with urban symbiosis options and a circularity scenario in terms of environmental, social, and economic aspects

1.3 Research Questions

- What are the key issues of the current built environment and agricultural system that may be addressed by integrating the two?
- What are the potentials and limitations of conventional agriculture, UA, and BIA methods in terms of the three pillars of sustainability?
- What is the difference between the crop yields and environmental loads (energy and resource consumptions) of conventional agriculture and different BIA methods?

- How can the vacant areas of a multi-storey carpark be turned into a place for food production and, at the same time, be beneficial for the built environment with a possible circularity scenario via BIA use and urban symbiosis options?
- How can BIA systems use exhausted CO_2 from the environs (buildings, traffic, occupants, and vehicles that use the multi-storey carpark) for both air purification and crop production efficiently?

1.4 Hypotheses

Hypothesis 1:

BIA methods create a difference of crop yields and required food miles when they are compared with conventional agricultural production.

Hypothesis 2:

Conventional agriculture and BIA methods differ in terms of environmental loads such as water, energy, and resource consumptions. Different BIA methods have different amounts of energy and resource use according to different needs.

Hypothesis 3:

There is a correlation between the vehicle entry-exit data and CO_2 concentrations at the car parking floors of Sıhhiye Multistorey Car Parking Building.

Hypothesis 4:

There is an air purification effect by CO_2 reuse possibility of BIA application in Sıhhiye Multistorey Car Parking Building.

1.5 Procedure

The thesis research started with understanding the ancient bond between agriculture and architecture that started to dissolve in today’s world. After examining the environmental, economic, and social impacts of conventional agriculture and the built environment through a literature review, the research problem and objectives were decided upon.

It should be noted that before initiating a thorough review of the literature, a bibliometric analysis was made to determine and select necessary and relevant sources for the review. The selected literature sources were reviewed to examine urban agriculture and building-integrated agriculture with their types, impacts, potentials, and limitations. As a result, the first step was to reveal the differences between different agricultural methods for a meta-analysis that compares different numerical data of a wide range of case studies from the literature and producers in Turkey to demonstrate the differences.

The second step of the research methodology was conducting an empirical survey with data loggers to determine the CO_2, humidity, and temperature differences throughout the days in the selected building, which was the Sıhhiye Multistorey Car Park. The building was also studied for its relation to its surroundings and the potential to transform it into an urban farm with a circularity scenario having different symbiotic local relationships.

In this last step, the scenario was shaped by the knowhow gained from the literature and case studies in Turkey, analyses that were made, concerns about environmental loads, and possible local opportunities. Rainwater harvesting capacity, renewable energy production capacity via photovoltaics (PVs), air purification possibilities, reuse options of exhausted CO_2 of vehicles and occupants of the building, revaluation possibilities of the structure as a base for production and education were examined in the scenario finalization process.

1.6 Disposition

This thesis research contains five chapters that are demonstrated in Figure 1.1 as a flowchart of the research process followed in this thesis.

The first chapter introduces a summary of the background information about the concepts and motivation behind the research. Moreover, the research problem, research objectives, research questions, hypotheses, and a summary of the research methodology is included in the introduction chapter.

The second chapter is devoted to the literature review about the ancient bond between agriculture and architecture, current problems due to the impacts of conventional agriculture and the built environment, and the possibility of an up-to-date mutual relationship between them as urban agriculture and building integrated agriculture. Types of both are mentioned in the chapter with environmental, economic, and social impacts of applying building-integrated agricultural methods. Possibilities of a systematic urban symbiosis via different sub-system symbioses and circularity of the whole system with BIA strategies to close open loops in urban food production processes are also examined in the second chapter.

The third chapter explains the research design with material of research and method of research that includes bibliometric analysis, literature review, data gathering for meta-analysis, data logging as empirical research, and design of transformation project scenarios. In the material section of the chapter, case studies from both the literature and Turkey are given with relevant numerical data. Furthermore, Sıhhiye Multistorey Car Park is given as the focus building for the transformation project and scenario with site analysis, its historical background, and current local use patterns. Data logging equipment for the empirical survey about the structure is also given. In the method section of the chapter, the parameters of meta-analysis, the scenario with local symbiotic relationships, and the data logging method are given.

The fourth chapter is based on the analyses and obtained results from case studies in the literature and case studies in Turkey in terms of different agricultural methods and their environmental loads, data and calculations for the transformation project as well as the project scenario. The analyses of the transformation project of Sıhhiye Multistorey Car Parking Building include potential food production and yield efficiency, approximate rainwater harvesting capacity, renewable energy production capacity via PVs, data regarding natural light in the structure, emitted CO_2 amounts of the local sources (vehicles, occupants, and traffic), humidity values, temperature differences, vehicle entry-exit data, and air purification capacity of BIA system use. Moreover, the discussion part of all those results of the thesis research is included in the chapter.

The final chapter concludes the thesis research, transformation project scenarios, and results of the transformation with future recommendations.

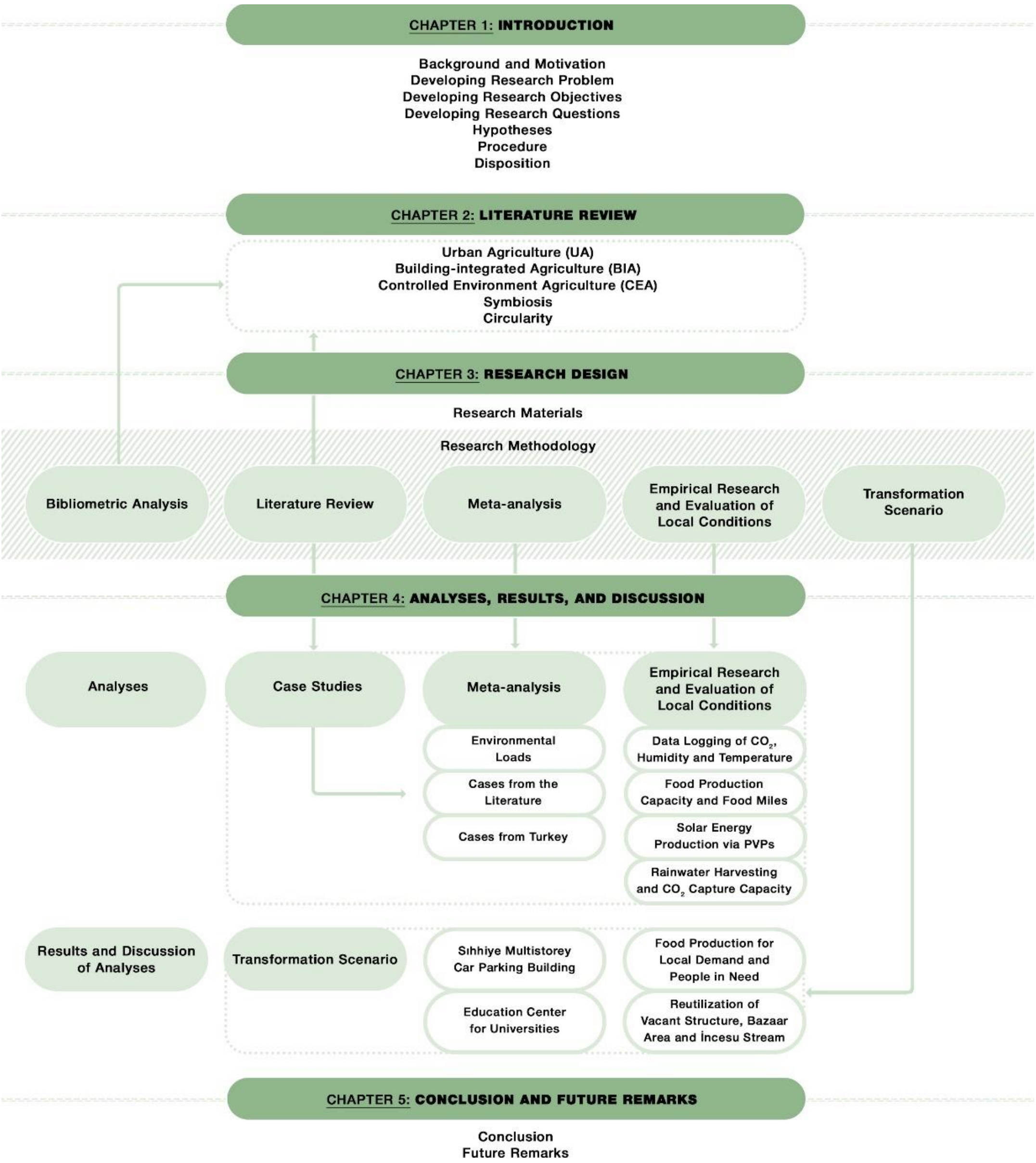


Figure 1.1 Flow chart of the thesis structure.

CHAPTER 2

LITERATURE REVIEW

Weinmaster (2009) and Benis et al. (2017b) argue that agriculture and architecture have been related from the start of civilization when the first settlements were established after the advent of formal agriculture. Steel (2008) also points out that the existence and growth of the cities were directly associated with agricultural lands and food production; the author gives the example of Anatolia, Mesopotamia, and the Middle East where agriculture and urbanism emerged together 10,000 years ago because it was the first time that human beings could produce an adequate amount of food for their self-sufficiency thus ending the need for migration to find new food sources other than the food that obtained from hunting and gathering. However, in today's world, this relationship has shifted gradually for an urban-rural duality and a more global world with no necessity of the built environment's proximity to agricultural lands (Steel, 2009) but with worldwide sophisticated systems for food production, processing, delivery, and storing because of excessive food demand by the population. These systems can only continue with more and regular food production, mostly with conventional agricultural methods; they seem sufficient to fulfill all the food demands of the population. On the contrary, those conventional methods are not and will not be enough for the world's food needs due to the increasing population. Their current priority is providing food for people who can afford to buy; on the other hand, millions of people are suffering today due to food inadequacy. Furthermore, the expected population of the world by 2050 is 9.5 billion people and the urban population is 6.3 billion people, which is more than a 50% increase (Despommier, 2009; Kozai, 2019).

The increasing global population demands not only food but also shelter and service from the built environment which also faces insufficiencies. Both agriculture and the built environment become impactful sectors on the environment, economy, and social life to fulfill the demands. The integration of these two industries to create a mutual relationship can be a remedy for mitigating their negative impacts while promoting new positive ones. In fact, the idea of integrating the built environment and agriculture is not new; as Weinmaster (2009) exemplified, even the Hanging Gardens of Babylon is an example of the ancient bond between them. Hopkins and Goodwin (2011) and Al-Kodmany (2018) also gave more examples from ancient Mesopotamia as ziggurats, ancient Rome (Figure 2.1), medieval Europe, cooling facades, and living wall infrastructure from modern city gardens. Furthermore, old cities were surrounded by agricultural lands to sustain and fulfill their food demand; in some cases, those agricultural lands could be surrounded and protected by the city walls.

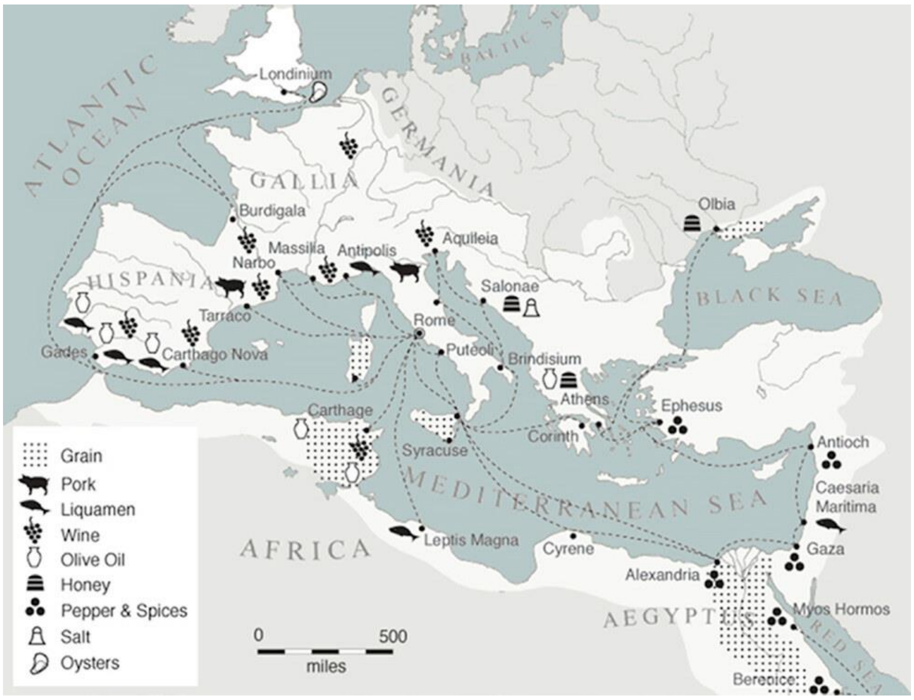


Figure 2.1 Ancient food supply routes from Rome. (Steel, 2009)

After the industrialization period, transportation, production, preservation, and refrigeration capabilities evolved. With the evolution, old cities that produced for their consumption only became new cities that produced for global consumption, processing, and commerce; the relationship between the city and agricultural land started to dissolve. Vehicular ways, railways, and seaways started to be used vastly for faster and easier transportation of food (Figure 2.1). As Steel (2009) indicated, people started to use vast peri-urban or rural lands for food production after transportation developments; the local production was mostly stopped. Moreover, as Steel (2009) states, cities were planned and their plans were shaped by local food types, food markets, and docks that were the main locations of food transportation; all of them can be denoted as a “Sitopia” which means “food place” in Greek with sitos (food) and topos (place) words. According to the author, even Ebenezer Howard’s Garden City was shaped by the idea of food and city symbiosis. The radial cities were designed with railways that connected the surrounding small cities with the central main city to sustain food delivery; while land located between those smaller and the main cities was also used as agricultural fields. Thus, today’s alternative agricultural methods such as urban agriculture (UA) and building-integrated agriculture (BIA) can be identified as modern examples of re-valuation of the bond between agriculture and architecture that was rigid in the past. At this point, as Nowysz and Trocka-Leszczynska (2021) call it, the integration of “urban agriculture” and architecture can be bonded as an “urban agriculture architecture” (UAA) concept that contains possible building typologies and design decisions according to edible plant or non-food plant production and their requirements in buildings. The UAA concept considers the needs of both the built environment and productive landscape from an architectural perspective.

2.1 Impacts of Conventional Agricultural

After centuries, Bingöl (2019) and Despommier (2013) claim that people understand that our planet is suffering from many environmental threats such as climate change, global warming, food-borne diseases, infertility of soil, erosion, drought, and irregular weather conditions due to excessive human activities, especially in the “Anthropocene” era (Chou, 2017). Conventional agriculture is one of those human activities. With the increasing demand for food due to the “explosion” of the human population, people try to process more land for agriculture to harvest more produce; the razing of forests and green areas is the temporary solution for new agricultural lands (Figure 2.2). As Gould and Caplow (2012) state, more than 40% of all available land is already being used for agricultural activities. This use includes harvesting again and again without any fallow time for the soil; thus, as Turhan (2005) states, soil cannot regenerate itself for the next harvest, and it loses its fertility even forever. Moreover, continuous harvesting of commercial farming methods creates contamination in soil, water, and air with the use and accumulation of chemicals (Despommier, 2009) such as pesticides, herbicides, fungicides, and artificial fertilizers. The author (2009) claimed that the rehabilitation and remediation process of soil and water can be long and hard to achieve after fertility loss and contamination.

Figure 2.2 Forest razed to clear land for agriculture and livestock grazing in Amazonian rainforests. (Jenkins, 2018)

More land use for agriculture means more consumption of other resources that cause environmental problems. According to Gould and Caplow (2012), approximately 65% of all potable water sources are being used for agricultural irrigation, and this percentage is still rising (Despommier, 2009). With global warming, wrong applications, and unplanned irrigation patterns, most of the irrigation water is lost by evaporation and percolation. Underground water sources are contaminated with the accumulation of toxic chemicals and pesticides, and they are over-pumped for irrigation causing depletion of underground water sources and collapses of soil layers as sinkholes (Despommier, 2009) (Figure 2.3). Moreover, new urban settlements and industrial areas continue to be located around water sources due to the need for industrial cooling, industrial waste disposal needs, and agricultural irrigation. Thus, many rivers, lakes, and streams are facing the danger of being depleted and poisoned. This water depletion and the wrong use of irrigation water can also cause infertility problems with the runoff of fertile layers of soil and percolation of nutrient-rich water through groundwater channels.

Figure 2.3 Agricultural runoff (left), excessive irrigation patterns (top left), and pesticide use (bottom left) in conventional agriculture. (Despommier, 2009)

Bingöl (2015) claimed that the use of artificial fertilizers and pesticides can change the content of soil and water with chemicals in them, and they can also affect the pH and salinity balance of soil. At the end of this process, soil and water become contaminated, and it is hard to cultivate more produce in those agricultural brownfields.

Lack of biodiversity in terms of crop and plant types is another environmental impact of conventional agriculture. Some conventional fields are used for monoculture techniques or mono cropping that includes only one type of plant for the whole field due to the local conditions and ease of harvesting. (Kanbak, 2018). Therefore, as Skar et al. (2020) claim, unlike alternative agricultural methods, there can be a lack of biodiversity which is unhealthy for wildlife, pollination possibilities, and richness of soil components.

With the advent of transportation means that can carry food and resources through cities via railways, highways, and seaways, the proximity between settlements and agricultural lands started to disappear. Benis et al. (2017b) and Astee & Kishnani (2010) claim that the increase in the distance for food delivery which is called “food miles” and the delivery time cause increases in harmful greenhouse gas and carbon dioxide emissions. As Gould and Caplow (2012) examined, approximately 25% of all greenhouse gas emissions come from agricultural processes, and 80% of the energy in conventional food production is used for transportation, packaging, and storing. The authors also point out that the chance of food-borne illnesses and the existence of food with fewer nutrient values can increase with longer food miles and longer storage time with the loss of freshness.

The greenhouse gas emission is not only caused by the food production process and food miles but also the razing of forests and green areas for new agricultural land; as Aydınalp and Cresser (2008) claimed, soil, plants, and trees in forests are significant CO_2 binders and holders that can release excessive amounts of CO_2 through the atmosphere after they are razed to the ground.

Besides the impact of conventional agriculture on the environment, there are also problems in terms of the economy. Firstly, the distribution chain of food consumes considerable amounts of energy and costs a lot. As Gould and Caplow (2012) claimed transportation of goods consumes a nearly equal amount of energy and resources with the production of the food. Agricultural lands are generally located far from the urban environments; however, this situation creates a gap between the place of production and the place of consumption. According to Benis et al. (2017b) and Astee & Kishnani (2010), long distances as “food miles” cause more expenses of fossil fuel consumption with a significant amount of delivery time with vehicular transportation, transatlantic ships, airplanes, and trains that can be long enough for losing the freshness of food, and this situation can also cause unwanted economic loss with food wastage.

Another economic issue is excessive land and resource use. Agricultural lands are valuable because they are fertile enough for food production, and they are rare especially in today's world after the loss of an important amount of soil with improper management of agricultural production throughout decades or even centuries (Zaffi & D'Ostuni, 2020). The soil dependence on agriculture shapes one of the main economic problems due to increased land prices and the limited amount of yield from a certain unit area. Moreover, Kalantari et al. (2017) state that resources such as water for irrigation, fuel for agricultural machinery, fertilizers, and pesticides are used much more with the use of more land; they form significant expenses and economic impact.

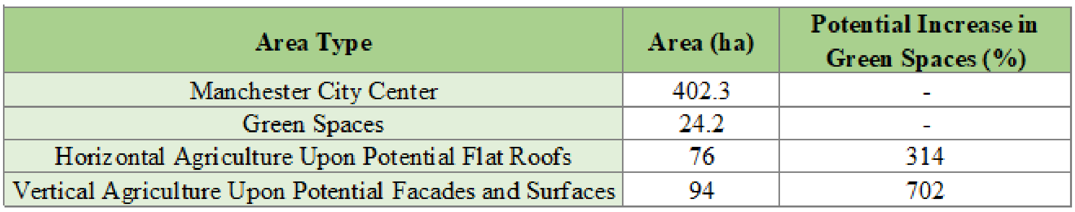
Lastly, as Skar et al. (2020) claim seasonal changes, unwanted temperature differences, lack of daylight, wrong livestock grazing applications, and pests like external factors can decrease the economic gain and profitability of conventional agriculture. If the weather has been cloudy for months in a place, the crop yields will inevitably decrease. If unwanted cold or heat occurs, plants will be affected and there can even be a total harvest loss with its economic gain that cannot be obtained anymore.

2.2 Impacts of the Built Environment

The built environment is continuously expanding with the population explosion and migration from rural to urban areas; the need for the built environment is also inevitable because people spend more than 80% of their lifetime in buildings, interior spaces, or designed built environments nowadays (Bonda, 2007). In "concrete jungles", one of the most urgent needs of the urban population is green areas which cannot be provided properly due to unplanned rapid urbanization and razing existing green areas to clear land for construction. Moreover, most of the land was already razed for the demand of land and resources for industrial activities in the "Anthropocene" era. As a result, growing urban areas are abstracted from greenery. This abstraction causes negative environmental impacts in the built environment such as the emergence of urban heat islands, lack of biodiversity in the urban context, fewer pollination options in cities, lack of oxygen sources, increasing air pollution, and problems with stormwater management (Skar et al., 2020). For instance, the current situation of Manchester city center with the lack of urban greenery and potential ways of increasing it can be observed in Figure 2.4 and Table 2.1. Furthermore, urban green areas provide shading, cooling effect with evaporation of water, absorption of rainwater with absorbent/porous soil surfaces, filtration of air, and habitat for wildlife. They also work as green infrastructure elements for a competent and efficient urban infrastructural system that should bear the infrastructural load of citizens, buildings, and natural conditions (Specht et al., 2014).

Figure 2.4 Manchester city center's existing green spaces (left) and possible green spaces (right) via urban agriculture. (Jenkins & Keeffe, 2017)

Table 2.1 Potential green space increase in Manchester City Center. (Jenkins & Keeffe, 2017)



Area Type	Area (ha)	Potential Increase in Green Spaces (%)
Manchester City Center	402.3	-
Green Spaces	24.2	-
Horizontal Agriculture Upon Potential Flat Roofs	76	314
Vertical Agriculture Upon Potential Facades and Surfaces	94	702

Another environmental impact of the built environment is the consumption of excessive energy and resources. Buildings are one of the biggest energy and resource consumers in the built environment. Ghaffarianhoseini et al. (2013) and Santi et al. (2019) claimed that approximately 40% of all global energy is used in the built environment, 70% of which consists of heating and cooling energy. Thus, to control the excessive consumption of both energy and resources, responsible planners, designers, architects, and engineers should develop new remedies to cope with this environmental impact of expanding the built environment via active and passive design strategies (Banham, 1969).

Urban pollution is another environmental impact of the built environment that is an urgent issue to deal with. All the construction processes from the excavation stage to setting detailed finishing layers emit high levels of greenhouse gases, especially carbon dioxide. This emission constitutes nearly half of the whole greenhouse gas emission of the USA (Gould & Caplow, 2012). One of the main factors behind the considerable amount of greenhouse gas emissions is the excessive expansion of cities with large distances between city centers and production spaces such as agricultural fields and industrial zones. Local self-sufficiency cannot be sustained due to these distances; the built environment starts to rely on peri-urban production zones for energy, food, resources, and products.

As the economic impacts of the current built environment situations, cities accommodate most of the employment opportunities, health services, education options, and a wide range of cultural activities. Inevitably, people try to migrate to urban areas or try to establish relationships with the urban context to benefit from the facilities, opportunities, and possible profits (Zaffi & D’Ostuni, 2020). However, over-migration through urban areas creates bigger socio-economic differences, inequalities, and urban poverty due to inadequate amount of employment options for the newcomers (Yurday et al., 2021). Moreover, urban expenses are way higher than rural ones with higher land prices, rents, fees, taxes, energy prices, and service prices. Food security and food access are also under threat because when the distance between agricultural fields and urban areas gets longer, food prices also get higher even if the delivered food is less fresh (Avgoustaki & Xydis, 2020; Lehmann, 2011). People start to have economic difficulties living in urban areas, and the growing population consumes more energy and resources which also increases the prices. Economic self-sufficiency or production-based self-sufficiency cannot be sustained (Hallett et al., 2016).

The built environment also consists of different social sub-systems of settlements and communities such as districts, neighborhoods, streets, public spaces, communal areas, buildings, and individual houses. Urban areas seem to have many opportunities for social gathering and interaction. On the contrary, as De Zeeuw et al. (2011) state most of today's urban settlements face social isolation, social exclusion, cultural shock of individuals, and social alienation of immigrants, refugees, and minorities. Moreover, immigrant elders, young people, and people who are suffering from disabilities have difficulties to involved in the urban society (Doron, 2005). Even if there are many public spaces and potential social gathering places, most of them are not inclusive enough or do not include social activities to interact with people. The lack of Lehmann's (2011) green urbanism principles such as green areas, open-air public spaces, pedestrian-based transportation, and pedestrian-friendly urban areas are also other main reasons for the existing social impacts of the built environments.

2.3 Urban Agriculture (UA)

Plains of agricultural lands have started to decrease in amount, and become contaminated, or infertile (Albajes et al., 2013). The search for new agricultural lands causes rapid use of existing ones and the destruction of natural areas like forests to obtain new agricultural fields. However, those are not sustainable solutions, and their short-term benefits can return as long-term problems. Thus, as Albajes et al. (2013) state, new agricultural areas and methods have started to emerge in the last decades. Most of those methods can be identified under the main title of urban agriculture (UA) due to their urban context.

According to Poulsen et al. (2015) and Talbot and Monfet (2020), urban agriculture can be defined as agricultural activities in urban areas and surfaces such as exterior walls, facades, roofs, balconies of houses, containers, groceries, offices, or existing building stock of the city (Figure 2.5). Moreover, turning vacant lots, gardens, buildings, underground areas, and building floors into UA spaces is a strategy for efficient land use and for creating mutual relationships between the UA system and the vacant area (Poulsen et al., 2015). These potential urban spaces and Kozai's (2013) examples to integrate them with different urban agricultural methods are shown in Figure 2.5.

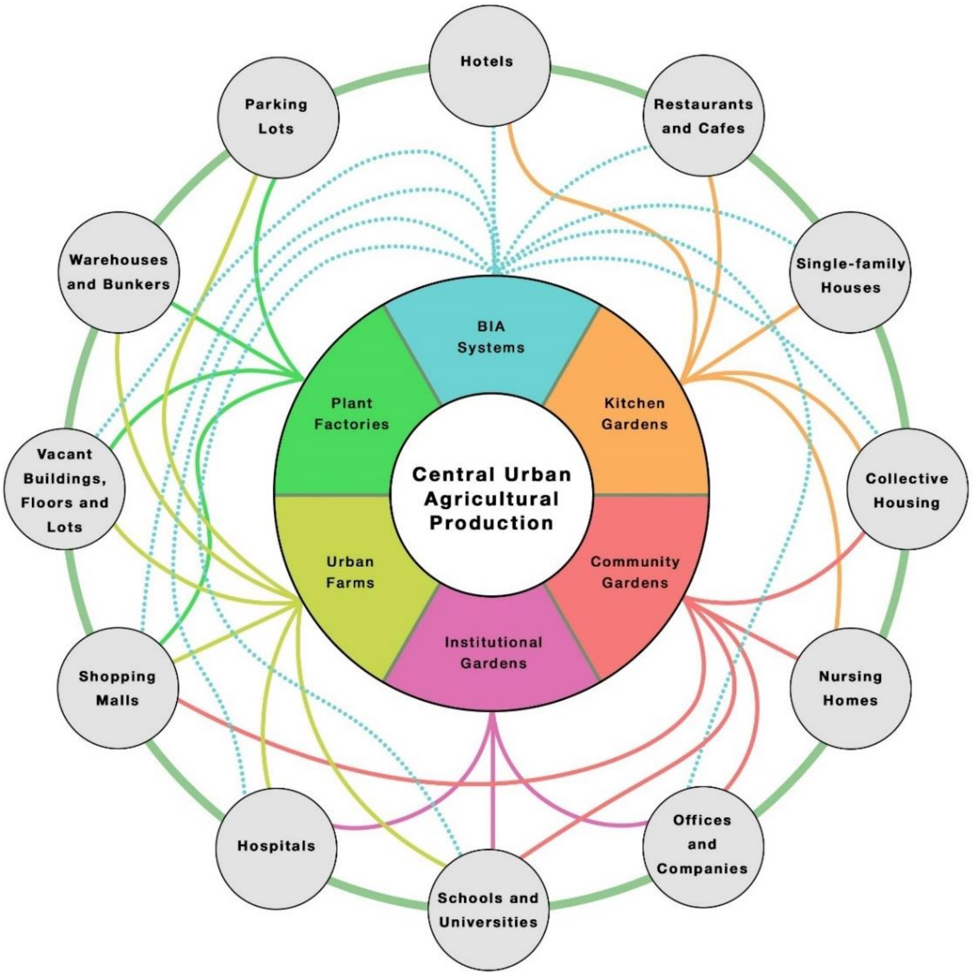


Figure 2.5 Urban areas for urban agricultural applications. (Kozai, 2013) (integrations adapted and redrawn by Author)

The main idea behind urban agriculture is generally the local food production for local consumption, local self-sufficiency, and fulfilling increasing demand with easily accessible food. Poulsen et al. (2015) indicate that food access is less dependent on price increases, fluctuations, long food miles for delivery, or stock problems thanks to local production (Figure 2.6). In this way, the freshness of products can be preserved, and community health can be increased.

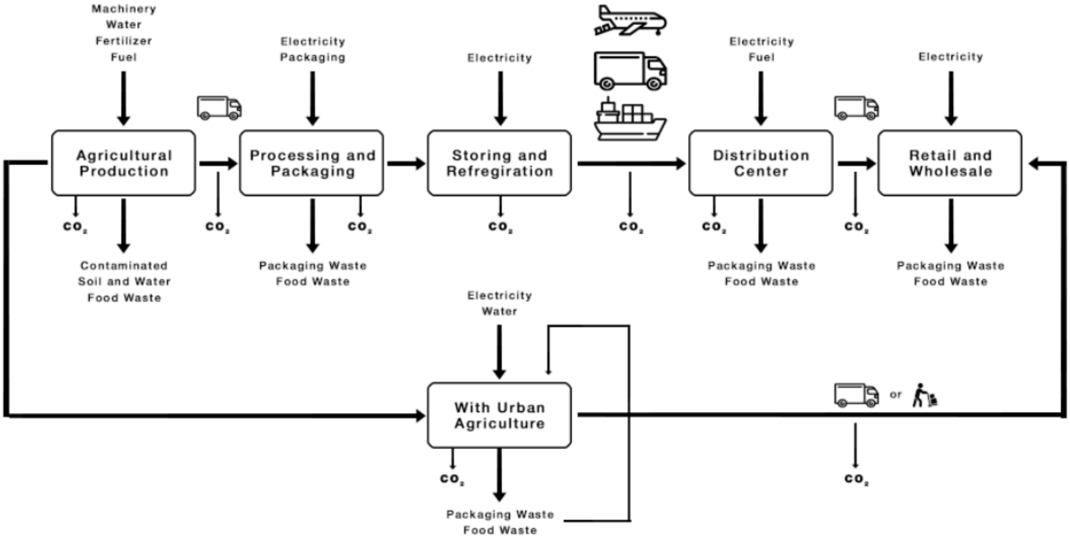


Figure 2.6 Food supply chain. (flowchart drawn by the author, based on information from literature sources: Benis et al., 2018; Casey et al., 2022; Lehmann, 2011)

Local food production can help to arrange new employment opportunities in cities, semi-urban areas, and especially for low-income people, unemployed women, young people, or elderly people (De Zeeuw et al., 2011). As Zezza and Tasciotti (2010) state, poor people in poor countries can benefit from urban agriculture for being economically available to buy food and for easy access to food due to local production. Urban agricultural methods are seen as expensive high technology-based systems like plant factories; however, there are also budget-friendly and much simpler UA systems that can be used by people in need to produce food locally (Platt, 2007) (Kalantari et al., 2017). Thus, it can be said that urban agricultural methods are beneficial to mitigate food insecurity-based problems. Moreover, locally produced food can be shared among local people to spread the awareness of local solidarity. This solidarity is also supported by social facilities to gather people such as community gardens, agricultural cooperatives, and urban farms (Madaleno, 2001).

Urban agriculture is also directly related to the terms urban farming and "ZFarming". As Şahin and Kendirli (2016) state, urban farming can be defined as a totalitarian concept that includes both plant-based UA methods and animal-based productions such as livestock grazing, beekeeping, leather production, silk production, wool production, dairy production, meat production, and fish production. As Specht et al. (2014), the ZFarming concept's name comes from zero acreage farming which means agricultural activities without any need for agricultural land use such as building-integrated agricultural systems. As examples of ZFarming concept, BIA used rooftop greenhouses in Brooklyn and Montreal are shown in Figure 2.7.

Figure 2.7 A. B. Rooftop greenhouse of Gotham Greens on Whole Foods supermarket in Brooklyn, C. D. Rooftop greenhouse of Lufa Farms in Montreal. (Proksch, 2017)

"Green urbanism" is a concept that must be considered for urban agricultural applications with its 15 main principles for achieving sustainable urban development goals and well-developed green infrastructure (Table 2.2). According to Lehmann (2011), green urbanism aims to mitigate energy and resource consumption in every step of the life cycle of a city, a district, or a building, from the designing stage to the reuse stage of the demolition wastes. To achieve green urbanism, interdisciplinary approaches must be provided by architects, urban planners, engineers, social scientists, etc.

Table 2.2 Green urbanism principles. (Adapted from Lehmann, 2011)

15 Principles of Green Urbanism

Climate and Context	•Orientation, compactness, topography, rain, wind, lighting, air pollution, solar radiation
Renewable Energy & Zero Emission	•Less fossil fuel, high building insulation, high energy efficiency, smart metering technology
Zero-Waste City	•3R (reduce, recycle, reuse) strategies and composting
Water	•Rainwater collection, stormwater harvesting, wastewater recycling, bio-filtration systems
Landscape, Gardens & Urban Biodiversity	•Wildlife rehabilitation, habitat and ecology
Sustainable Transport & Good Public Space	•Bicycle promotion, smart vehicles and infrastructure, transport-oriented development
Local and Sustainable Materials	•Lightweight and durable structures, local materials with minimal transport and waste
Density & Retrofitting of Existing Districts	•Urban renewal programs, retrofitting inefficient building stock and adaptive reuse
Green Buildings & Districts	•Passive design, bio-climatic architecture, renovating and retrofitting the entire building stock
Livability & Healthy Communities	•Compact communities, mixed use concepts, avoiding gentrification, affordable housing
Local Food & Short Supply Chains	•Local production, community vegetables, “eat local” and “slow food”, urban farming
Cultural Heritages & Identity	•Population desires, history
Urban Governance & Leadership	•Updating building code and regulations, encouraging community participation
Education, Research & Knowledge	•Technical training, research, universities as “think tanks”
Strategies for Cities in Developing Countries	•Low-cost building, new job opportunities

As Liesa et al. (2021) state, the proper urban planning for food production with green urbanism principles can make cities more efficient owing to their sophisticated webs of delivery, management, and logistic supply; resources are easier to reach, production is faster, delivery of products is not hard due to local production, and waste management is more feasible due to waste reuse opportunities as a source of fertilizer for the cultivation. Reuse options of waste and other resources create circularity possibilities in an urban system with a close loop of input and output relationship (Roggema, 2016). Smit and Nasr (1992) also indicated the possibility of transforming open loops of consumption and waste disposal into closed loops of consumption, revaluation, and utilization of resources and wastes via urban agricultural methods and green urbanism principles.

There can be a classification for urban agriculture's subcategories according to their different production scales and aims (De Zeeuw et al., 2011). For instance, UA can be applied via individuals or small communities in their housing units, gardens, and common places as a small-scale urban production of food for their consumption. Family gardens and allotment gardens are small gardens of a separated field for non-commercial production, community gardens, guerilla gardens that are abandoned gardens without legal rights to cultivate, institutional gardens that are cultivated by employees of companies or students at universities, and small rooftop gardens can be given as examples of them (Nowysz & Trocka-Leszczyńska, 2021).

Small-scale UA types can be exemplified more with container farms, in-store farms that are ready to harvest vertical farms by customers in shopping centers, plant boxes, and appliance farms that are small individual in-house food production cabinets (Benis et al., 2017b). As Koscica (2014) and Mok et al. (2014) note, small-scale UA types were also common especially in World War I as "war gardens" and in World War II as "victory gardens" to fulfill both civilian population demand and the demand of the army.

As mid-scale UA examples, rooftop greenhouses, rooftop gardens, and green edible facades and walls can be given (Nagle et al., 2017). Furthermore, Skar et al. (2020) state urban farms as an example of mid-scale production of food for both local and public use. Urban farms include not only agricultural activities but also possible livestock, fowl, and bee breeding (Smit & Nasr, 1992; Poulsen et al., 2015).

Regulated, planned, and mostly commercialized food production systems in cities can be exemplified as the big-scale UA types. Those types can be operated in open-air urban areas, highly used public spaces, indoor production spaces, or plant factories (Graamans et al., 2018). "Deep farms" which are underground and underwater agricultural systems as Chole et al. (2021) claim, are also examples of possible big-scale UA types for circular urban agricultural systems with the use of groundwater, ground heat, and waste of the system as their inputs.

The different types of UA are illustrated in the diagram below (Figure 2.8).

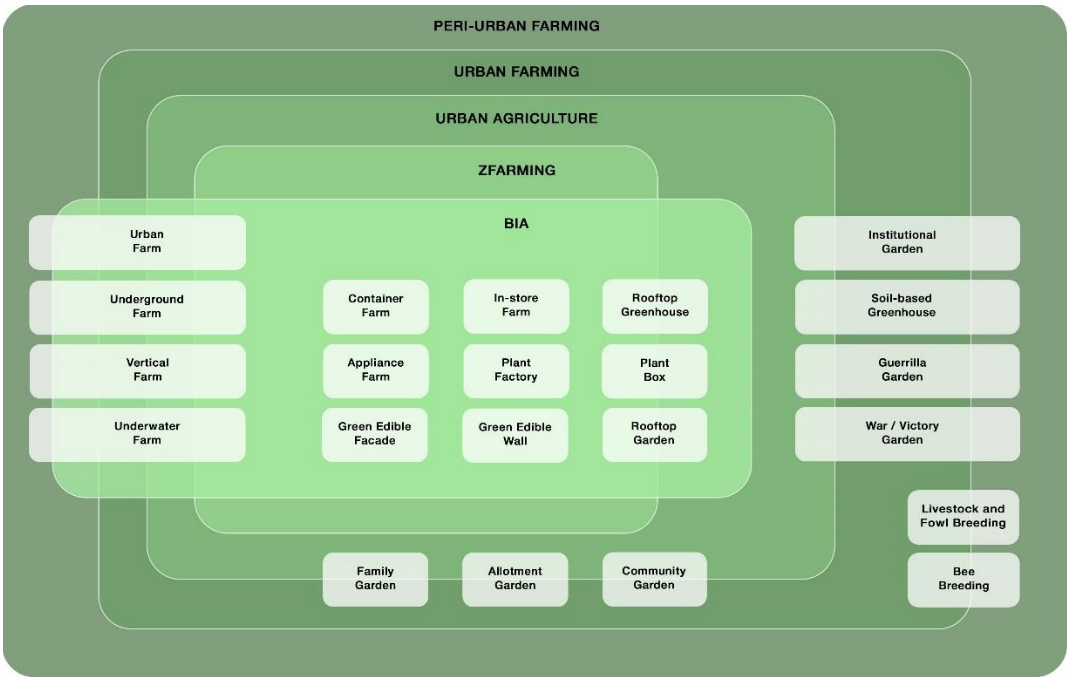


Figure 2.8 Urban agriculture typologies. (Flowchart drawn by the author, based on information from literature sources: D'Ostuni et al., 2022; Skar et al., 2020; Kozai et al., 2019)

2.4 Building Integrated Agriculture (BIA)

The building-integrated agriculture (BIA) topic can be examined under the urban agriculture concept. Gould and Caplow (2012) state that BIA is the combination of building and farm design in or on urban structures via generally hydroponic systems, preferably with the help of renewable energy sources, local resources, and possible integration strategies (Kalantari et al., 2017). The vertical farming concept is not the same as BIA; on the other hand, it is a general term for different vertical UA and BIA methods. It was first mentioned in 1915 in Gilbert Ellis Bailey's "Vertical Farming" book (Bingöl, 2015). After, Dickson Despommier (2009), who is considered as the pioneer of the vertical farming concept by the majority, used vertical farming approaches to vitalize real structural examples of vertical farming (VF). Afterward, the vertical farming concept was elevated with the integration of the built environment via BIA methods.

Most of the vertical BIA methods have tendencies to require technological assistance, professional maintenance, and operational attention; thus, vertical greenery systems (VGS) are used less than horizontal greenery systems (HGS) (Wang et al., 2016). There is also the building-integrated farming (BIF) concept which includes both agricultural production and livestock production (Şahin & Kendirli, 2016) conducted with the integration of buildings.

The advent of the first indoor vertical farming examples and trials of the modern era with hydroponics can be exemplified by Douglas (1977) and Kleszcz et al. (2020) as the one built in Armenia, the one built in Vienna, and the one built in Poland before 1970s. According to Januszkiewicz and Jarmusz (2017), Othmar Ruthner designed a greenhouse tower which is acknowledged as one of the first trials of factorial production of food and vertically integrated greenhouse (VIG) (Figure 2.9). They were pioneer examples of green architecture and integrated structures with greenery for their era (Nowysz, 2022). According to Benis et al. (2017a), BIA was first mentioned by Theodore Caplow in 2007; he applied well-insulated high-performance greenhouses to his building. Januszkiewicz and Jarmusz (2017) also claimed that at the beginning of the millennium, microbiologist Dickson Despommier enhanced the idea of Ruthner to shape today's modern vertical farming practices with real-life applications of BIA.

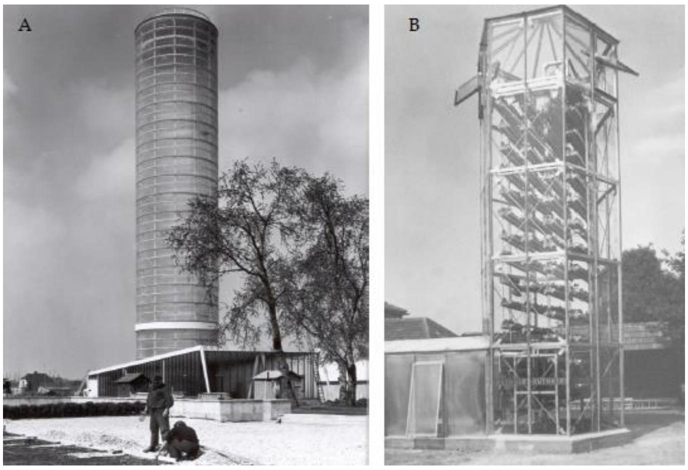


Figure 2.9 The vertical farm idea evolution: Othmar Ruthner's WIG64 Farm Structure in 1964 (left), and Othmar Ruthner's gardening tower in 1963 (right). (Kleszcz et al., 2020)

2.4.1 Urban Symbiosis and Urban Circularity

As agricultural methods, BIA systems adopt the “integration” possibilities with the built environment. The “circularity” of the urban system with a closed loop of inputs and outputs can be sustained via the integration of different sub-systems that create the whole (Morabito, 2021; Skar et al., 2021). Moreover, the “symbiosis” of sub-systems as integration is also significant to reach the final desired urban system that is sustainable, self-sufficient, and feasible (Kozai, 2013). BIA systems can use what the cities already provide such as CO_2, water, energy sources, and nutrients; at the same time, they can use buildings’ input and output materials as resources for the advantage of both agricultural systems and the built environment (Roggema, 2016). For instance, Delor (2011) claimed that an integration between a building and a rooftop greenhouse structure can store 40% more heat in both structures compared to separate ones, and the integration can mitigate annual energy consumption of both up to 15% with proper insulation, reduction of heat loss, and use exhausted heat of the building for greenhouse heating. Thus, as Roggema (2016) states, the circular urban system with different symbioses can be possible to create a “circular metabolic urban system” that is similar to a living organism with the most efficient use of inputs to create fewer outputs.

Moreover, not only the symbiosis of systems in terms of resource use but also the symbiosis of different disciplines should be investigated. Contextual potentials, local businesses, and infrastructural opportunities can enhance the circularity of the BIA system with different symbiotic relations. As an example, according to Martin et al. (2022) and Fahim (2021), a local brewery factory can be utilized to provide beneficial inputs for a BIA system (Figure 2.10). Brewery factories are important sources of CO_2 as an output of the fermentation process, heat, and grains of the brewery as biowaste. CO_2 can be captured and pressurized in tanks for the carbon enrichment process, heat can be transferred via infrastructural means, and waste of grains can be turned into compost or can be used as a growing medium. As Martin et al. (2022) claimed, this symbiotic relationship can decrease the amount of kgCO_2eq per kg of a plant by approximately 50% with a calculated optimal integration scenario. Thus, proximity can be provided between the factory and BIA used building to benefit from the factory's outputs and the BIA system's inputs.

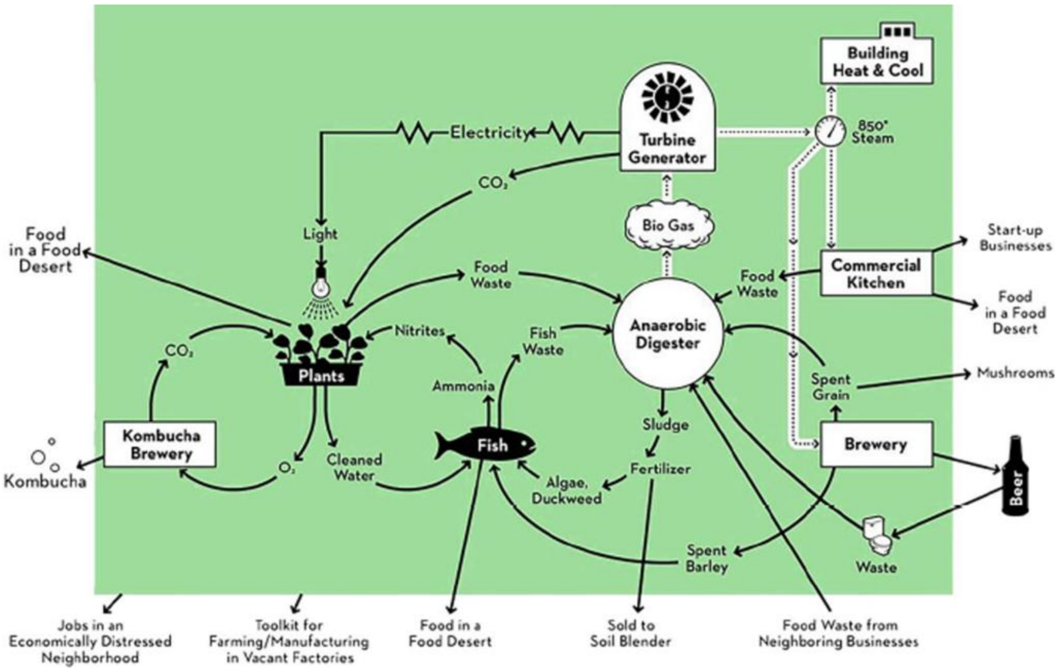


Figure 2.10 Closed-loop system example with the integration of a building, aquaponic system, brewery factory, and kombucha brewery factory. (Fahim, 2021)

This sample of agro-industrial symbiosis can also be exemplified with Plantagon greenhouse project in Sweden as a closed loop system (Figure 2.11) and with Atatürk Forest Farm urban farming project (Figure 2.12) in the early republic era of Turkey (Açıkgöz & Memlük, 2004). The farm was in Ankara as a symbiotic agro-industrial case with the integration of forest areas, agricultural fields, streams, rehabilitation fields, a zoo, a wine factory, and a beer factory.

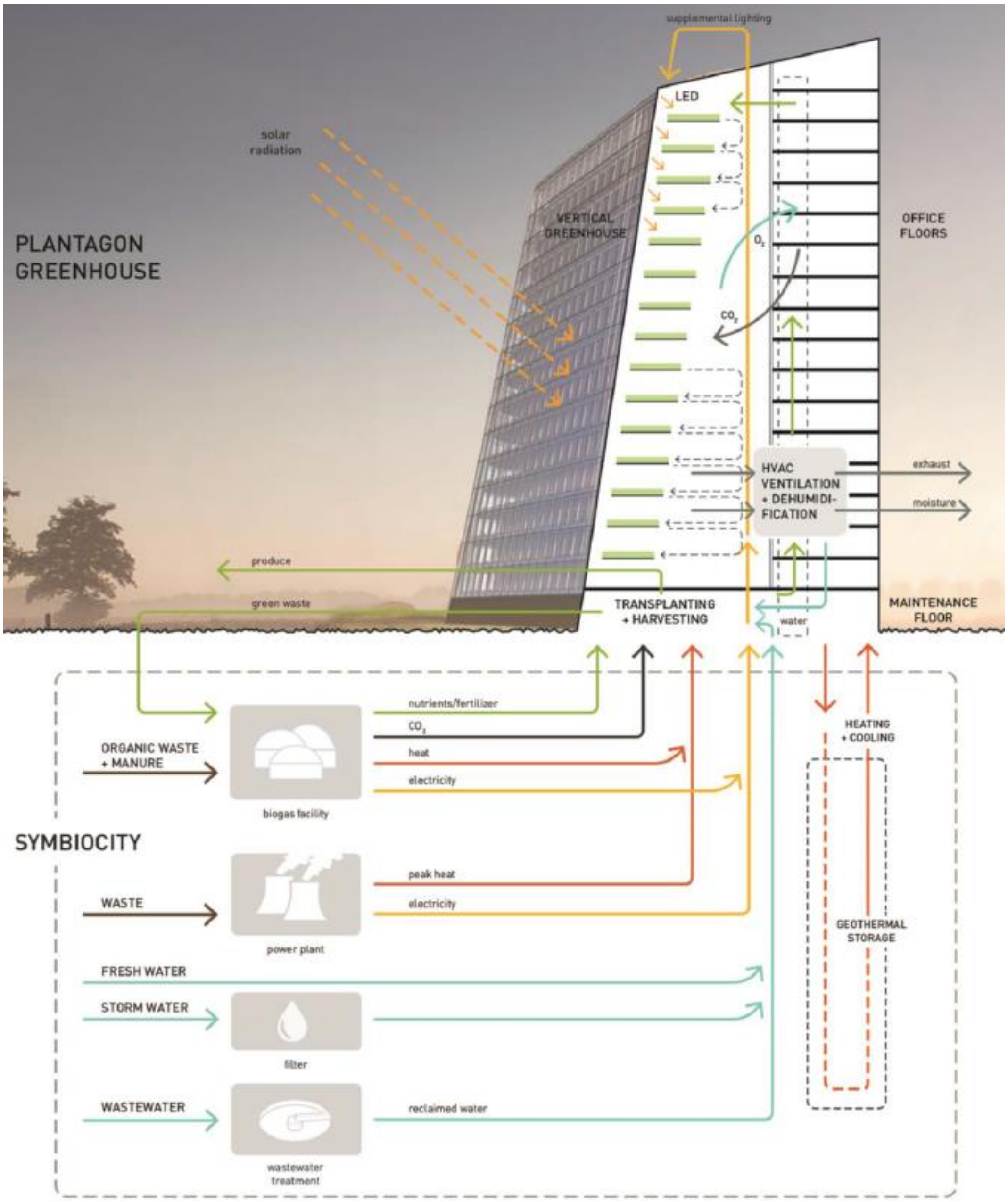


Figure 2.11 Operational diagram of Plantagon's vertical farm proposal. (Proksch, 2016)

Figure 2.12 Atatürk Forest Farm urban farming project with agricultural fields, brewery factory, social spaces, and local dairy production. (Kimyon & Serter, 2015)

2.4.2 Controlled Environment Agriculture (CEA)

As Benis et al. (2017b) claim, most of the BIA methods include many active design parameters and technological equipment for all-year production with less concern about external climatic conditions due to controlled-environment agriculture (CEA) techniques and systems. CEA techniques give the chance to have control over the entire food production process in terms of lighting, heating-cooling, indoor air quality, irrigation, exhausted output reutilization, monitoring, and automation.

Firstly, the lighting source is crucial for plant cultivation. There are secondary artificial lighting systems for optimal plant growth with different wavelengths of light as a significant active design parameter. High-pressure sodium lamps (HPS) and fluorescent lamps (FL) are earlier options for artificial lighting (Al-Chalabi, 2015); with the advent of LED technology, LEDs take priority in CEA systems with their low price, durability, longevity, efficient energy use values, desired light wavelength values, and low heat production aspect (Massa et al., 2008) (Despommier, 2019). The optimal range of light intensity by LEDs must be between

4000-17000 lx for an illumination period of 16 hours to 20 hours per day according to the plant's needs (Kalantari et al., 2017). Thus, a specific amount of light intensity should be provided by proper artificial lighting equipment choice. Moreover, designing the system and agricultural facility in the most efficiency way to benefit from both natural light and artificial light sources is a significant issue in decreasing lighting loads (Kalantari et al., 2017). According to Kozai (2013) and Kozai et al. (2020), in an average plant factory, approximately 80% of electricity is used for lighting sources. Thus, there are also passive design options for benefiting from natural light sources more such as the proper orientation of the building and the use of light shelves, operable windows, sky light tubes, reflective surfaces, and transparent cover materials of CEA spaces (Talbot & Monfet, 2020; Liesa et al., 2021).

Secondly, heating and cooling systems to provide indoor thermal control are another parameter of the CEA concept. As active design strategies, proper choices of heating and cooling systems, heat pumps, evaporative coolers, cooling towers, and the heat of exhausted air reuse can control thermal conditions in a CEA space as active design tools (Kalantari et al., 2017). Benis et al. (2017b) state that the orientation of the host structure for CEA spaces, cover material choice of the cultivation space, the window-to-wall ratio of the cultivation space, and the use of solar walls and trombe walls are passive design strategies for heating-cooling requirements (Kalantari et al., 2017).

The inputs and outputs of CEA systems that are determined based on information from literature sources and the parameters of CEA are depicted in Figure 2.13 below.

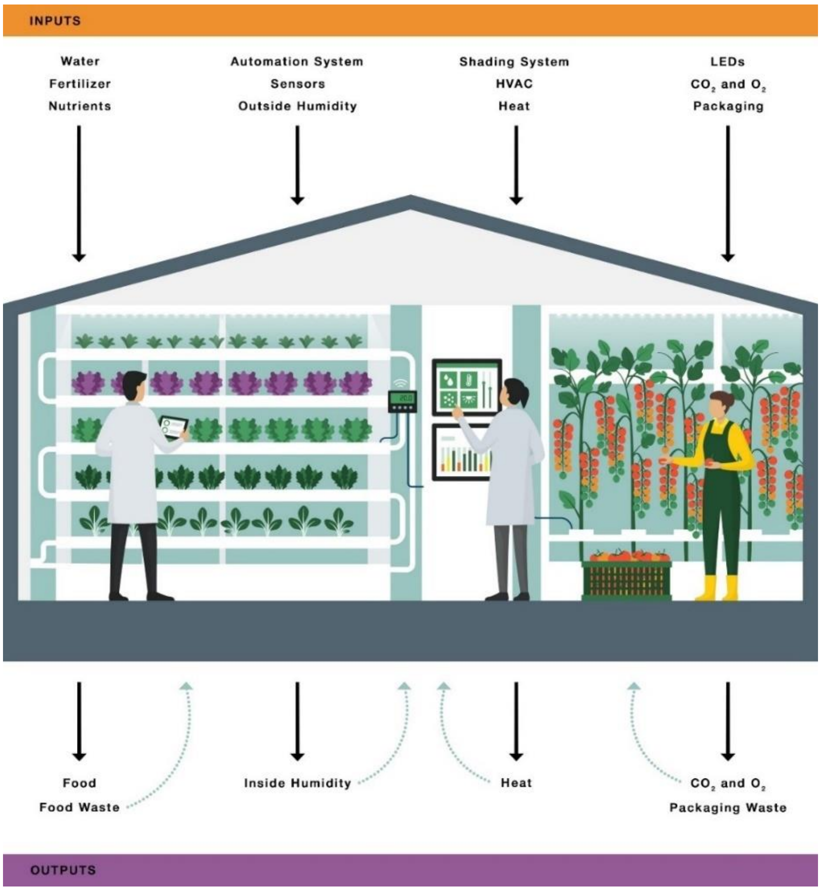


Figure 2.13 Inputs and outputs of controlled environment agriculture (CEA) systems. (drawn by the author, based on information from literature sources: Benis et al., 2017b; Shamshiri et al., 2018)

Thirdly, indoor air quality is another parameter of CEA spaces to consider. The use of air conditioners, air filters, and mechanical ventilators are active strategies for designing CEA spaces. Those systems are secondary when natural ventilation is insufficient to dispose of exhaust air or humidity inside (Blom et al., 2022). More exhaust air creates thermal indoor problems, and more humidity can cause condensation on any interior surfaces that can lead to corrosion or equipment malfunction (Talbot & Monfet, 2020). Thus, proper air conditioners and mechanical ventilation systems must be ready to use whenever secondary ventilation is required as an active strategy. Otherwise, as a passive design strategy, natural ventilation must be preferred to eliminate the energy requirement of energy-dependent equipment (Talbot & Monfet, 2020).

Furthermore, Liesa et al. (2021) and Benis et al. (2017b) claim that the choice of the cover material and indoor equipment materials are significant passive design strategies that can affect indoor air quality. Gould and Caplow (2012) note that material choices of covers, interior equipment, and cultivation products must be recyclable, easy to clean, low impact on nature, non-toxic, long-lasting, and durable for a long sustainable food production period. For example, most of the vertical CEA spaces use ethylene tetra fluoro ethylene (ETFE) as cover material due to not only its self-cleaning property but also its transparency, thermal conductivity rate, and lightness. ETFE can permit more than 90% of the light while being a hundred times lighter than an equal size of glass panel (Kalantari et al., 2017). On the other hand, the use of ETFE as a cover material and the use of lightweight PVC material for gutters, cultivation tubes, and hoses can be questionable due to plastic-based material choice even if it was chosen for its lightness aspect. With sunlight exposure, those plastic materials can release toxic materials into the air that are harmful to plants and people (Huelat, 2008). Although, they are way heavier and more expensive than plastic material options, solar glass and diffusive glass for the cover material, and galvanized steel for the tubes and gutters can be chosen for a healthier food production space (Kalantari et al., 2017).

Fourthly, Skar et al. (2020) state that irrigation methods and irrigation water types for food production are other parameters. Irrigation methods can differ as drip systems, spray types, pressurized ones, normal hosing, and mist/fog systems. Unwanted humidity from irrigation equipment, human beings, and external conditions must be avoided because it can cause algae or other organisms' reproduction that can cause undesired health issues. Thus, as Kalantari et al. (2017) claimed, controlled dehumidification via passive techniques such as natural ventilation and cold surface use, or active strategies such as chemical solution use and HVAC use are necessary to sustain CEA requirements. Moreover, according to Skar et al. (2020) and Kalantari et al. (2017), irrigation water types are potable water, harvested rainwater, groundwater, condensate water, evaporated water by dehumidification, treated or untreated wastewater/greywater, and treated stormwater. For instance, the treatment of greywater or filtration of different irrigation water types is crucial to minimize waterborne plant diseases, prevent harmful chemical absorption via plant roots, and sustain controlled environment conditions as active design strategies (Lehmann, 2011) (Koscica, 2014).

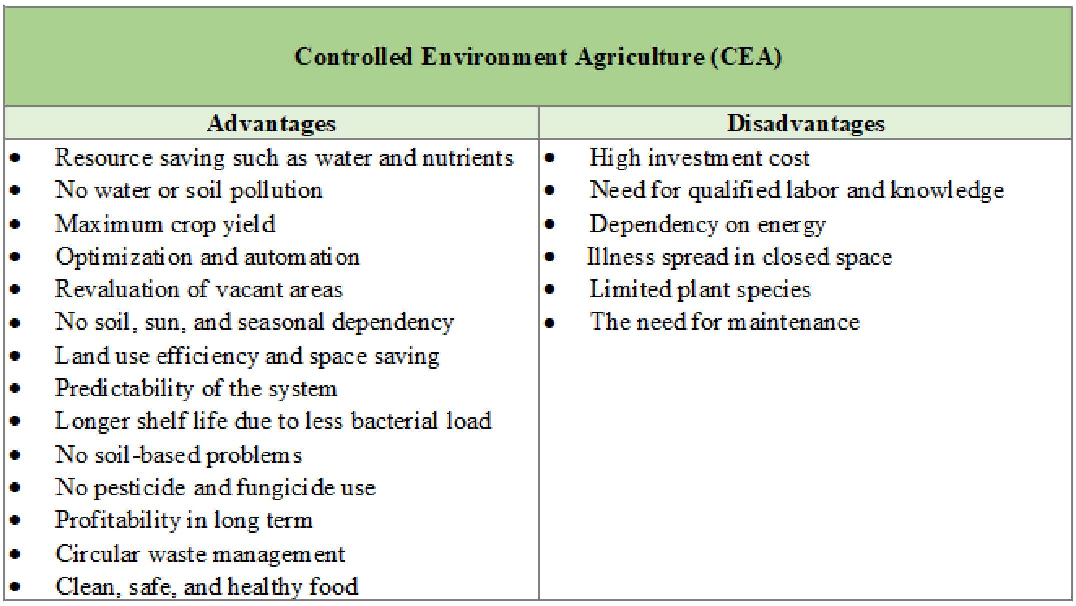
Fifthly, as another parameter, exhausted outputs of other systems can be reutilized with CEA conditions. Bao et al. (2018) and Şahin and Kendirli (2016) state that CO_2 enrichment systems can use local ambient CO_2, exhausted CO_2 of buildings, occupants, and industrial sources with proper filtration via high-efficiency particulate arresting (HEPA) technology against hazardous organisms and contaminants to use it for increasing crop yields by 25% to 60% in CEA and BIA systems. As Karadağ (2019) states, between 800-1200 ppm of enriched indoor CO_2 concentration is crucial and beneficial for an optimal photosynthesis period for lettuce production. Moreover, the utilization of wastewater, untreated greywater, or exhausted water from urban streams in CEA production with proper filtration (Lehmann, 2011) as active strategies can be exemplified as symbiotic relations between CEA spaces, buildings, industrial areas, and natural landscapes.

All those parameters are monitored with some sensors and automation systems as another CEA parameter to sustain the desired control over the food production process. For example, as Gould and Caplow (2012) note, the lighting level or wavelength of artificial lights can be controlled according to photo-sensors. When temperature difference occurs heating or cooling systems start to work due to heat-sensors. If the humidity of the space decreases to a level that is harmful to plants, vapor-sensors can indicate the decrease and give the order for mist/fog systems. If a leakage occurs, necessary warnings can be given by relevant sensors.

Thus, automation systems and sensors are useful to sustain the control of the cultivation environment in CEA spaces (Wang et al., 2016). Those monitoring systems aim to ensure the quality, efficiency, and continuity of the agricultural production process for healthy and nutrient-rich food with predictable production sequences. With all those parameters with their active and passive design strategies to sustain the control of the cultivation environment, CEA can even be used in extreme conditions and contexts such as drought areas, polar regions, underground stations, bunkers, space stations, and different planets (Giroux et al., 2006).

Advantages and disadvantages of CEA are given in Table 2.3.

Table 2.3 Advantages and disadvantages of controlled environment agriculture (CEA). (adapted from Karadağ et al., 2020)



Controlled Environment Agriculture (CEA)	
Advantages	**Disadvantages**
• Resource saving such as water and nutrients • No water or soil pollution • Maximum crop yield • Optimization and automation • Revaluation of vacant areas • No soil, sun, and seasonal dependency • Land use efficiency and space saving • Predictability of the system • Longer shelf life due to less bacterial load • No soil-based problems • No pesticide and fungicide use • Profitability in long term • Circular waste management • Clean, safe, and healthy food	• High investment cost • Need for qualified labor and knowledge • Dependency on energy • Illness spread in closed space • Limited plant species • The need for maintenance

2.4.3 Hydroponics, Aeroponics, and Aquaponics

As Bingöl (2019) states, BIA is mostly based on hydroponic systems (Figure 2.14). The emergence of hydroponic systems dates from Patrick Blanc, who is a French botanist, and his innovation of green walls with the first hydroponic systems to sustain their irrigation needs in the 1970s, as Weinmaster (2009) claimed. Those systems are generally soilless methods for food production with different growing media as flowing nutrient solutions or water holder organic/inorganic components instead of soil such as sand, pebble, perlite, vermiculite, rock wool, volcanic turf, coco peat, and sawdust. Contrary to common belief, as Despommier (2012) claimed, soil is not a must for agriculture; it is a solid layer for plant roots to hold, and it contains necessary minerals and nutrients. Thus, plants that have a stable root structure with any type of substrate can be cultivated with the necessary amounts of water, light, minerals, and nitrogen sources. Most of the leafy greens -such as lettuce, basil, parsley, spinach-, strawberry, cucumber, tomatoes, melons, and beans are suitable plants for hydroponic cultivation (Bingöl, 2019). Plant roots are not placed in closed sections, they are suspended or floated in a circulated water system with up to 75% less water consumption. Skar et al. (2020) claimed that there are no soil-borne diseases, no contamination of pesticides and artificial fertilizers, and no need for fertile lands.

According to Kalantari et al. (2017), there are different hydroponic techniques such as nutrient film technique (NFT), wick system, deep water culture technique, flood and drain system, and drip system. Moreover, hydroponic systems are scalable and flexible systems that provide root and plant observation opportunities, nutrition monitoring, and optimized growth conditions for better yields and healthier food production without any toxic substances (Tocquin et al., 2003).

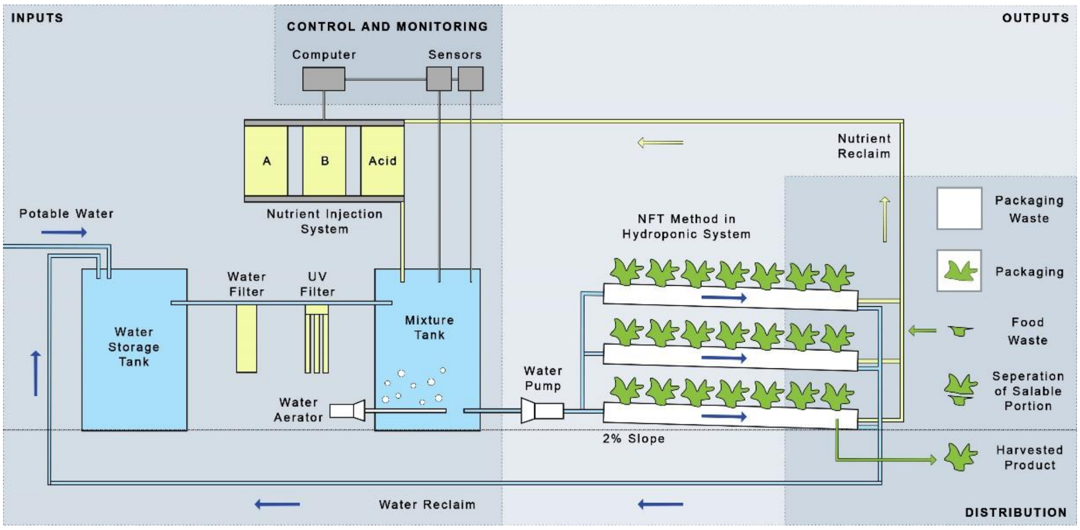


Figure 2.14 Hydroponic system schematic drawing. (drawn by the author, based on information from literature sources: Proksch, 2016; Birkby, 2016)

Bingöl (2019) notes that other important BIA methods are aeroponic systems (Figure 2.15) which can also be considered as a sub-type of hydroponics. The aeroponic name comes from aer (air) and ponos (work) words. According to Bingöl (2019), aeroponic systems can decrease the amount of water consumption by up to 98%, nutrient use by 60%, and pesticide use completely. Lettuce, cabbage, basil, parsley, carrot, cucumber, tomatoes, strawberry, potatoes, and more plant options can be cultivated via aeroponic systems (Bingöl, 2019). They are very similar to hydroponics, but they use aerated irrigation with spraying and mist/fog through suspended plant roots instead of flowing water to fulfill the nutrient needs of foods. The pressure of those spraying systems can differ as Bingöl (2019) claimed. Low-pressurized ones are cheaper and easier to install, whereas high-pressurized and ultrasonic-pressurized ones are way more expensive and require more professional maintenance. There are extra demands for aeroponics such as regular cleaning of suspended root systems and no light exposure of the root box against fungus and pathogens because there is no continuous flow of water (Bingöl, 2015).

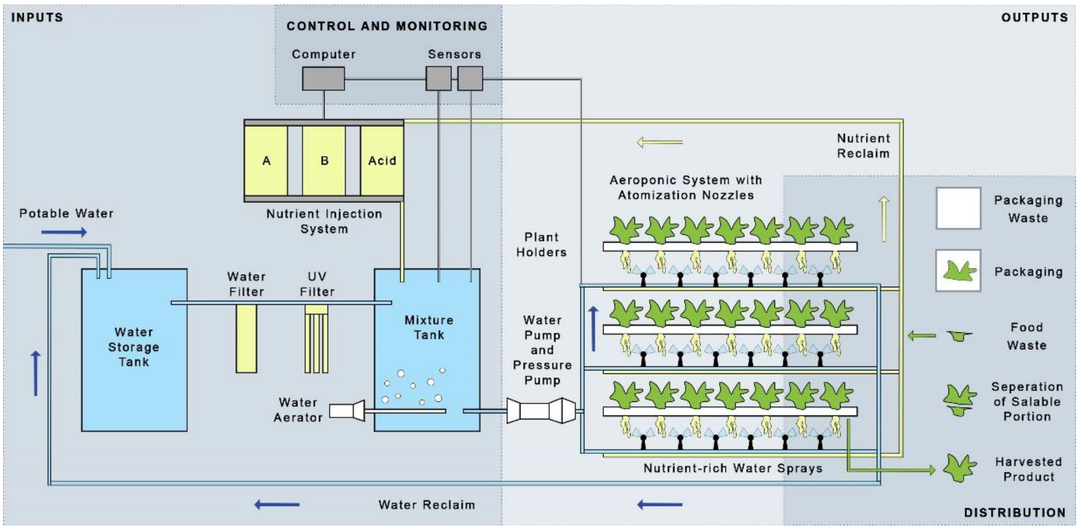


Figure 2.15 Aeroponic system schematic drawing. (drawn by the author, based on information from literature sources: Proksch, 2016; Lakhiar et al., 2018)

According to Bingöl (2019), another integrative use of hydroponics is called the aquaponics system (Figure 2.16). In this system, there is a mutual or symbiotic relationship between plants and aquaculture organisms like fish. Food and fish are produced synchronously in these systems: plants as water purifiers, and fish as fertilizer sources. As Kargın and Bilgüven (2018) and Bingöl (2019) note, tilapia, koi, goldfish, carp, catfish like fish and lettuce, spinach, arugula, basil, mint, pepper, cucumber, beans-like plants can be produced via aquaponic systems. They (2018) also claimed that the emergence of aquaponics dates to the ancient Aztec and ancient Egypt civilizations; also in recent history, terraced and flooded rice fields can be used for fish breeding in Eastern Asia which is a pioneer reference for both vertical farming and aquaponics.

As Çiçekli and Barlas (2014) claim, plants use waste from fish as fertilizers while cleaning the water, and fish protect plants' root systems by eating harmful organisms while converting bacteria into nitrogen sources for the plants. In aquaponics, bio-waste output is less than in hydroponics due to fish breeding and the mutual relationship between plants and aquaculture. This cycle is depicted in Figure 2.16.

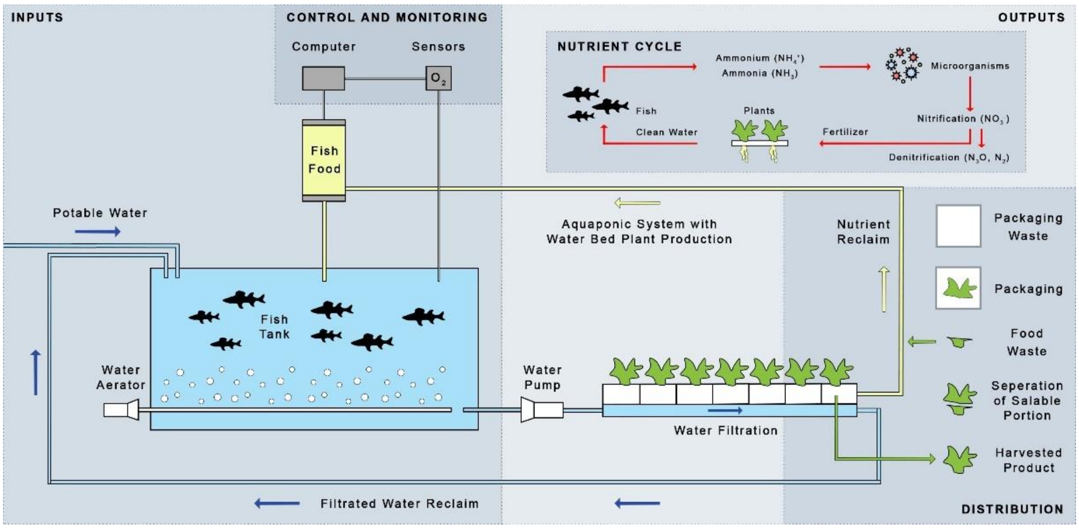
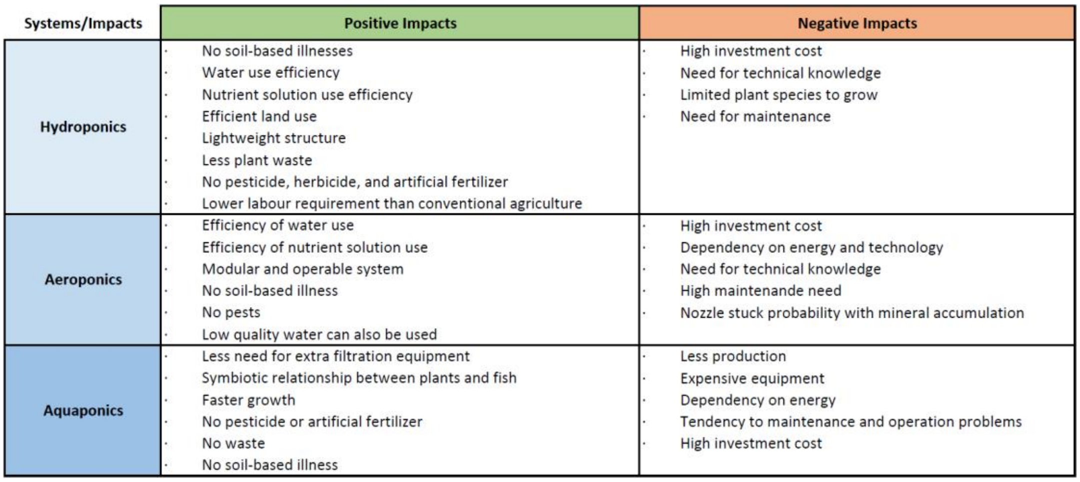


Figure 2.16 Aquaponic system schematic with nutrient cycle. (drawn by the author, based on information from Proksch, 2016)

Kalantari et al. (2017) note that vertical farming systems or BIA systems are generally expected to work in a closed loop which means the outputs of the system can also be used as new inputs. In aquaponic systems, bio-waste of plants can be used as food for fish. Meanwhile, bio-waste of fish can be used as liquid fertilizer for plant cultivation. Thus, aquaponics can be considered as more appropriate system for a closed loop understanding. However, those BIA systems require a high level of maintenance, monitoring, qualified labor, investment cost, energy, and structural load-bearing capacity (Bingöl, 2019).

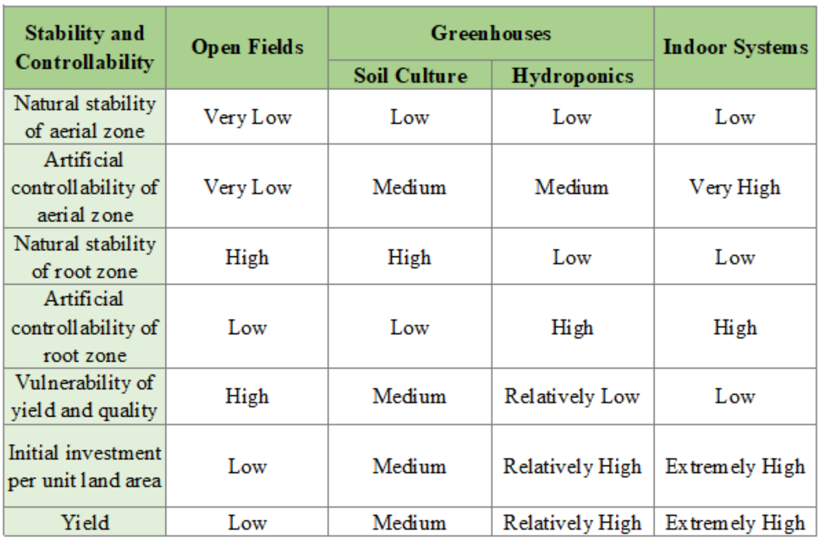
The positive and negative impacts of hydroponics, aeroponics, and aquaponics are given below in Table 2.4 while a comparison of the 3 commonly employed agriculture systems, namely open field, greenhouse, and indoor agriculture, in terms of stability and controllability aspects are given in Table 2.5.

Table 2.4 Positive and negative impacts of hydroponics, aeroponics, and aquaponics. (information derived from Bingöl, 2019; Chole et al., 2021)



Systems/Impacts	Positive Impacts	Negative Impacts
Hydroponics	· No soil-based illnesses · Water use efficiency · Nutrient solution use efficiency · Efficient land use · Lightweight structure · Less plant waste · No pesticide, herbicide, and artificial fertilizer · Lower labour requirement than conventional agriculture	· High investment cost · Need for technical knowledge · Limited plant species to grow · Need for maintenance
Aeroponics	· Efficiency of water use · Efficiency of nutrient solution use · Modular and operable system · No soil-based illness · No pests · Low quality water can also be used	· High investment cost · Dependency on energy and technology · Need for technical knowledge · High maintenande need · Nozzle stuck probability with mineral accumulation
Aquaponics	· Less need for extra filtration equipment · Symbiotic relationship between plants and fish · Faster growth · No pesticide or artificial fertilizer · No waste · No soil-based illness	· Less production · Expensive equipment · Dependency on energy · Tendency to maintenance and operation problems · High investment cost

Table 2.5 Comparison of open field, greenhouse, and indoor agricultural production in terms of stability and controllability aspects. (adapted from Kozai et al., 2019)



Stability and Controllability	Open Fields	Greenhouses		Indoor Systems
		Soil Culture	Hydroponics	
Natural stability of aerial zone	Very Low	Low	Low	Low
Artificial controllability of aerial zone	Very Low	Medium	Medium	Very High
Natural stability of root zone	High	High	Low	Low
Artificial controllability of root zone	Low	Low	High	High
Vulnerability of yield and quality	High	Medium	Relatively Low	Low
Initial investment per unit land area	Low	Medium	Relatively High	Extremely High
Yield	Low	Medium	Relatively High	Extremely High

2.4.4 Types of BIA

Building-integrated agriculture (BIA) methods differ according to their location as in or on buildings, predetermined production requirements, choice of equipment, and local opportunities. Types of BIA can be divided into on-building and in-building methods for the scope of the thesis, and they are shown below in Figure 2.17.

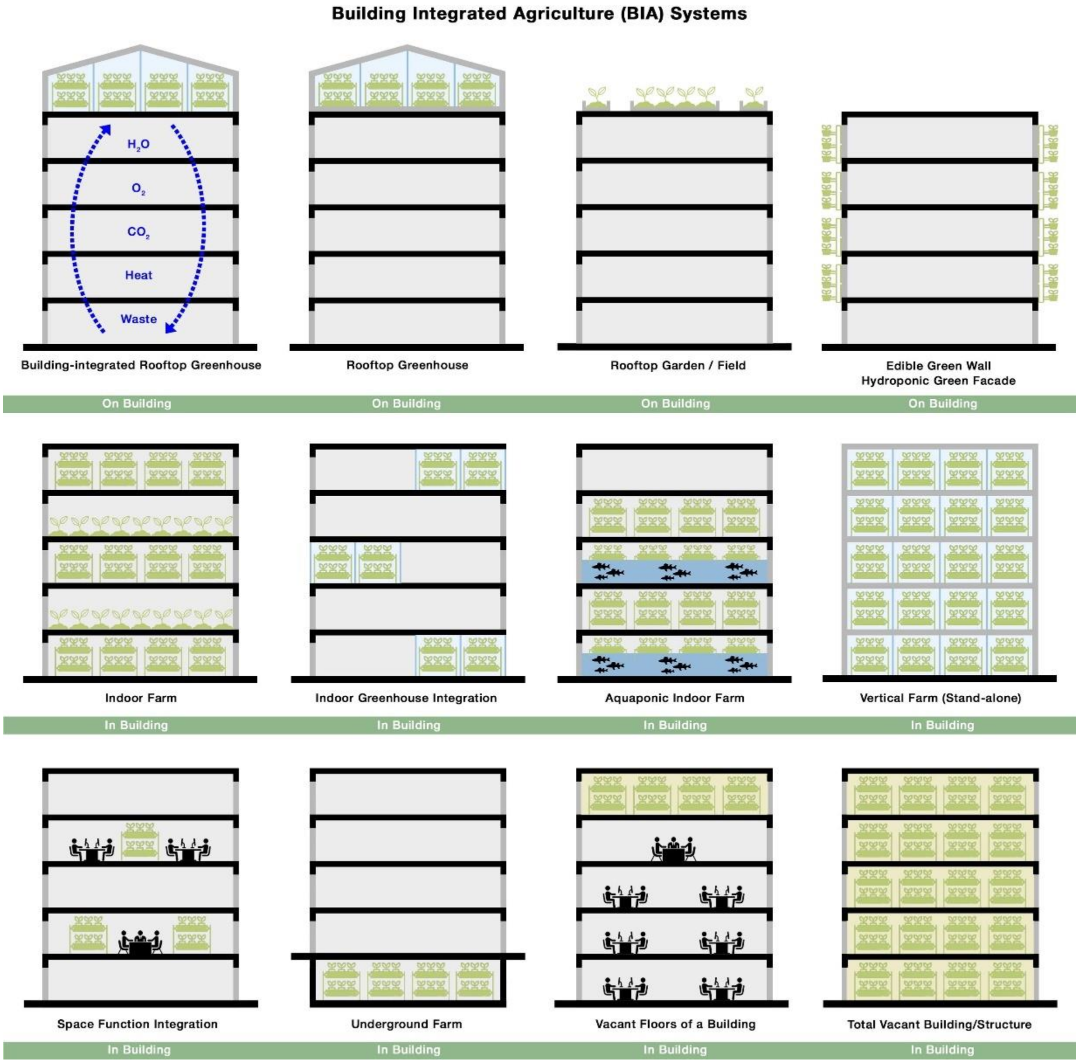


Figure 2.17 Building-integrated agriculture (BIA) systems. (drawn by the author, based on information from: Nowysz, 2022; Beacham et al., 2019; Proksch, 2016)

Firstly, Liesa et al. (2021) and Skar et al. (2020) state that BIA has on building types mostly with hydroponic systems such as rooftop greenhouses, rooftop gardens, green roofs, green walls, modular boxes at facades, and green balconies. Except for rooftop greenhouses, all other on-building BIA types are exposed to external conditions; therefore, they can be habitats for wildlife, can increase biodiversity and pollination possibilities in the urban environment, can purify the air, can save energy as insulation layers, and can increase permeable and absorbent urban surfaces for stormwater management (Lehmann, 2011; Bass, 2008; Badami & Ramankutty, 2015). They can also cool the built environment via the evapotranspiration feature of plants to mitigate the heat island effect which is a significant strategy to decrease environmental load because above a certain threshold, every degree of Celsius increase in the urban environment can cause a 5% raise of electricity consumption with an additional demand on air conditioning systems and refrigeration systems (Bass & Baskaran, 2001; Luvall et al., 2002).

Furthermore, as Lehmann (2011) indicated, rather than focusing on a building, structure, or a piece of landscape, acknowledging the significance of a holistic urban approach is more valuable to sustain city life with desired beneficial results. Viljoen et al. (2012) state the possibility of creating continuous productive urban landscapes (CPULs) with this kind of holistic urban planning with the use of on-building BIA methods. As Benis et al. (2017a) note some simulation-based programs and software about BIA technologies can be helpful as a guide for food-based urban planning with necessary data and comparison information.

Rooftop greenhouses are the most common types of on-building BIA methods as Liesa et al. (2021) state. Unutilized rooftops can be revitalized via rooftop greenhouses with the integration of their host buildings to produce local food for commercial purposes or urban poor (Figure 2.18). As Gould and Caplow (2012) exemplify, BIA food production with approximately 5000 ha area of hydroponic rooftop greenhouses can meet the annual vegetable needs of 30 million people.

Figure 2.18 Vacant factory roof transformation by Urban Farmers rooftop greenhouse in the Netherlands. (spaceandmatter.nl)

Rooftop greenhouses can also be integrated with PVs for renewable energy, evaporative coolers, waste heat capturers, and rainwater harvesting equipment for self-sufficiency of the BIA system and closing the open urban loops (Figure 2.19). Other than those integrations, waste from other urban systems such as exhausted CO_2 from transportation means, polluted water of urban streams, and organic wastes can be utilized with BIA methods to shape a circular system (Gould & Caplow, 2012). According to Martin et al. (2022), BIA methods can be more efficient in terms of crop yields, resource use, and energy consumption via the symbiotic use of materials and resources.

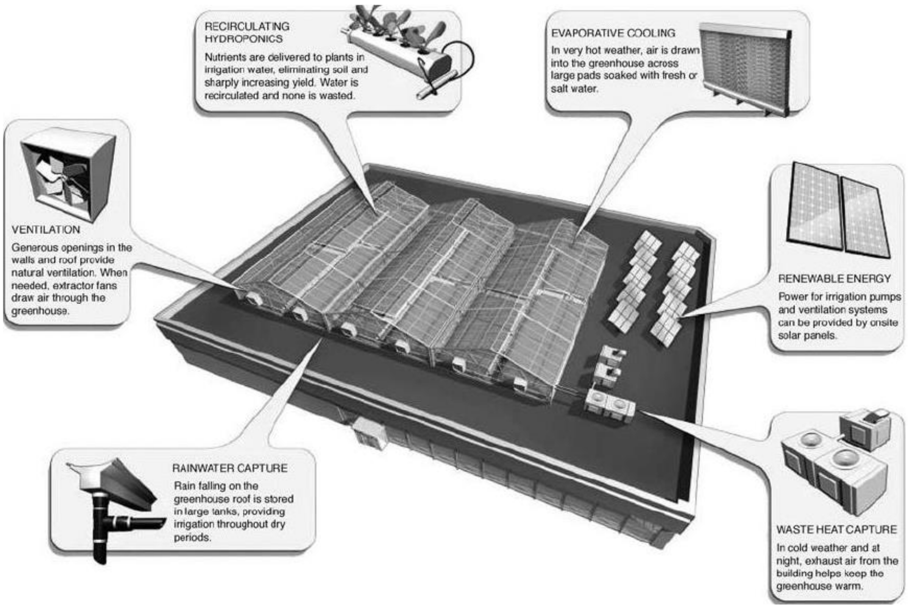


Figure 2.19 Rooftop greenhouse as a BIA method with its elements. (Gould & Caplow, 2012)

Grant and Jones (2008) claim that green roofs or vegetated roofs are also widely used on-building BIA systems. Green roofs can be classified as extensive or intensive according to their substrate depths, substrate types, and vegetation types; as Toland et al. (2014), they act as elements of environmental protection and landscape with their layers such as vegetation, soil, filtration, drainage, protection, root, insulation, water isolation, and structural layer. Agricultural purposes can also be integrated with green roofs via BIA systems as an additional local food production option (Grant & Jones, 2008). Moreover, the irrigation need can be decreased via the use of drought-tolerant native plants and the xeriscaping method, as Yalçınalp et al. (2018) claim.

Green facades and green walls are different that can be claimed according to the locations of vegetation roots, structural properties, and vegetation systems (Weinmaster, 2009). Green walls are usually stand-alone vertical surfaces; on the other hand, green facades are always integrated with buildings. Both can be naturally vegetated surfaces with climber plantations that are rooted in the ground or soil, whereas they can also be vegetated via modular boxes or horizontal/vertical tiers connected with irrigation systems. Modular boxes and tiers of vegetation can shape the structural system of the vertical surface, or they can be attached to the structural system of the surface. Most of the green facades and walls are the cheapest options with their surface greening opportunities and easily operable features as Weinmaster (2009) claims.

Secondly, according to Skar et al. (2020) and Benis et al. (2017b), BIA has in-building types such as modular box farming, container farming, warehouse-basement farming, and indoor vertical farming with and without artificial lighting. Most of them include controlled environment agriculture (CEA) technologies to sustain regular monitoring, maintenance, and operation due to more isolated interior conditions than on-building types. With the controlled indoor environment, maximum crop yields are aimed at optimum conditions for plant growth (Avgoustaki & Xydis, 2020).

Plant factories (PF) can be considered devoted structures for in-building agricultural activities of BIA. Those structures can be built from scratch, or they can be transformed from vacant structures or vacant floors of existing typologies such as nursing homes, shopping centers, hotels, offices, schools, prisons, and hospitals (Graamans et al., 2018). The use of vacant structures can decrease the investment cost of BIA systems by approximately half (Kozai, 2013). PFs' main aim is to produce food in the most efficient ways for commercial benefits and profitability. PF can be a hundred times more profitable than conventional agricultural field production when there is a comparison between them in terms of crop yield per unit of land area (Figure 2.20). Kozai (2007) also indicated the controlled environment agriculture (CEA) concept is applied in those structures with well-insulated envelopes, artificial lighting, proper air conditioning, CO_2 supply/enrichment units, automation systems, required sensors, resource and nutrient supplies.

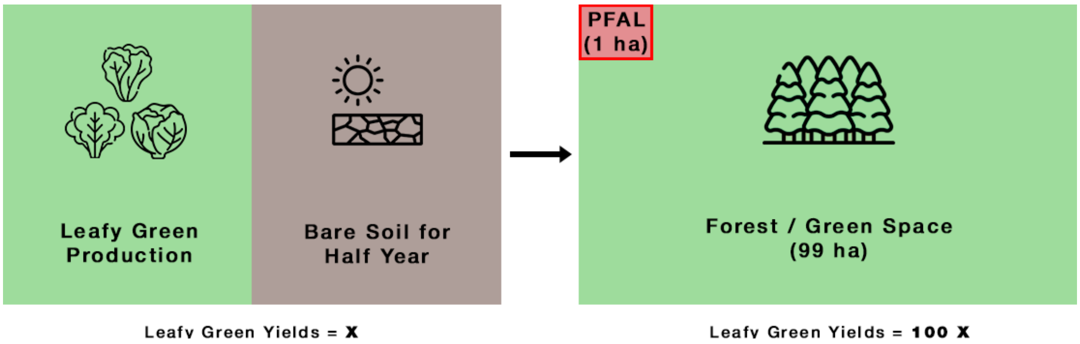


Figure 2.20 Comparison of land use and crop yields between conventional agricultural fields and plant factories with artificial lighting (PFAL). (drawn by the author, based on information from: Kozai et al., 2019)

Those facilities are kept as sterilized as possible to avoid unwanted problems, health issues, and loss of the agricultural environment's control (Graamans et al., 2018). For instance, workers and modern farmers in PF sterilize themselves with showers, sterilized clothes, and disinfection processes before getting into the cultivation spaces (Figure 2.21). To increase the efficiency of the BIA system and to avoid such external factors, as Shamshiri et al. (2018) indicated, some of the plant factories are even using robotic systems, drones, artificial intelligence (AI), and the internet of things (IoT) technologies to remove people, bacteria, fungus, and other organisms from the equation of food production.

Figure 2.21 Plant factory with controlled environment agricultural (CEA) production. (Kozai et al., 2019)

2.4.5 Environmental Impacts of BIA

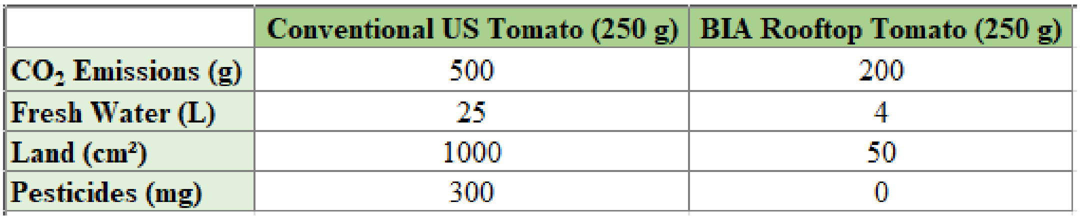
As a first positive impact, BIA creates energy efficiency for the built environment throughout the food production process and later with urban cooling effect to mitigate cooling needs, air purification to decrease air filtration needs, and insulating buildings and urban surfaces to minimize heat losses. As Specht et al. (2014) state BIA methods such as green roofs, rooftop greenhouses, green walls, and green facades act as insulation layers for buildings to be more energy-efficient with the decrease in energy and fuel use for thermal comfort (Gould & Caplow, 2012), to protect the building against harsh weather conditions, ultraviolet (UV) radiation, and corrosive acid rains (Weinmaster, 2009), to protect the urban context against the heat-island effect with its natural aspect of cooling the surface via evapotranspiration and permeability for water holding into urban surfaces to cool the surroundings, and to provide new habitats for wildlife, increase pollination possibilities and biodiversity with bringing a part of nature back to the cities (Skar et al., 2020).

Another positive impact of BIA is its inclusion of renewable energy sources via solar panels, wind turbines, biogas, biofuel, biomass, heat pumps, or geothermal sources. Liesa et al. (2021) state there is a significant demand for energy and electricity in BIA because of automation systems, sensors, production equipment, lighting equipment, air conditioning, heating-cooling systems, and monitoring systems. Therefore, those renewable energy sources can meet this demand for energy to control interior climatic conditions, indoor air quality, and food production processes.

According to Benis et al. (2017b), a drop in food miles is another positive impact of BIA on the environment. This situation mitigates fossil fuel consumption and the effects of global warming with less greenhouse gas emissions due to local food production and local delivery of food (Astee & Kishnani, 2010). In this way, the ecological footprint of the food production system can be decreased; it can be named as “food-print” to identify specific carbon footprint values that are the results of the food production process (De Zeeuw et al., 2011) (Goldstein et al., 2014). As Skar et al. (2020) claim, UA and BIA systems uses instead of conventional agriculture fields reduce risks of flood, erosion, desertification, and other soil-based problems due to soil wash with poor management of irrigation water use in conventional agriculture.

Most BIA methods do not need soil to cultivate; thus, land use, fertile land need for agriculture, water and soil contamination decrease with fewer agricultural processes that include the chemical use of artificial fertilizers and pesticides to increase the fertility of the soil (Specht et al., 2014) (Table 2.6). Moreover, according to Skar et al. (2020), BIA methods allow people to reuse resources, and use waste materials as fertilizer and as an energy source. According to Lehmann (2011), green urbanism also has the principle of waste elimination in a closed-loop system with possible 3R strategies as reuse, recycle, and reduce. For reuse and recycle strategies with a close loop circularity option, organic waste can be turned into compost, and unusable organic wastes can be turned into biomass to obtain renewable energy, or they can be transformed into biofuel from plant oil. For reduce, the reduction of organic and inorganic wastes in the production process is also significant for BIA systems. Morabito (2021) indicated another waste reduction possibility as not tearing down a vacant structure but refunctioning it with BIA systems to mitigate demolition wastes, their emissions, and possible contamination.

Table 2.6 Environmental impacts of growing tomatoes with the comparison of conventional agriculture and BIA methods. (Gould & Caplow, 2012)



	Conventional US Tomato (250 g)	**BIA Rooftop Tomato (250 g)**
CO_2 Emissions (g)	500	200
Fresh Water (L)	25	4
Land (cm^2)	1000	50
Pesticides (mg)	300	0

As another positive impact, existing brownfields of water and soil contaminations can be remediated by BIA and urban agricultural techniques. Remediation processes can be conducted as excavations, soil washes, or biochemical processes such as fungal, microbial, and phytoremediation (Skar et al., 2020). Phytoremediation means a plant-based remediation process with specific plant species use such as canola and corn. After the remediation process, those plants become holders of contaminants, and they can be processed to obtain biofuel to close the loop.

According to Gould and Caplow (2012), BIA methods are also capable of using the exhausted air of buildings with their rich content of carbon dioxide. As a symbiotic relationship between BIA systems and hosting buildings, this exhausted CO_2 can be derived from both occupants of interior spaces and external factors such as vehicles. This exhausted air increases crop yields via “CO_2 fertilizing”, and it decreases the need for heating energy consumption because this air was heated before its disposal, and it can be used as a heat source for interior BIA space. As Benis et al. (2017b) said, heat that is emitted from artificial lighting sources and other BIA equipment also can be reused for interior heating.

As Benis et al. (2017b) claimed, one of the most important positive impacts of BIA techniques on the environment is the decrease in water consumption. In conventional agriculture, there is an excessive demand for irrigation because water loss occurs more in open-air conditions with evaporation, percolation of water through the underground, and evapotranspiration of plants. On the other hand, according to Gould and Caplow (2012), BIA methods which include mostly hydroponic systems, use approximately 70%-75% less water than conventional ones because there is a circular loop system for water flow with necessary nutrient solutions in it. Circulating water can also be reclaimed (Grewal et al., 2011) with included nutrients such as N, P, and K as a potential nutrient recovery option. Recovery causes resource-saving and prevents the discharge of water into nature that can cause contamination.

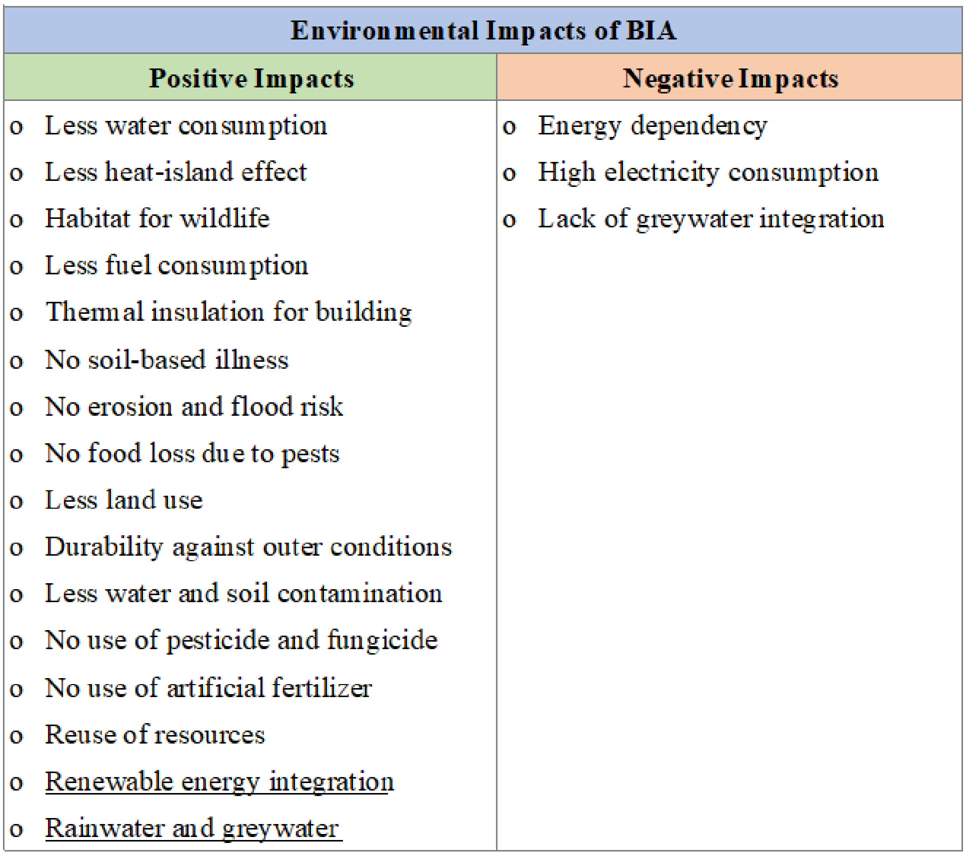
On the other hand, with the use of aeroponic systems that include mist, fog, or spray systems to irrigate suspended plant roots in the air, the water saving percentage even goes up to 90%-95%. As Gould and Caplow (2012) state, most of the global water pollution is caused by agricultural activities, especially around water sources, underground water cisterns, riversides, and coastal zones that are discharge locations of wastewater. Furthermore, another water-saving feature of BIA methods is clean foods that do not require washing before consumption due to CEA conditions. There is also the gain of more water into the system with rainwater harvesting and wastewater/greywater treatment with infiltration processes via vegetative filtration layers of BIA (Gould & Caplow, 2012). The unused portion of them can also be filtered and released back into nature as a stormwater management strategy.

There are also potential negative impacts of BIA methods on the environment. The most problematic issue with BIA is the high dependence on energy and technology. According to Benis et al. (2017b), this energy dependence results from the energy demand for sensors, operative equipment, heating-cooling equipment, HVAC systems, irrigation equipment, and especially artificial lighting sources. As Gould and Caplow (2012), most of those systems use electricity; on the other hand, heating systems use fossil fuels to heat the indoor environment such as natural gas and coal. Thus, the CO_2 emissions of climate control systems are high for BIA.

Another considerable negative impact of BIA methods is using a significant amount of potable water, even if it is way less than the use in conventional agriculture but there can be more decrease in use with proper rainwater harvesting and wastewater treatment methods (Lehmann, 2011). The use of treated greywater is very rare in current BIA projects and other agricultural means in the literature. According to Skar et al. (2020), less than 20% of today’s BIA hydroponics use greywater as the water source.

Positive and negative environmental impacts of BIA methods are given in Table 2.7.

Table 2.7 Environmental impacts of BIA. (compiled from the literature)



Environmental Impacts of BIA	
Positive Impacts	**Negative Impacts**
o Less water consumption	o Energy dependency
o Less heat-island effect	o High electricity consumption
o Habitat for wildlife	o Lack of greywater integration
o Less fuel consumption	
o Thermal insulation for building	
o No soil-based illness	
o No erosion and flood risk	
o No food loss due to pests	
o Less land use	
o Durability against outer conditions	
o Less water and soil contamination	
o No use of pesticide and fungicide	
o No use of artificial fertilizer	
o Reuse of resources	
o Renewable energy integration	
o Rainwater and greywater	

2.4.6 Economic Impacts of BIA

BIA methods have significant positive impacts on the economy with new production technologies and methods that increase crop yields while decreasing resource, fuel, and logistics costs. Resource costs can be reduced by the benefits of BIA methods for interior climatic conditions such as less cooling costs for the building, and less heating costs with the use of exhausted air from the building and interior equipment (Gould & Caplow, 2012). Another resource expense saving is possible because BIA methods use less water by 75% to 95%, there is no pesticide use due to safe controlled environment conditions against external effects, and fertilizer use is almost none (Liu et al., 2016). Thus, the expenses of those kinds of resource usage are eliminated by BIA methods. Moreover, it is possible to use wastewater and waste as resources such as biomass or biofuel to decrease resource expenses.

Gould and Caplow (2012) also state that one of the most important reasons for the cost reduction is the disappearance of food miles. As Liesa et al. (2021) claim self-sufficient local production of food makes food access easier due to the exclusion of logistics, marketing, and storing costs on food. This situation is beneficial for low-income people to sustain their economic purchasing power (Kalantari et al., 2017).

Furthermore, as Skar et al. (2020) state, BIA methods provide employment opportunities for low-income people to produce locally. They both gain economic benefits and access to cheaper food. According to Benis et al. (2017b), there are also cheaper places and methods for food production with BIA like shipping containers with their transportable feature and systematic simplicity (Figure 2.22). As another example, according to Koont (2004), Cuba is a proper example of cheap UA method use. “Organoponicos”, which was a kind of garden with a container-like cultivation bed filled with soil and fertilizer, was the first method. The second method was vacant lot use while the third one was using their houses’ gardens. With those UA methods, Cuba increased its food production capacity a thousand times, in less than 10 years, according to Koont (2004).

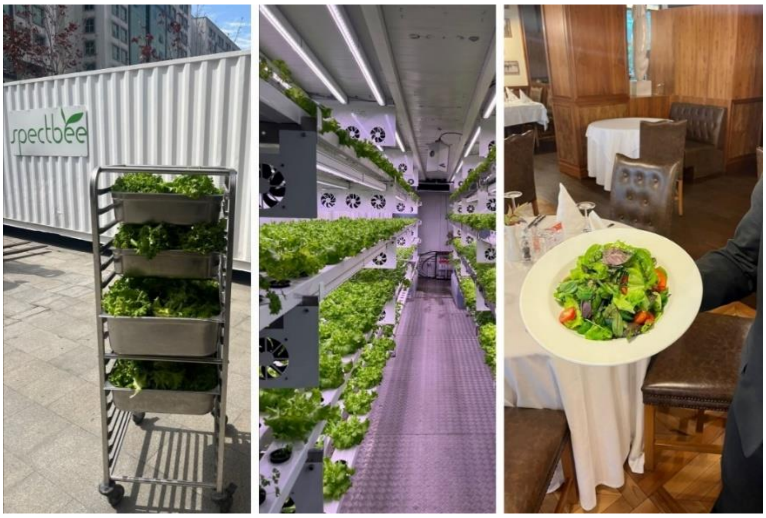
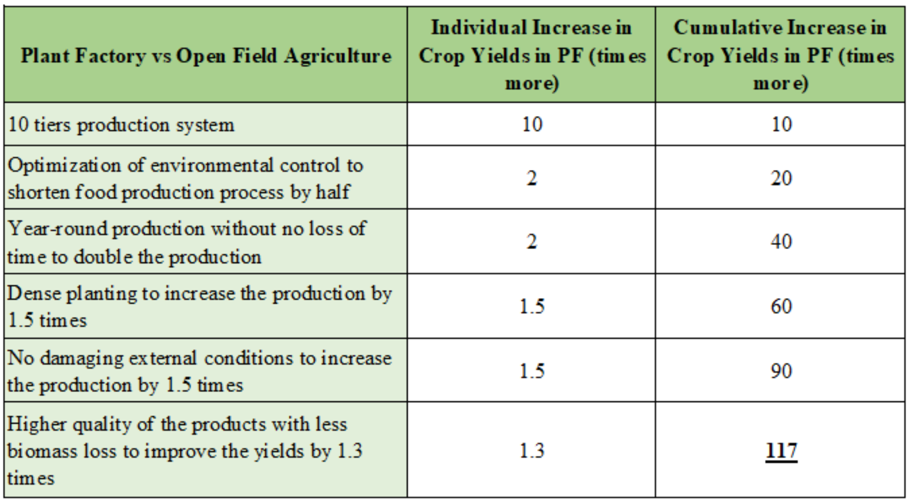


Figure 2.22 Spectbee container vertical farm project by Prof. Dr. Hasan Silleli in Gorrion Otel İstanbul. (linkedin.com/HasanSilleli)

As Kozai (2013) states, most of the investment cost of BIA comes from the construction of a structure for BIA activities, approximately half of which. Thus, adaptive reuse of a vacant structure or transforming it can save a considerable amount of the investment cost which is highly criticized and be named as one of the biggest negativities of BIA systems. Kozai et al. (2019) note that the investment cost of BIA systems is high in the initial stage; however, when it is compared with normal greenhouse structures, BIA methods have shorter payback periods with higher crop yields and other benefits (Table 2.8).

Table 2.8 The comparison between plant factory (PF) and open field agriculture. (Kozai, 2013)



Plant Factory vs Open Field Agriculture	Individual Increase in Crop Yields in PF (times more)	Cumulative Increase in Crop Yields in PF (times more)
10 tiers production system	10	10
Optimization of environmental control to shorten food production process by half	2	20
Year-round production without no loss of time to double the production	2	40
Dense planting to increase the production by 1.5 times	1.5	60
No damaging external conditions to increase the production by 1.5 times	1.5	90
Higher quality of the products with less biomass loss to improve the yields by 1.3 times	1.3	**117**

Moreover, Şahin and Kendirli (2016) state that old factories, warehouses, industrial structures, or some historical buildings can be utilized for plant production because of their spatial volume, high ceiling levels, and lack of interior partitions while they are also revitalized and refunctioned instead of being demolished. According to Morabito (2021), the tearing down or recycling of vacant structures is costly and harmful due to demolition waste emissions. It is significant to consider how vacant structures and the existing building stock can be refunctioned and can be turned into urban values (Benis et al., 2017a) such as the vacant rooftop of a car parking building example in Figure 2.23.

Figure 2.23 Rooftop of a car parking building transformed into Melbourne Skyfarm, Australia. (melbourneskyfarm.com.au)

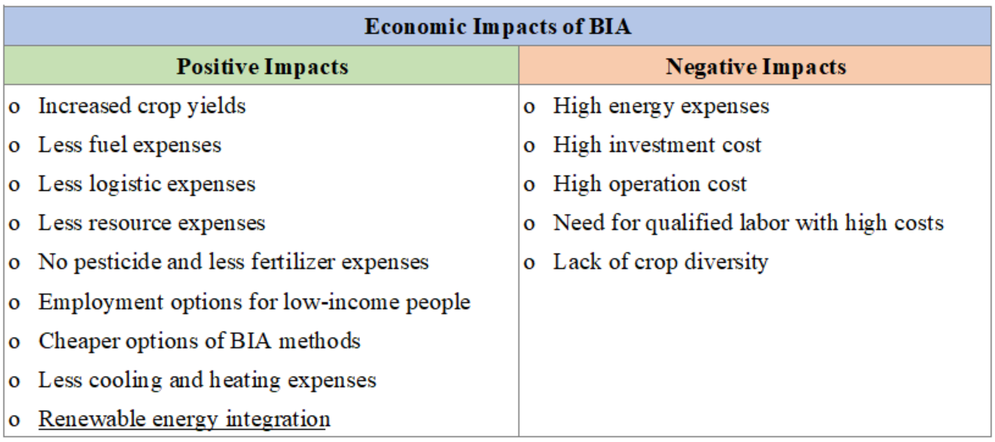
There are also some negative economic impacts of BIA methods such as the high investment cost of the system and high operation costs due to excessive energy consumption for operational systems for nearly every step of the food production process with BIA such as lighting, ventilation, heating-cooling, irrigation, nutrient flow, packaging, and monitoring (Benis et al., 2017b) (Liesa et al., 2021). Qualified labor force requirement for complex processes of BIA also causes high labor costs (Kozai, 2013).

Another negative economic reflection of BIA systems is the limited diversity of crop types that can be cultivated via BIA systems due to the limited height of the racks, specific types of substrates, and the limited amount of research and development about the systems (Kalantari et al., 2017). Most of the leafy greens, berries, and vegetables can be cultivated that are equal to or shorter than 30 cm. The reason behind this is, as Kozai et al. (2019) claim, vertical tiers or racks of the system have around 40 cm of height for optimal spacing for maximizing space use. Crops such as olives, avocados, bananas, nuts, and wheat are still hard or not feasible to cultivate with BIA. As Kozai (2013) indicated, staple food plants such as wheat and rice are hard to cultivate with BIA methods because of not only their systematic incapabilities but also their lower profitability per area when they are compared with leafy greens. Thus, it creates a loss of crop diversity that can directly affect the potential economic gain of the system.

Moreover, as an updated discussed topic, being a monopoly can have a possible negative economic impact on rural areas and people in need. In this scenario, as Şahin and Kendirli (2016) state, the educated, wealthy, and investor segment of the society can have the whole control of BIA systems that cause monopolization and a poorer rural population.

Positive and negative economic impacts of BIA methods are given in Table 2.9.

Table 2.9 Economic impacts of BIA. (compiled from the literature)



Economic Impacts of BIA	
Positive Impacts	**Negative Impacts**
o Increased crop yields	o High energy expenses
o Less fuel expenses	o High investment cost
o Less logistic expenses	o High operation cost
o Less resource expenses	o Need for qualified labor with high costs
o No pesticide and less fertilizer expenses	o Lack of crop diversity
o Employment options for low-income people	
o Cheaper options of BIA methods	
o Less cooling and heating expenses	
o Renewable energy integration	

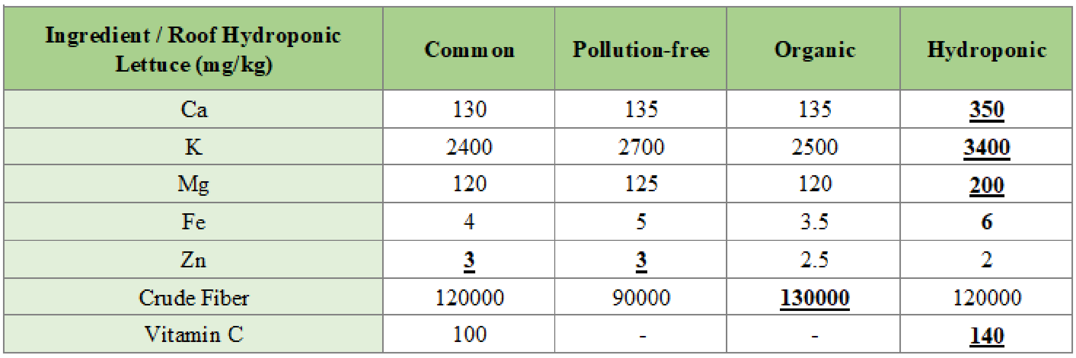
2.4.7 Social Impacts of BIA

BIA methods are gatherers of people with different social activities such as food production, recreational purposes, and education for common knowledge. As Gould and Caplow (2012) and Skar et al. (2020) state, this education includes a “green learning” process to spread awareness and consciousness about BIA methods and food-borne concepts (Figure 2.24). The educational side of BIA methods can create adequate motivation and social pressure on people to disseminate the idea of using and enhancing BIA technologies.

Figure 2.24 Urban care farms, volunteer-based works, and education programs in Singapore. (dbs.com)

According to Gould and Caplow (2012), BIA-based food production activities provide new employment opportunities for low-income people, and they can be involved in the community with their social and economic re-existence (Appendices A). As Liesa et al. (2021) and Gould and Caplow (2012) claim, these employments cause the production of easily accessible locally produced foods for everyone in the community to mitigate food insecurity and to increase nutrients of healthy foods (Kalantari et al., 2017) (Table 2.10). In this way, common values are protected via community-supported agriculture (CSA) activities, and community resilience is sustained with ensured community food security (CFS) as Badami and Ramankutty (2015) and Kalantari et al. (2020) state.

Table 2.10 Minerals and ingredients of roof hydroponic lettuces for different agricultural approaches. (adapted from Liu et al., 2016)



Ingredient / Roof Hydroponic Lettuce (mg/kg)	Common	Pollution-free	Organic	Hydroponic
Ca	130	135	135	**350**
K	2400	2700	2500	**3400**
Mg	120	125	120	**200**
Fe	4	5	3.5	**6**
Zn	**3**	**3**	2.5	2
Crude Fiber	120000	90000	**130000**	120000
Vitamin C	100	-	-	**140**

Yurday et al. (2021) suggest that there should be proper training and professional assistance for communities and farmers about UA methods for a conscious food production process. According to Benis et al. (2017b), with the related training, shipping container alike BIA systems can be used in any location due to their mobility which can also be beneficial for disaster victim areas and impoverished areas with quick response opportunities of mobile food production units.

According to Gould and Caplow (2012), there are also psychological benefits of BIA methods such as productivity increase and stress reduction. Ulrich (2022) claimed that those methods, as an example of “biophilia” and “biophilic design” (Huelat, 2008), can also foster clinical improvements and positive outcomes such as reduction in pain, intake of medicine, and period of hospital stays. With psychological effects, physiological effects, and the production of medical herbs, BIA methods have healing properties and rehabilitative aspects. Many urban agricultural methods are used in rehabilitation centers, hospitals, nursing homes, nurseries, kindergartens, and schools for healing, rehabilitation, and human well-being (Kalantari et al., 2017).

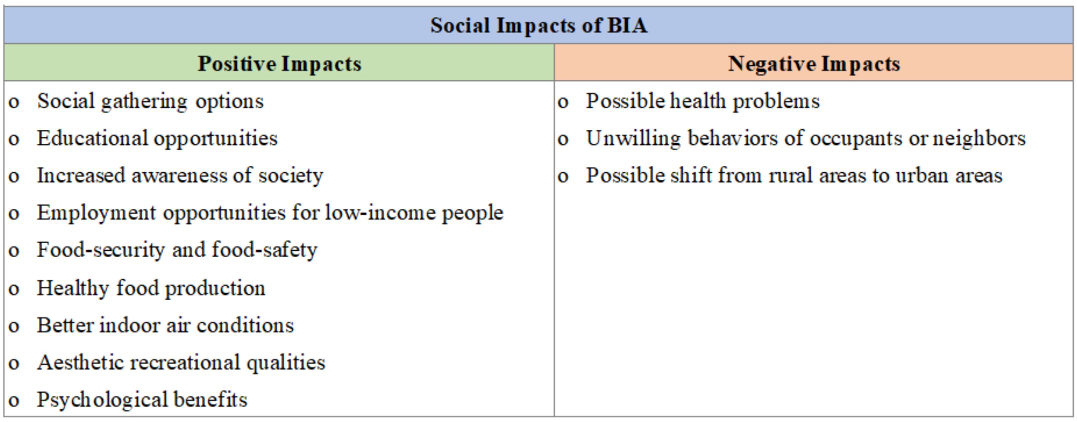
Furthermore, in a world where most citizens spend more than 80% of their lifetime indoor environment (Shao et al., 2021), BIA methods can enhance indoor air quality to avoid sick building syndrome and related health problems such as cancer, allergies, and asthma, which are called building-related illnesses (BRI) as a general term, in the built environment (Weinmaster, 2009) (Bonda, 2007).

There are also a few negative impacts of BIA methods. According to Skar et al. (2020), occupant behavior can be shaped against BIA due to possible systematic problems, high investment costs, allergic reactions, and smells from waste resources. Possible health problems are other negative impacts, and they may result from indoor and outdoor conditions at BIA spaces, emission of chemicals, possible volatile organic compounds (VOC), and possible existence of insects/fungi (Shao et al., 2021).

Lastly, the migration of rural farmers from rural to urban areas for new UA and BIA opportunities, better employment, education, and health options (Türk et al., 2017) can cause a higher urban population and less workforce for rural works. As Poulsen et al. (2015) note UA is not adequate on its own for all the food production needs, and it cannot completely replace conventional agriculture.

Positive and negative social impacts of BIA methods are given in Table 2.11.

Table 2.11 Social impacts of BIA. (compiled from the literature)



Social Impacts of BIA	
Positive Impacts	**Negative Impacts**
o Social gathering options	o Possible health problems
o Educational opportunities	o Unwilling behaviors of occupants or neighbors
o Increased awareness of society	o Possible shift from rural areas to urban areas
o Employment opportunities for low-income people	
o Food-security and food-safety	
o Healthy food production	
o Better indoor air conditions	
o Aesthetic recreational qualities	
o Psychological benefits	

CHAPTER 3

RESEARCH DESIGN

The materials and methodology of the research are explained in this chapter. Materials of different research stages are described as materials for literature review, materials as case studies data for meta-analysis and comparison of different agricultural method examples; and materials for the empirical research part of a real-life example of building-integrated agricultural (BIA) system use in Sıhhiye Multistorey Car Park. Bibliometric analysis, literature review with case study selection, meta-analysis for agricultural methods' comparison, empirical research, and creating a transformation scenario are given as different methodology stages of the research.

3.1 Material of Research

Materials of the study include academic search engines and the bibliometric analysis tool for choosing academic sources for the literature review. Case studies are selected from both the literature and Turkey as the materials for the comparison of different agricultural methods with meta-analysis. For the comparison, 16 parameters are defined as the guidelines for qualitative and quantitative data gathering from different cases in terms of their general properties and numerical values about their production-consumption relationships in the process of food production. Data loggers, measuring devices, and relevant software were used to gather and analyze data from the Sıhhiye Multistorey Car Park that was selected as the focus building to propose a BIA scenario for growing vegetables; and lettuce (Lactuca sativa) was selected as the possible food crop.

3.1.1 Literature Review and Case Studies for Meta-analysis

For the literature review, academic search engines such as Google Scholar and Scopus were used for bibliometric analysis to determine academic sources to examine for background information about UA, BIA, CEA, VF, urban symbiosis, and urban circularity concepts with case studies for numerical value comparison between them as meta-analysis. The bibliometric analysis is supported by the VOSviewer tool to demonstrate the relationship between different concepts via key word cooccurrence diagrams. After bibliometric analysis, review of the literature for qualitative and quantitative data collection about UA and BIA methods' differences, production values, consumption values, resource use efficiencies, and impacts on nature for meta-analysis is conducted among 231 independent studies such as data paper, book chapters, articles, conference papers, reviews, etc. 156 of those academic sources are given as references of the research. Among those independent studies, case studies are selected for numerical data about their differences in terms of agricultural production methods for the meta-analysis table. Case studies are not only found in the literature but also Turkey as 8 different researchers, companies, and agricultural producers. Numerical data about their agricultural production process is publicly available. According to the pre-defined 16 parameters about agricultural production processes, the numerical data is gathered from them to compare and understand the differences between various agricultural production methods. The definition of 16 parameters has been made after the decision of dependent and independent variables for the comparison. Independent variables are set as the constants to control the comparison. Different farm cases are indicated for the meta-analysis phase with different typologies, system locations in a building, and cultivation techniques (conventional fields, soil-based greenhouses, hydroponic used greenhouses, soil-based rooftop fields, rooftop greenhouses, indoor vertical farms) as the independent variable of "farm type". Moreover, the constant crop type (test crop) to use in all cases to compare is decided as lettuce (Lactuca sativa) due to its short harvesting period, resilience, and ease of cultivation. On the other hand, in every case from the literature and Turkey, the values of crop yields (ton/ha, kg/m²), water consumption ((L/kg), electricity consumption (kWh), fuel consumption (L/kg), land use (m²), pesticide use (mg), fertilizer use (kg), and CO_2 emission (ppm or kg) are changing as dependent variables.

After the variable definitions, those 16 parameters to gather data from cases are set as follows:

- The location of the agricultural area/system,
- Agricultural method and crop type that is cultivated in the agricultural area/system,
- The main source of light for vegetation,
- Total m² of the agricultural area/system,
- Total kg of the crop can be grown in a m² area of the agricultural area/system per harvest cycle,
- The duration that is equal to one cycle of harvesting for the crop type,
- The number of days that can be used for agricultural purposes per year,
- The amount of waste per kg or m² area of production per harvest cycle, (kg)
- The amount of water that is consumed per kg or m² area of production per harvest cycle, (liter)
- Total kWh of electricity that is consumed per kg or m² area of production per harvest cycle (lighting, air conditioning, cooling, heating, monitoring, automation systems, sensors, analyses, etc.),
- The amount of fuel (diesel, gasoline, natural gas) that is consumed per kg or m² area of production per harvest cycle (transportation, logistics, tractor, generator/power plant, heating, etc.), (liter)
- Total grams of pesticide that is consumed per kg or m² area of production per harvest cycle,
- Total grams of fertilizer that is consumed per kg or m² area of production per harvest cycle,

- Total "food miles" as km for the delivery of food from the agricultural area/system to the furthest target location,
- Total amount of CO_2 emission per harvest cycle (if calculated and available),
- Total structural load of the agricultural system (if there is any). (kg/m^2)

According to those parameters, only 8 case studies from Turkey can be investigated due to time constraints of the research, or unwillingness to share commercial data, and the lack of UA and BIA examples in Turkey. Those cases include some examples of conventional agriculture on university campuses, a hydroponic greenhouse, and some plant factory companies. However, in the comparison given in the meta-analysis table, the identities of the companies are not revealed for ethical reasons.

3.1.2 Materials for the BIA Transformation Project

As the main material of the thesis research to create an urban transformation scenario via urban symbiosis options and urban circularity concept, Sıhhiye Multistorey Car Parking Building is determined to be transformed into an urban farm. The symbiosis comes from its local opportunities to integrate with the BIA system use in the project. The reason behind the selection is the uniqueness of the building with its location, its vacant floors and unused rooftop, its user profile, and different use patterns of the building such as car parking, studying, education, and socializing. Moreover, it is located near the concealed İncesu Stream, Sıhhiye Bazaar Area, two hospitals (Hacettepe and Ibn-i Sina), Vedat Dalokay Wedding Hall/Marriage Registry Office, and university campuses such as TED University, Hacettepe University, and Ankara University (Figure 3.1 and Figure 3.2). All photographs presented in the thesis have been taken by the author except those where the sources are cited.

The site is also analyzed with surrounding land use patterns, sun path, prevailing wing directions, transportation opportunities in the area, average temperature ranges, average ground temperature ranges, average illumination ranges, and sky cover ranges. Most of the site analysis parameters are investigated via Climate Consultant

6.0 software with specific data sets of Ankara. The patterns of surrounding land uses are demonstrated by the land use map (Figure 3.1) that also claims the dominance of Kurtuluş Park, hospitals, university campuses, Office buildings, and housings around the car parking building structure. Ziya Gökalp Street and Aksu Street are widely used by vehicles especially in the peak and rush hours of the day between 8 am-10 am in the mornings and between 4 pm-7 pm. The location is a key point with the streets that constitute the main transportation roadways of Kolej, Kurtuluş, and Sıhhiye districts. Moreover, both main streets are widely used as public transportation routes via public buses and public minibuses due to the proximity of the area to both Kızılay, Sıhhiye, and Ulus which are public transportation centers of Ankara. Subway and light rail systems such as Ankaray are also located nearby. Kolej station of Ankaray is located 250 meters away from Sıhhiye Multistorey Car Parking Building. Therefore, it can be claimed that the area is heavily used by local people, visitors of the surrounding facilities, pedestrians, public transportation means, individual vehicles, and university students. Users of the building are diverse in terms of their profile, and the building serves as a significant facility for vehicles as a car park and to people as a social and educative gathering place.

Figure 3.1 Land use map of the surrounding area where the Sıhhiye Multistorey Car Park is located.

Figure 3.2 TED University, Vedat Dalokay Wedding Hall/Marriage Registry Office, Ankara Tıp, and Hacettepe University as important surroundings of the building.

The building was widely used until the beginning of the 2000s. After a long period of disuse owing to security problems (Figure 3.3; Figure 3.4; Figure 3.5), the building was opened again at the end of 2021 but only as a car parking facility; alter in 2023 further functions, such as government offices, BELPA Youth Academy Center, and shops. Therefore, between 2000-2021, the building can be identified as a vacant building. Although now the building is actively used by students, car owners, and visitors; two car parking floors (3rd and 4th) and the rooftop of the building are still vacant.

Figure 3.3 Closing of Sıhhiye Multistorey Car Parking Building in the beginning of the 2000s due to security problems. (memurlar.net/haber/87221)

Figure 3.4 Sıhhiye Multistorey Car Parking Building. (umke.org)

Figure 3.5 Sıhhiye Multistorey Car Parking Building from northwest.

After the selection of the building and obtaining the necessary permissions from responsible directorates of the municipality, old drawings of the building were examined and photographed in the Ankara Metropolitan Municipality archives (Appendices B). Due to the lack of digitalized architectural drawings of the building, only some raw architectural drawings could also be obtained from the building's architect, ACE Mimarlık, to understand the structural properties, functions of different spaces of the building, and their dimensions.

As a brief historical background of the building, Sıhhiye Multistorey Car Parking Building was built in the 1980s near Kurtuluş Parkı, Sıhhiye Bazaar, TED College (today's TED University), and Vedat Dalokay Marriage Office Building. Ahmet Can Ersan was the architect of the building. The structure was used by both local people and people who came to Sıhhiye for the bazaar, for the Hacettepe Hospital Complex, and for the wedding ceremonies in Vedat Dalokay Wedding Hall/Marriage Registry Office Building.

At the beginning of the year 2000, the building was closed until the takeover of the structure's operational rights by Ankara Metropolitan Municipality in 2021. The building opened on 23 November 2021 for car parking only, but the renovations continued (Figure 3.6). The BELPA Youth Academy Center in the building opened unofficially in March 2023 by the Directorate of Public Works and the Directorate for Women and Family Services; in July 2023, it was officially opened with car parking floors, a training center of a security firm, public offices, mufti's office (Figure 3.7), the Youth Academy which contained a cafeteria and library, the Center for Homeless Children, and shops on the ground floor, most of which have been open since the building was constructed.

Figure 3.6 Renovation and revitalization of the building. (anamurekspres.com)

Figure 3.7 ANFA Private Security Training Institution and Çankaya Mufti's Office at the first floor of the building.

According to the BELPA which is the responsible municipality unit of the Youth Academy activities in Sıhhiye Multistorey Car Parking Building, the aims of the academy are providing free education programs, cheap cafeteria services such as free Wi-Fi, free working spaces, and a quiet library section for students (Figure 3.8). The 1000 m² cafeteria has a capacity of 300 people, whereas the 500 m² library has a reading room capacity of 100 people and a quiet study area for 150 people (Figure 3.9). Furthermore, there are two conference halls for 30 and 100 people that are also used as education halls. The academy works 7 days a week from 9 am to 10.30 pm. Nearly 1000 people are registered at the youth academy, but the intensity of use differs according to the days of the week or weekends, and special occasions (Figure 3.10). There can sometimes be events and celebrations when the academy hosts more than 1000 people. According to BELPA (2023), when there are no such cases, the academy hosts approximately 200 to 400 people on weekdays and from 150 to 200 people on weekends. Moreover, people who are working in the area, shopping in the bazaar, attending weddings at Vedat Dalokay Marriage Office, or visiting patients at Hacettepe Hospital or Ibn-i Sina Hospital, use the building for the cafeteria and/or for parking their cars.

Figure 3.8 BELPA Youth Academy Cafeteria on the ground floor of the building.

Figure 3.9 BELPA Youth Academy Cafeteria at the ground floor of the building. (2nd and 3rd photos from ankahaber.net)

Figure 3.10 Cultural activities in the building. (ankahaber.net)

There are also education programs of BELPA for students in need, elderly people, children who are working on the streets and/or are homeless. As BELPA (2023) claimed, education programs such as effective communication skills and body language are for people between the ages of 15-65. However, priority to take those education programs and social support services is given to people in need such as children who are homeless and the urban poor. From some universities, student communities come to visit and take advantage of the educational opportunities. Furthermore, BELPA (2023) states, TED University made a deal for using some of the conference halls and rooms for some of the lectures.

At the northeastern side of the building, 20-30 meters away, there was the İncesu Stream that was relocated underneath the road to run through a concealed concrete conduit. The closing of İncesu Stream was caused by the risk of flood and urbanization developments in the area. Today, sewage lines are disposed of through Ankara’s old streams, İncesu Stream is one of them. Thus, from the manholes, there is generally a bad smell of sewage lines and polluted İncesu Stream at the opposite sidewalk. The stream can be used for the advantage of local people and BIA systems.

Sıhhiye Bazaar or Yenişehir Bazaar area (Figure 3.11) is located at the northern part of Sıhhiye Multistorey Car Parking Building. The bazaar is frequently used by customers every day. On Mondays and Tuesdays, the bazaar area acts as a clothes market. On Wednesdays and Saturdays, there are fruit and vegetable stalls. On Thursdays, which are the most popular days in the bazaar area, there is a “high society” market; these days are also the most frequented days of the car parking building by the customers. The bazaar is also open on Sundays.

Figure 3.11 Yenişehir Bazaar near the building.

In the 80s, the rooftop of the structure was used as a second-hand vehicle market area for the weekends (Figure 3.12) while the ground floor was used as a marketplace and shopping center (Figure 3.13) especially for medical products due to the importance of Sıhhiye as a healthcare district with Hacettepe Hospital Complex, Ibn-i Sina Hospital, and old Hıfzıssıhha Center Directorate.

Figure 3.12 Rooftop and rooftop view of the building.

Figure 3.13 Ground floor bazaar of Sıhhiye Multistorey Car Parking Building.

The needs of local people have been changed; car parking area needs have been decreased when compared to previous years, according to the vehicle entry-exit data taken from BELTAŞ which is the municipality's company for the operation of the building. In the past, the building hosted more than 4 floors (Figure 3.14) for vehicles to park owing to excessive car parking needs. However, according to the vehicle entry-exit data, even 2 floors of the building are adequate for vehicles to park; there is no demand for more than that (Figure 3.15).

Figure 3.14 Color code of Sıhhiye Multistorey Car Parking Building's floors.

Figure 3.15 Emptiness of 3rd and 4th car parking floors.

There is also an open-air car parking area of the municipality with a capacity for 100 vehicles near the southern campus area of TED University, 400 meters away from the car parking building (Appendices B). This open-air car parking area is widely used especially by TED University students and other locals. Thus, the area fulfills a considerable amount of the car parking area demand that decreases the potential number of users of the car parking building. According to BELTAŞ (2023), the structure has 27500 m² available area. The car parking prices, available hours, and signalization of available car parking lots on the car parking floors are placed at the entrance of the building (Figure 3.16). Car parking areas of 4 floors serve 800 vehicles of which 40 are reserved for electric vehicles with charging units and for disabled people (Figure 3.17).

Figure 3.16 Prices, working hours, and signalization system of the car parking building.

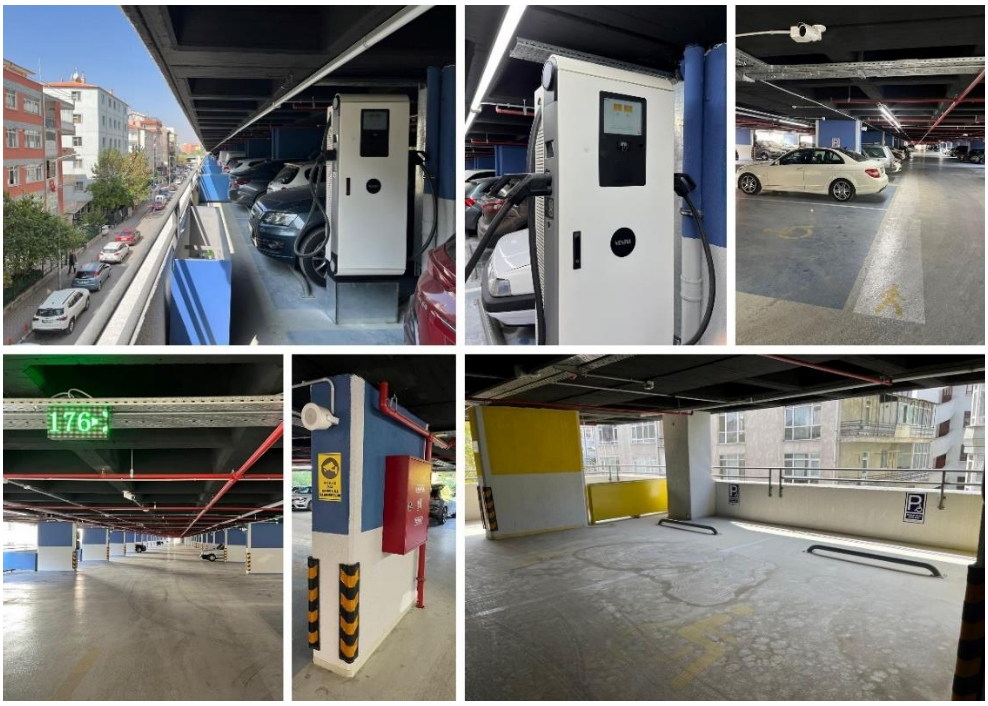
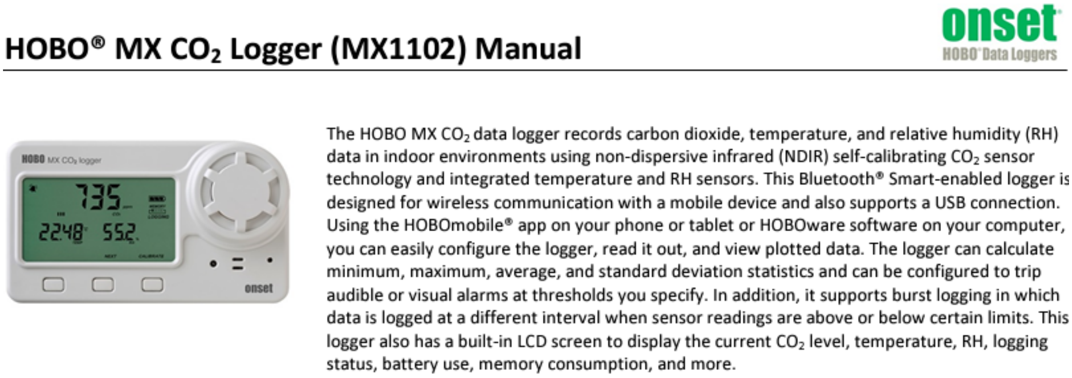


Figure 3.17 Electric vehicle charging stations, CCTV cameras, pedestrian walkways, parking lot signalization, fire extinguishing equipment, and parking lots for disabled people in the building.

3.1.3 Materials for Empirical Research

To understand the potential of CO_2 emissions in and around the structure, data loggers (HOBO MX CO_2 Logger MX1102) (Figure 3.18 and Figure 3.19) were deployed in the car parking floors of the building several times to record temperature, relative humidity, and CO_2 emissions. Five data loggers (EQ05, EQ06, EQ07, EQ08, EQ09) and HOBOware software for data extraction from the loggers to the computer in the file formats of xlsx, csv, and hobo were used. Before deploying the loggers, necessary permissions from Middle East Technical University Architecture Faculty and Rectorate, Ankara Metropolitan Municipality, and BELTAŞ firm were taken (Figure 3.20). Moreover, vehicle entry and exit data have been taken from BELTAŞ with entry time, parking duration, and exit time of vehicles to find their potential effects on logged CO_2 emissions. Data loggers were also placed a few times at the Youth Academy cafeteria section to determine potential CO_2 sources for fertilizing BIA systems and to demonstrate the indoor air quality and the inefficiency of operable windows to ventilate the whole ground floor area.



HOBO® MX CO_2 Logger (MX1102) Manual

The HOBO MX CO_2 data logger records carbon dioxide, temperature, and relative humidity (RH) data in indoor environments using non-dispersive infrared (NDIR) self-calibrating CO_2 sensor technology and integrated temperature and RH sensors. This Bluetooth® Smart-enabled logger is designed for wireless communication with a mobile device and also supports a USB connection. Using the HOBOmobile® app on your phone or tablet or HOBOware software on your computer, you can easily configure the logger, read it out, and view plotted data. The logger can calculate minimum, maximum, average, and standard deviation statistics and can be configured to trip audible or visual alarms at thresholds you specify. In addition, it supports burst logging in which data is logged at a different interval when sensor readings are above or below certain limits. This logger also has a built-in LCD screen to display the current CO_2 level, temperature, RH, logging status, battery use, memory consumption, and more.

Figure 3.18 HOBO MX CO_2 Logger (MX1102) manual. (onsetcomp.com)

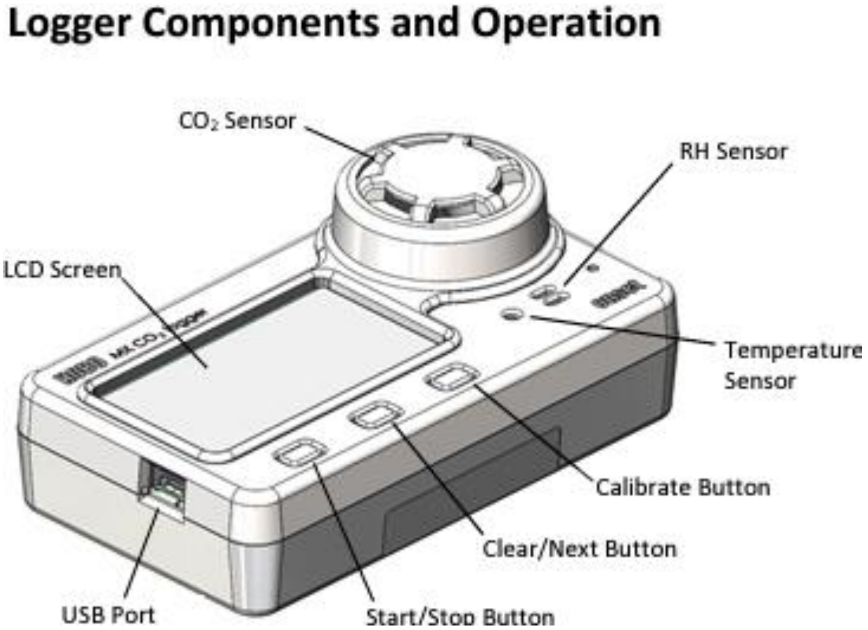
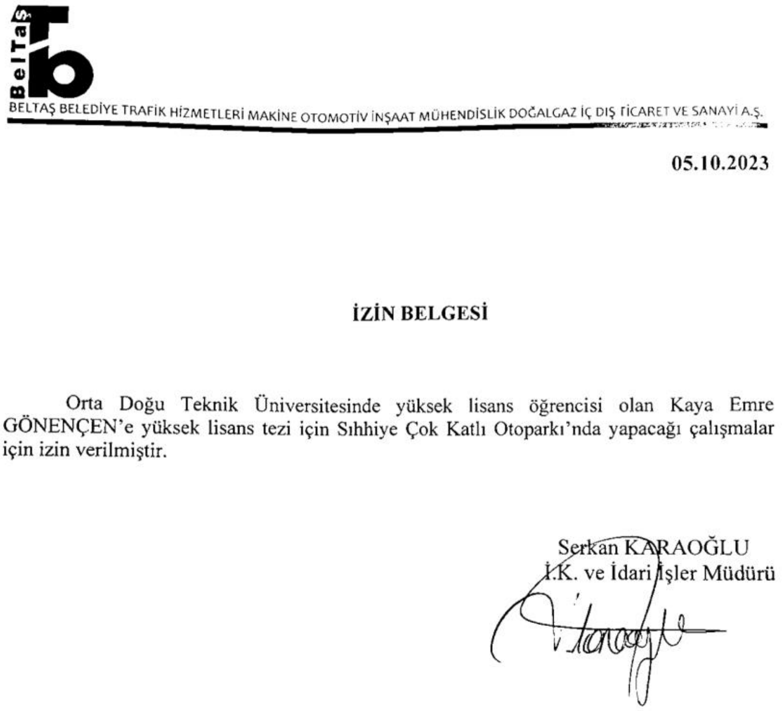


Figure 3.19 HOBO MX CO$_2$ Logger (MX1102) components. (onsetcomp.com)



BelTaŞ

BELTAŞ BELEDİYE TRAFİK HİZMETLERİ MAKİNE OTOMOTİV İNŞAAT MÜHENDİSLİK DOĞALGAZ İÇ DIŞ TİCARET VE SANAYİ A.Ş.

05.10.2023

İZİN BELGESİ

Orta Doğu Teknik Üniversitesinde yüksek lisans öğrencisi olan Kaya Emre GÖNENÇEN'e yüksek lisans tezi için Sıhhiye Çok Katlı Otoparkı'nda yapacağı çalışmalar için izin verilmiştir.

Serkan KARAOĞLU
İ.K. ve İdari İşler Müdürü

Figure 3.20 Permission letter from BELTAŞ for research and data measuring in the Sıhhiye Multi-storey car park building.

Lighting data was also gathered manually by a lux meter, Roline RO-1332 Digital Lux Meter (Figure 3.21), to demonstrate day lighting opportunities and the amount of light in lux for BIA systems and plant growth. Moreover, a personal smart phone was used for all in-building measurements, documentation, information saving, and visual recording. To show different scenarios, measured data, and architectural properties of the building, Rhino 8 software was used to draw and shape the building model.

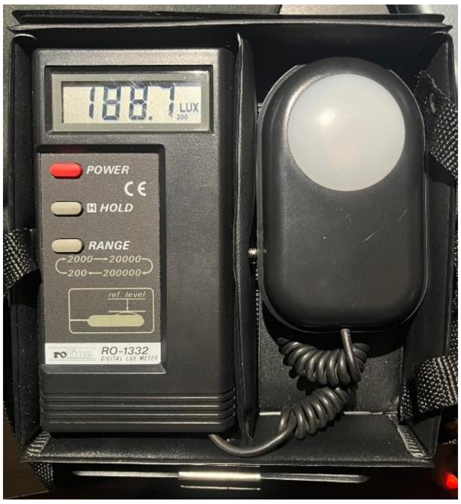


Figure 3.21 Roline RO-1332 Digital Lux Meter.

3.2 Method of Research

After defining research problems, background information about the research, and its motivation, which is about the possible bond between architecture and agriculture, stages of the method were determined. After bibliometric analysis, the literature is reviewed according to the selected key words to gather information about existing studies about UA and BIA, existing methods in those studies, and insufficient numerical data about environmental loads of BIA systems. A detailed literature review with case study research was conducted, and a list of parameters to gather quantitative data for the comparison table and graphs of the meta-analysis stage was determined. In addition to the case studies from the literature, different cases are investigated from Turkey such as plant factories, greenhouses, conventional fields, and other BIA-used controlled environment farms for the meta-analysis phase.

For creating an urban symbiosis scenario with a circularity approach, Sıhhiye Multistorey Car Parking Building is selected due to its unique characteristics in terms of the use pattern of the building, surrounding natural elements, and surrounding anthropogenic factors. After site analysis and historical background research of the building, the existing situation of the case is investigated by introducing its current potential and limitations. Then, the initial scenario for the case is established for further analysis and empirical research about the food production possibilities, building consumption patterns, and air purification opportunities. Finally, the scenario is evaluated according to the analyses and data logging sessions to demonstrate a possible urban symbiosis with a circular system design which includes a mutual relationship between BIA systems and the building itself for environmental, economic, and social benefits.

3.2.1 Bibliometric Analysis

Bibliometric analysis via Web of Science, Scopus, Google Scholar, and VOSviewer is conducted to reveal the relationship between sources and to select the most relevant studies to gather qualitative data for the literature review and numerical data for the meta-analysis. Some limitations and rules are determined for the searching process. Those elimination criteria are as followings:

- The search is made for 4 main key words that are “urban agriculture”, “building integrated agriculture”, “controlled environment agriculture”, and “vertical farming”. Those main key words are selected according to their relevance and co-occurrence rates in the literature. After the main search, 4 alternative key words that are “symbiosis”, “environmental loads”, “environmental impact”, and “circularity” are used for the intersection studies that include both the main key words and the alternative ones. For specific sources and research, more key words and relevant synonyms of them are used such as plant factory, rooftop greenhouse, and lettuce.

- The search is made for the sources between 2000-2024 to find up-to-date data; others are excluded.
- The search is made for data papers, conference papers, conference reviews, articles, book chapters, book reviews, and reviews; others are excluded.
- The search is made for English and Turkish sources; others are excluded.
- Relevant subject areas, key words, and publication titles are selected for the search.

3.2.2 Literature Review

For the literature review -after the bibliometric analysis- abstracts, key words, methodology parts, and results of selected studies are examined for further elimination of irrelevant sources. Extra studies, which are independent of the elimination criteria, are also selected for their unique and relevant content or data. All studies are examined for qualitative and quantitative (graphs, tables, etc.) features that are required for the decided research objectives. Environmental, as the focus of the research, economic, and social impacts of the expansion of the built environment, use of UA methods, and the advent of BIA methods are main qualitative features to gather. From selected 231 independent and interrelated studies, 156 of them are chosen as main references.

Research methods about the topic in the literature are examined for the decision of the research methodology. UA and BIA-based studies include the following different methods:

- Literature review and systematic literature review,
- Survey (consumers, producers, perception, application),
- SWOT analysis,

- Scenario/case analysis,
- Life cycle impact assessment,
- Software simulation, performance-based simulation,
- Database creation and BIM integration,
- Visualizing and mapping (GIS, drones),
- Structural assessment,
- Bibliometric analysis,
- Defining design criteria (rooftop greenhouse, green roof, green facade),
- Crop-specific calculations and simulations.

According to the research objectives, meta-analysis is chosen as one of the methods of the research for comparing different data sets about conventional agriculture, UA types, and BIA methods. Thus, numerical data, graphs, and tables are collected from 142 selected studies. For a more precise meta-analysis comparison, different case studies are chosen from the literature and Turkey for more quantitative data. Different international plant factories and companies with different agricultural methods are selected as case study examples from the literature to gather numerical data. Data is gathered from both the academic sources and websites of the companies that include publicly available information about them. Example case studies from Turkey are determined as Root İstanbul, Plant Factory, Farminova, Kağıthane Municipality’s indoor farm, and some small-scale greenhouse and conventional agriculture companies. The examples in Turkey which use BIA methods as their main food production system are rare.

3.2.3 Meta-analysis

The meta-analysis method is chosen due to the lack of statistical, empirical, and quantitative data about BIA methods with their impacts on environmental loads in both urban scale and building scale settings. Moreover, some samples of conventional agriculture and UA methods are also included for comparison of their efficiencies and impacts. Via meta-analysis, qualitative and quantitative data from individual studies -that are gathered from the literature review and companies in Turkey- can be compared comprehensively to reveal more objective results about their impacts. Thus, possible data types and parameters to gather are determined according to the literature and companies in Turkey. The case and sample numbers are tried to be kept as high as possible for more meaningful results. Table 3.1 was devised to collate the gathered data.

Table 3.1 Meta-analysis data table with different case studies and selected parameters.

Parameters	Unit	Conventional 1	Conventional 2	Conventional 3	Greenhouse 1	Greenhouse 2	Greenhouse 3	BIA 1	BIA 2	BIA 3
Location	City									
Crop Type	Type									
Growing Medium	Type									
Light Source	Type									
Plant Weight	kg									
Harvest Cycle-Annual Amount	Day-Cycle									
Area Use Period	Day/year									
Total Area	m^2									
Crop Yields	Kg/m^2/cycle									
Water Consumption	L/m^2/cycle									
Energy Consumption	kWh/m^2/cycle									
Pest Control	Method									
Pesticide Consumption	g/m^2/cycle									
Fertilizer Consumption	g/m^2/cycle									
Max. Transportation Amount	km									
CO2 Emission	Kg/m^2.lettuce									
Structural Load	Kg/m^2									
REFERENCES										

With crop type limitations as lettuce (Lactuca sativa), due to its short harvesting period, resilience, and ease of cultivation features, the numerical data is gathered from selected sources and companies from Turkey. The comparison of the numerical data is conducted according to the values of resource consumption, energy consumption, crop yield, CO_2 emissions, area efficiency, and - as Casey et al. (2022) suggested - structural loads if data is available.

Selected cases are mostly classified under conventional agriculture, greenhouse agriculture, and BIA methods. Rooftop greenhouse and indoor farming options are chosen as BIA methods to investigate and compare, in order to understand the effects of CEA units as BIA methods in and on buildings. By limiting external effects on the cases by choosing enclosed and more isolated systems, the number of energy-used activities is maximized for more variables to compare. Moreover, sudden, unexpected, or unwanted value changes due to open-air conditions and natural forces are mitigated by this choice of BIA types.

For more numerical data to compare in addition to the ones in the literature, a list of parameters for comparison is prepared to gather quantitative data from producer companies and researchers in Turkey. Moreover, the set of parameters is determined as inclusive as possible also for the case studies from the literature to analyze and compare. The list includes the following parameters:

- The location of the agricultural area/system,
- Agricultural method and crop type that is cultivated in the agricultural area/system,
- The main source of light for vegetation,
- Total m^2 of the agricultural area/system,
- Total kg of the crop can be grown in a m^2 area of the agricultural area/system per harvest cycle,
- The duration that is equal to one cycle of harvesting for the crop type,
- The number of days that can be used for agricultural purposes per year,
- The amount of waste per kg or m^2 area of production per harvest cycle, (kg)
- The amount of water that is consumed per kg or m^2 area of production per harvest cycle, (liter)
- Total kWh of electricity that is consumed per kg or m^2 area of production per harvest cycle (lighting, air conditioning, cooling, heating, monitoring, automation systems, sensors, analyses, etc.),
- The amount of fuel (diesel, gasoline, natural gas) that is consumed per kg or m^2 area of production per harvest cycle (transportation, logistics, tractor, generator/power plant, heating, etc.), (liter)
- Total grams of pesticide that is consumed per kg or m^2 area of production per harvest cycle,
- Total grams of fertilizer that is consumed per kg or m^2 area of production per harvest cycle,

- Total “food miles” as km for the delivery of food from the agricultural area/system to the furthest target location,
- The total amount of CO_2 emission per harvest cycle (if calculated and available),
- Total structural load of the agricultural system (if there is any). (kg/m^2)

Most of the numerical data is derived from different sources and case studies; thus, the connection between them is mostly weak. Finally, separate analysis method is used for comparing data, which is weakly connected, in meta-analysis section with separating data sets into different parameters to compare.

3.2.4 Empirical Research

Due to the lack of quantitative data about the impacts of BIA methods on environmental load and the potential utilization of local sources for BIA systems to create an urban symbiosis with a circularity approach, empirical research can be conducted for further investigations of the study. The following parameters, variables, and possibilities are determined for further evaluation via empirical research:

- Potential electricity production via PVs,
- Potential rainwater harvesting,
- Relative humidity,
- Dry bulb temperature,
- CO_2 concentration in indoor conditions and car parking floors,
- Potential air purification via carbon capture from occupants and vehicles.

Among those parameters, variables, and possibilities, searching for a correlation between the number of vehicles that enter Sıhhiye Multistorey Car Parking building and CO2 concentration on car parking floors, and potential air purification capacity via carbon capture technology from the interior spaces and car parking floors are chosen as main focuses of the study. The empirical research aims to reveal the potential of the transformation scenario of the vacant and unused areas of the building into food production spaces while providing self-sufficiency opportunities to the building via renewable energy production, rainwater harvesting, and CO_2 fertilization with captured CO_2.

For data logging of dry bulb temperature, relative humidity, and especially CO_2 concentration in car parking floors, “HOBO MX CO_2 Logger MX1102” data loggers were deployed at different car parking floors at the same time, and they were left at their deployment location for a week or more at a time; data was recorded at 10 minutes’ intervals. Before the deployments, data loggers were calibrated for proper CO_2 emission data (Figure 3.22).

Figure 3.22 Before and after the calibration of HOBOware data loggers. (2023)

Moreover, for the interior data logging of the Youth Academy Cafeteria that is located on the ground floor of the building, data loggers were kept with the author while studying because BELPA allowed the use of data loggers for this period only in this area (Figure 3.23). Thus, data logging sessions for the interior space were limited to 3 times while the ones for the car parking floors were limited to 5 times due to special occasions in the building, problems with data loggers, deployment problems due to vehicle locations, weather conditions, and long periods of data logging, extracting the data from the loggers, and processing the data. The problems of data loggers were about errors that the loggers gave such as condensation errors, memory full errors, altitude errors for CO_2 measurement, and empty data cells due to unknown reasons (Figure 3.24).

Figure 3.23 Data logging in the cafeteria. (10.01.2024; 03.03.2024; 16.05.2024)

Figure 3.24 Errors of data loggers in the cafeteria as “altitude error” with 0 CO_2 ppm value and “Fail CLH error” for condensation risk. (16.05.2024)

For the data logging sessions in the car parking floors, 4 data loggers were deployed near the middle circulation core of the structure in the cable trails which are hanging from the ceiling at each car parking floor of the building for the first 2 data logging sessions in October and November 2023 (18.10.2023-28.10.2023 and 12.11.2023-26.11.2023) (Figure 3.25). For the first and second sessions, the aim was to understand the semi-open car parking structure’s characteristics of CO_2 concentrations throughout the data logging process. Only the first and the second car parking floors are used for parking purposes. However, two of the data loggers were also deployed on the third and fourth floors to understand the effect of vehicle entries and exits on the CO_2 concentration change in the daytime.

Figure 3.25 Data logger deployment location near the middle circulation core for 1st and 2nd data logging sessions. (18.10.2023-28.10.2023 and 12.11.2023-26.11.2023)

For the remaining 3 data logging sessions (10.01.2024-22.01.2024; 03.03.2024-18.03.2024; 24.04.2024-06.05.2024), 4 or 3 data loggers were deployed near the entrance core of the structure in similar cable rails hanging from the ceiling (Figure 3.26). For those sessions, the aim was to measure the CO_2 concentration in the entrance location because all vehicles must pass through the entrance core to park their vehicles (Figure 3.27). Moreover, when the vehicles are climbing through the entrance ramp, they emit more CO_2. Thus, specifically, the entrances of the vehicles were aimed to be measured to demonstrate the effect of vehicle entries on the CO_2

concentration. There can be a correlation between car entries and CO_2 concentration values; however, due to the nature of the building with its semi-open structural design, there are many more factors that may affect the CO_2 concentration in the car parking floors such as wind, traffic congestions at Aksu Street, flowing polluted urban air, temperature differences, humidity differences, fuel types of the vehicles, and vehicle types.

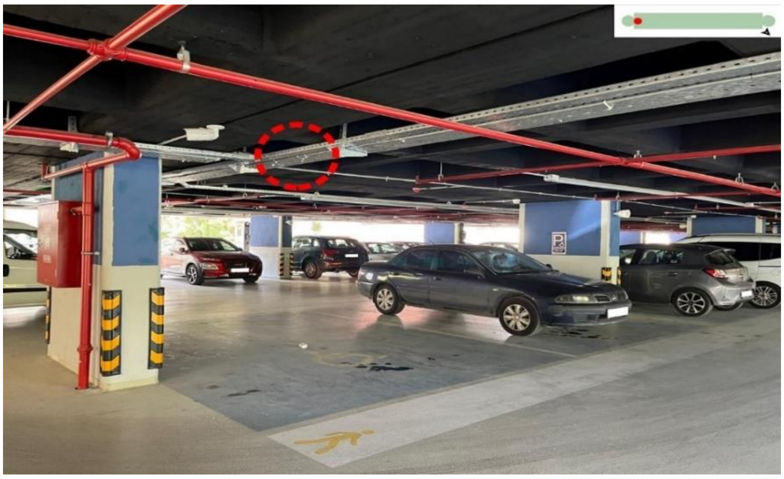


Figure 3.26 Data logger deployment location near the circulation core at the entry point of the vehicles for 3rd, 4th, and 5th data logging sessions. (10.01.2024-22.01.2024; 03.03.2024-18.03.2024; 24.04.2024-06.05.2024)

Figure 3.27 Helical vehicle ramps, entrance circulation core with staircases and elevator shafts, and data logging location for 3rd, 4th, and 5th data logging sessions. (10.01.2024-22.01.2024; 03.03.2024-18.03.2024; 24.04.2024-06.05.2024)

The illumination intensity in lux (lx) units was measured 10 times from each car parking floor (from the “front” of the building as northeast, from the “back” of the building as southwest, and from the front and back of the “middle” axis of the floors) and the outside of the building. The lux measurements were done manually with a Roline RO-1332 Digital Lux Meter while holding the light absorber part of the equipment parallel to the ground at eye level.

For the calculations of potential rainwater harvesting capacity, potential renewable energy production capacity by PVs, and potential food production capacity of the transformation scenario of Sıhhiye Multistorey Car Parking Building, estimated values for per m^2 area of PV for electricity production, roof for rainwater, and controlled environment for BIA systems are found from the literature or gathered from researchers in Turkey.

When the data logging and data gathering processes were completed, hypotheses regarding relationships were investigated by plotting correlation charts; and testing the self-sufficiency of the building for BIA systems in the transformation scenario by comparing the differences between the consumed and produced resources in the BIA processes.

3.2.5 Transformation Scenario

The transformation scenario of Sıhhiye Multistorey Car Parking Building is based on turning vacant floors and the rooftop of the structure into plant production facilities with different local symbioses for a circular system design. The existing building use patterns are preserved while they are being utilized for new building-integrated agriculture (BIA) based activities.

For the calculation of the transformation scenario in terms of electricity production from PVs, rainwater harvesting, food production in the BIA systems that are determined for the building, and reutilized CO_2, CEA-based production systems are taken into consideration as sterilized food production areas to ease the calculations with the help of numerical data from the literature. After the calculations, passive design strategies are suggested for mitigating the loads of the system in terms of energy consumption and to make it more energy independent.

Building-integrated rooftop greenhouse (BiRGH) is chosen as the main production BIA method on the rooftop of the structure. For the BIA units that are located at the middle axis of the car parking floors of the selected building, CEA-based container systems are chosen with artificial lighting and a fully sterilized environment due to direct contact with vehicles on the car parking floors. Rooftop greenhouse and indoor farming options are chosen as BIA methods to investigate and compare, in order to understand the effects of CEA units as BIA methods in and on buildings. By limiting external effects on the cases by choosing enclosed and more isolated systems, the number of energy-used activities is maximized for more variables to compare. Moreover, sudden, unexpected, or unwanted value changes due to open-air conditions and natural forces are mitigated by this choice of BIA types. As the main crop type for the study, lettuce (Lactuca sativa) is selected due to its ease of harvesting, relatively short harvest cycles, appropriateness for BIA systems, and resilience of the crop. The combination of various inputs into the BIA project scenario are presented in Figure 3.28.

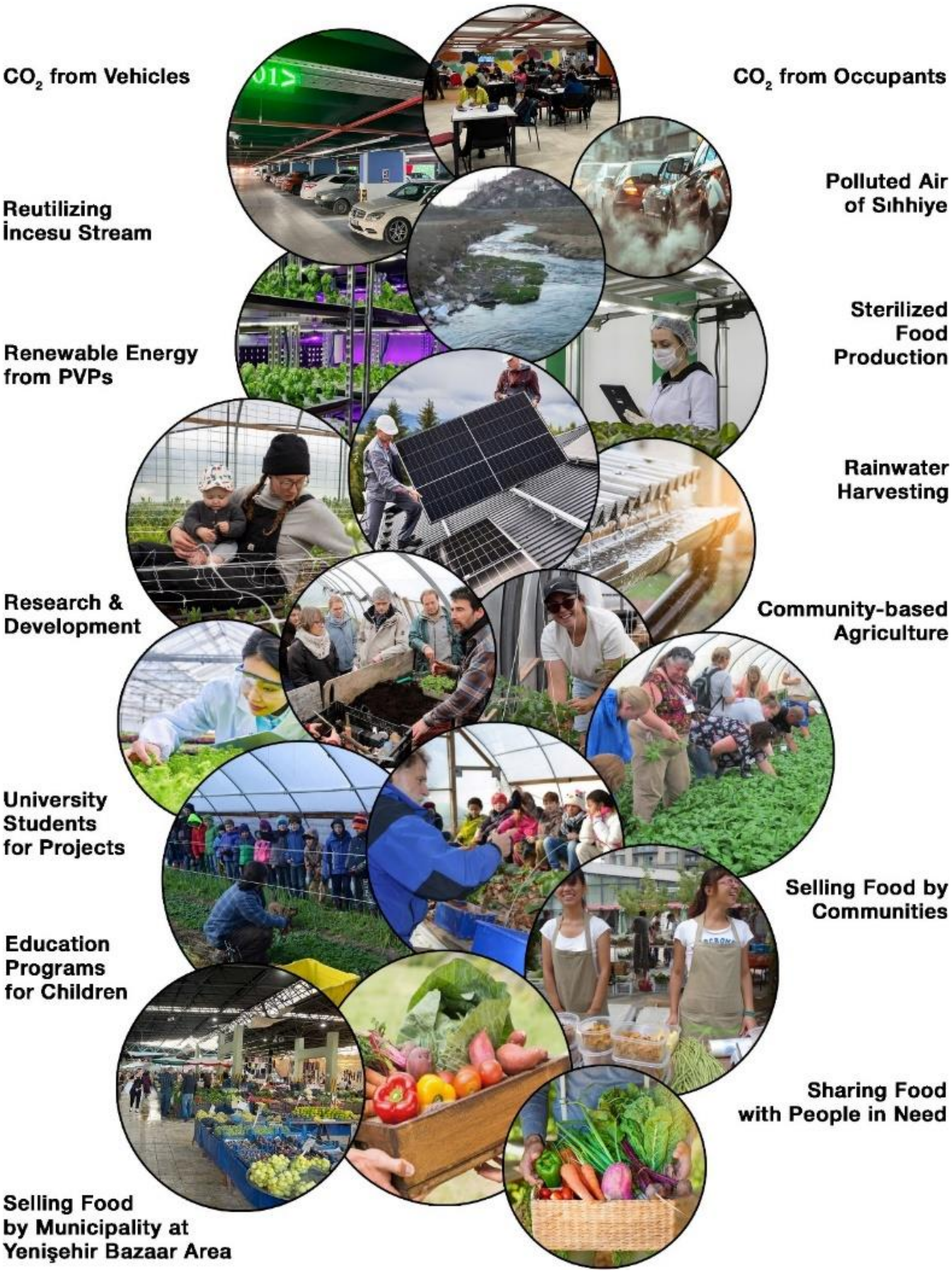


Figure 3.28 Final BIA scenario of the transformation Project by using CEA method.

CHAPTER 4

ANALYSES, RESULTS AND DISCUSSION

4.1 Bibliometric Analysis

All three of the academic search engines are examined for bibliometric analysis; however, Web of Science analysis is shown in this section as the chosen one. Others are kept in Appendices D.

In the search of Web of Science, the lack of BIA-related sources in the literature becomes obvious compared to UA-related ones. CEA methods are also less mentioned in the literature compared to UA and VF (Table 4.1). For the search of alternative key words and their intersections with UA, BIA, CEA, and VF, the environmental load key word is almost not mentioned at all in the literature with those four main keywords. The intersection of alternatives with BIA demonstrates the same result of the lack of BIA in the literature. For the alternatives, symbiosis and circularity are also barely mentioned especially with the relationship between them and BIA, CEA, and VF (Table 4.2). In Appendices D, the lack of literature about the concepts of the thesis research can be seen more clearly with the percentages of Web of Science search results. According to VOSviewer diagrams of Web of Science search (Appendices D), all the selected works were done between 2016-2024. Moreover, BIA seems related to “rooftop”, CEA to “greenhouse” and “renewable energy”, and VF to “plant factory” keywords whereas UA to a complex web of key words that includes environmental, economic, and social concepts.

Table 4.1 Web of Science search for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF).

Web of Science	**UA**	**BIA**	**CEA**	**VF**
First Search	3993	**43**	516	562
Date (2000-2024)	3923	43	499	562
Data Paper, Conference Paper, Conference Review, Article, Review, Book Chapter	3423	40	395	463
English and Turkish	3253	40	395	462
Relevant Subject Areas	1836	32	99	179
Publication Titles	624	22	37	87

Table 4.2 Web of Science search for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF) with symbiosis, environmental load, environmental impact, and circularity.

Web of Science	**UA**	**BIA**	**CEA**	**VF**
Symbiosis	36	**6**	**5**	**6**
Environmental Load	**1**	**0**	**0**	0
Environmental Impact	56	**3**	12	12
Circularity	20	**1**	**0**	**5**

Sources for the literature review are chosen according to the bibliometric analysis. Determined key words, their synonyms, and some related key words are used for further database searching. The most relevant and the most cited sources are chosen for the literature review and comparison of data in the meta-analysis section. More elimination and addition of sources are made according to required and related parameters and data. To demonstrate the cooccurrence amounts of key words that were used in the searched sources, the VOSviewer tool is used to create bibliometric charts, cooccurrence diagrams, and relationship diagrams (Appendices D).

According to bibliometric analysis via academic databases and VOSviewer, the lack of sources in the literature about building-integrated agriculture is revealed with numerical data. Especially the sources that include the relationship between BIA and symbiosis concept, or BIA and circularity concept are very rare in the literature.

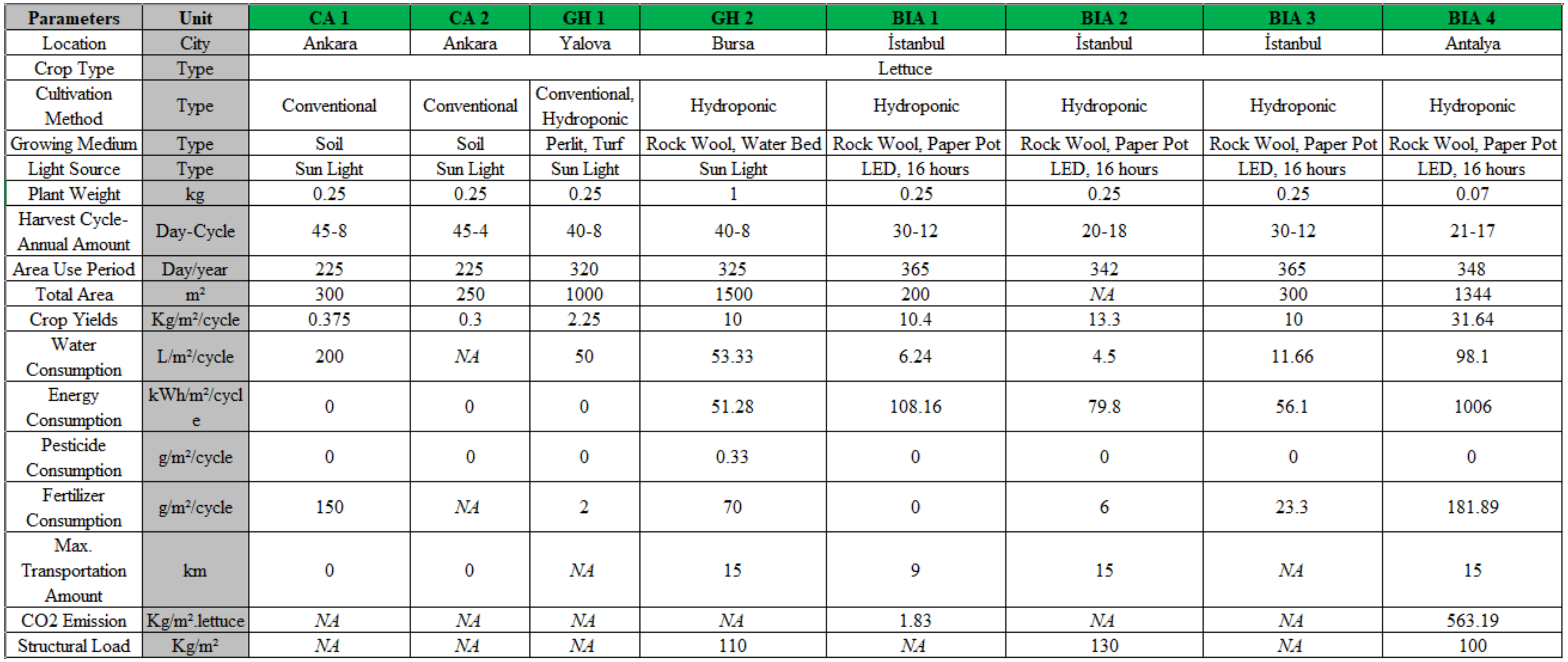
Therefore, the research is conducted to focus on possible symbiotic relationships between BIA and urban systems. Furthermore, the impact of BIA methods on environmental loads is also prioritized for the research due to the lack of literature.

4.2 Meta-analysis

Meta-analysis is done among 8 producers from Turkey which contain two conventional agricultural methods, two greenhouses, and four plant factory (PF) examples (Table 4.3). The comparison between selected cases is done according to the determined parameters of search. For all the cases, lettuce (Lactuca sativa) is chosen as the main crop type to ease the comparison of other parameters. The weight per lettuce can differ among selected cases between 70 grams to 1000 grams, dependent on external conditions and agricultural methods. The cultivation methods of the chosen cases are hydroponic except for the conventional ones. PF examples use only artificial lighting for 16 hours a day whereas greenhouses and agricultural fields benefit from sunlight.

Harvest cycles of lettuce can be shortened and can be increased in number throughout the year via controlled environment agriculture (CEA) conditions in plant factories. Rather than 40-45 days for each harvest cycle in agricultural fields and greenhouses, plant factories can harvest lettuces every 20-30 days which claims the increase in crop yields with BIA methods, due to CEA conditions. Moreover, with the year-round production of lettuce via CEA in PFs, the number of annual harvests can be doubled compared to conventional agriculture examples. The year-round production capabilities of PFs can be observed in Table 4.3 as almost the entire year rather than 200-250 days of field use period which is also not optimal all the time for lettuce cultivation. When crop yield values are examined, the difference between conventional methods and BIA methods becomes more obvious in terms of food production capacity. According to the meta-analysis, plant factories can produce from 30 times to 100 times more food than conventional agricultural fields due to CEA conditions and land use efficiency of stacked vertical food production.

Table 4.3 Companies from Turkey for meta-analysis.



Parameters	Unit	CA 1	CA 2	GH 1	GH 2	BIA 1	BIA 2	BIA 3	BIA 4
Location	City	Ankara	Ankara	Yalova	Bursa	İstanbul	İstanbul	İstanbul	Antalya
Crop Type	Type	Lettuce							
Cultivation Method	Type	Conventional	Conventional	Conventional, Hydroponic	Hydroponic	Hydroponic	Hydroponic	Hydroponic	Hydroponic
Growing Medium	Type	Soil	Soil	Perlit, Turf	Rock Wool, Water Bed	Rock Wool, Paper Pot	Rock Wool, Paper Pot	Rock Wool, Paper Pot	Rock Wool, Paper Pot
Light Source	Type	Sun Light	Sun Light	Sun Light	Sun Light	LED, 16 hours	LED, 16 hours	LED, 16 hours	LED, 16 hours
Plant Weight	kg	0.25	0.25	0.25	1	0.25	0.25	0.25	0.07
Harvest Cycle-Annual Amount	Day-Cycle	45-8	45-4	40-8	40-8	30-12	20-18	30-12	21-17
Area Use Period	Day/year	225	225	320	325	365	342	365	348
Total Area	m^2	300	250	1000	1500	200	*NA*	300	1344
Crop Yields	$Kg/m^2/cycle$	0.375	0.3	2.25	10	10.4	13.3	10	31.64
Water Consumption	$L/m^2/cycle$	200	*NA*	50	53.33	6.24	4.5	11.66	98.1
Energy Consumption	$kWh/m^2/cycle$	0	0	0	51.28	108.16	79.8	56.1	1006
Pesticide Consumption	$g/m^2/cycle$	0	0	0	0.33	0	0	0	0
Fertilizer Consumption	$g/m^2/cycle$	150	*NA*	2	70	0	6	23.3	181.89
Max. Transportation Amount	km	0	0	*NA*	15	9	15	*NA*	15
CO2 Emission	Kg/m^2.lettuce	*NA*	*NA*	*NA*	*NA*	1.83	*NA*	*NA*	563.19
Structural Load	Kg/m^2	*NA*	*NA*	*NA*	110	*NA*	130	*NA*	100

For water consumption, nearly all plant factory cases demonstrate 10 times less water consumption than greenhouses and 20 times less than conventional fields. BIA methods with CEA conditions and planned irrigation patterns can be viable solutions against global water depletion and drought problems. The energy intensification aspect of BIA methods and CEA conditions can be observed from the selected cases. Conventional agriculture cases seem to have no energy consumption according to the meta-analysis comparison (Table 4.3). However, fuel consumption in agricultural machinery and even in food logistics should be considered to compare their energy consumption values realistically.

For the comparison of pesticide consumption, fertilizer consumption, and maximum transportation amount, those 8 selected cases from Turkey are not appropriate because even 2 conventional agriculture cases use no pesticide, no artificial fertilizer, and they distribute their produce locally without any transportation need. In general, conventional agriculture methods include high amounts of pesticides and artificial fertilizers to control the open-air conditions of agricultural fields to not lose any produce due to pests and insufficiency of nutrients from the soil. The use of fertilizer in PFs is based on liquid fertilizers and nutrient solutions that are used in hydroponic systems. Those fertilizers do not include toxic ingredients and chemicals; they consist of vital minerals and other nutrients for plants.

Total CO_2 emission value is hard to find and calculate for companies; thus, there is almost no numerical data about the total CO_2 emissions of companies throughout the food production process. Furthermore, there is no structural load for buildings in conventional agriculture and greenhouse examples. However, BIA methods should be considered according to the system loads that are carried by buildings due to structural stability needs and possible integration scenarios.

For the meta-analysis, agriculture-based companies are examined from the literature as case studies to compare. 93 case studies can be found in the literature; more than 60% of them started their business after 2010 as relatively new companies (Figure 4.1). Nearly 40% of them were established in the USA while the Netherlands, Canada, Japan, Singapore, the UK, and Sweden are following as other host countries to most of the companies. Almost 60% of all those companies have commercial purposes whereas there are 9 retailers and 5 tech-provider companies.

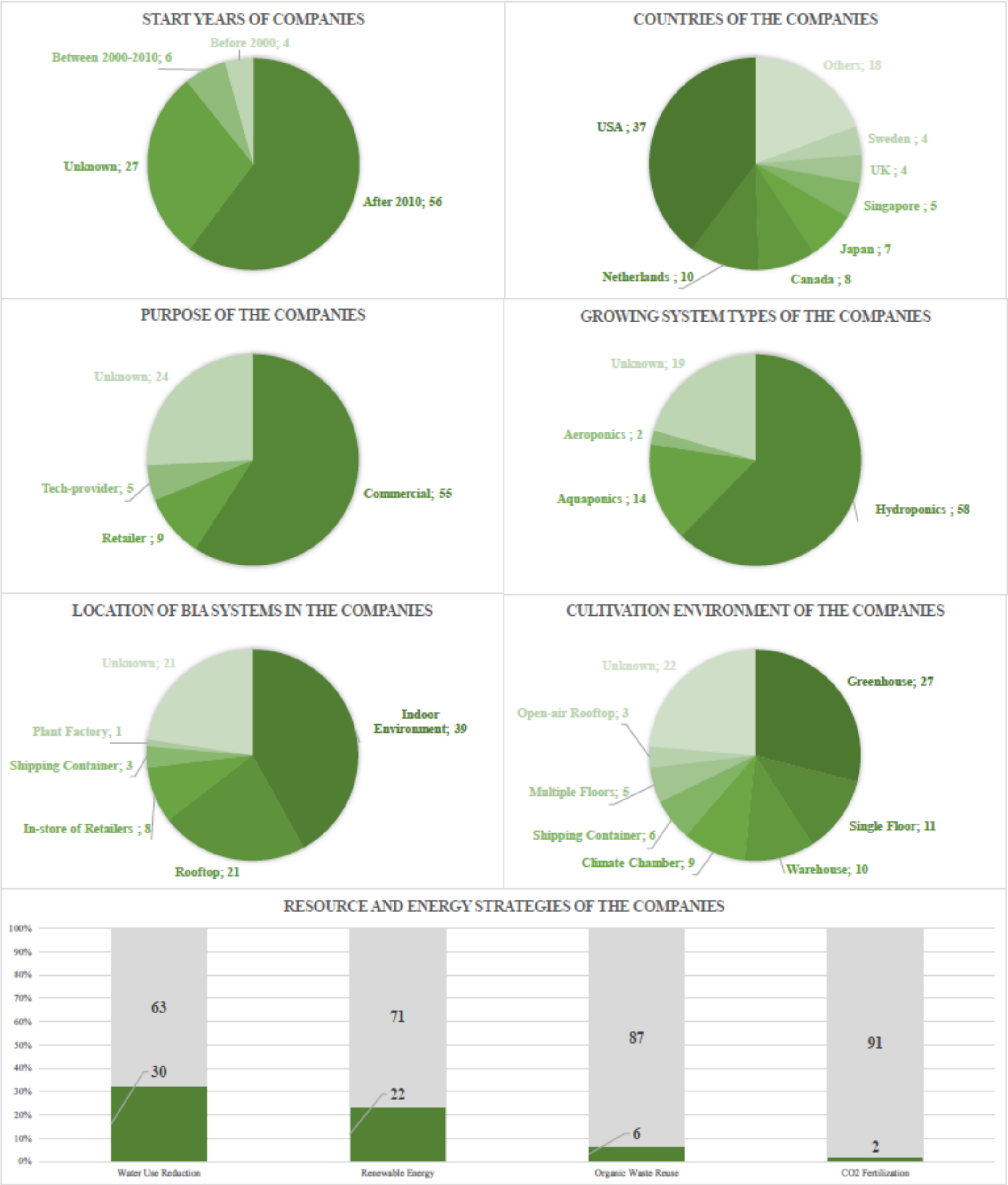


Figure 4.1 Meta-analysis of the data from agricultural companies that use BIA systems, as reported in the literature. (Data collected from literature sources: Bingöl, 2015; Birkby, 2016; Kozai et al., 2020; Parkes et al., 2022; Shamshiri et al., 2018)

According to the cultivation process of the companies, 62% of them are using hydroponics while 14 companies are using aquaponics, and 2 companies are using aeroponics. For the location of the BIA system examination, it is claimed that 39 out of 93 companies from the literature use indoor environments for locating BIA systems and cultivation. Moreover, 21 of them use rooftop areas for plant cultivation via BIA methods. Cultivation environment is also another parameter for those companies to compare; food production via a greenhouse environment is the most used option with nearly 30% in number of companies. On the other hand, indoor environments of buildings as single or multiple floors and vacant areas such as warehouses and shipping containers are being used as cultivation environments by 34% of the companies.

According to the literature review for those companies as case studies, strategies for resource and energy use in BIA methods of those companies can be examined. However, relevant features of some of these companies are missing in the literature. With the existing data about them, it can be stated that 32% of those companies use city-water use reduction strategies such as rainwater harvesting. Moreover, for the renewable energy production and energy consumption reduction needs due to the energy-intensive BIA systems, 24% of the companies use PVs to produce electricity and sunlight for cultivation to mitigate energy consumption. On the other hand, there are 6 out of 93 companies that utilize organic waste for reuse in the food production process, and there are only 2 companies that reuse CO_2 as fertilizer to boost crop yields. The meta-analysis of those 93 companies claims that all those companies with different strategies to mitigate their consumption values are rare in the field. There can be more integration of those strategies with BIA systems of companies and individual producers to mitigate environmental loads.

4.3 Transformation Scenario

In the scenario, the building acts as a "food hub" while it is used by university students from Hacettepe University, Ankara University, and Gazi University as their study area. Especially students from Ankara University Faculty of Agriculture can use the structure for their research, projects, and experiments. The building can act as an agricultural laboratory with the necessary food production area in the CEA-based rooftop greenhouse, indoor vertical farms in the middle of car parking floors, and a research and development area (Figure 4.2). Moreover, as İmga (2014) states, Kurtuluş Park area near the structure was designed and used as a green urban space for incubating seedlings, saplings, and trees for the city, for the landscape works of municipalities, and for Ankara University Faculty of Agriculture. Thus, the structure refers to the old local values with local food, seedling, and sapling production via BIA methods.

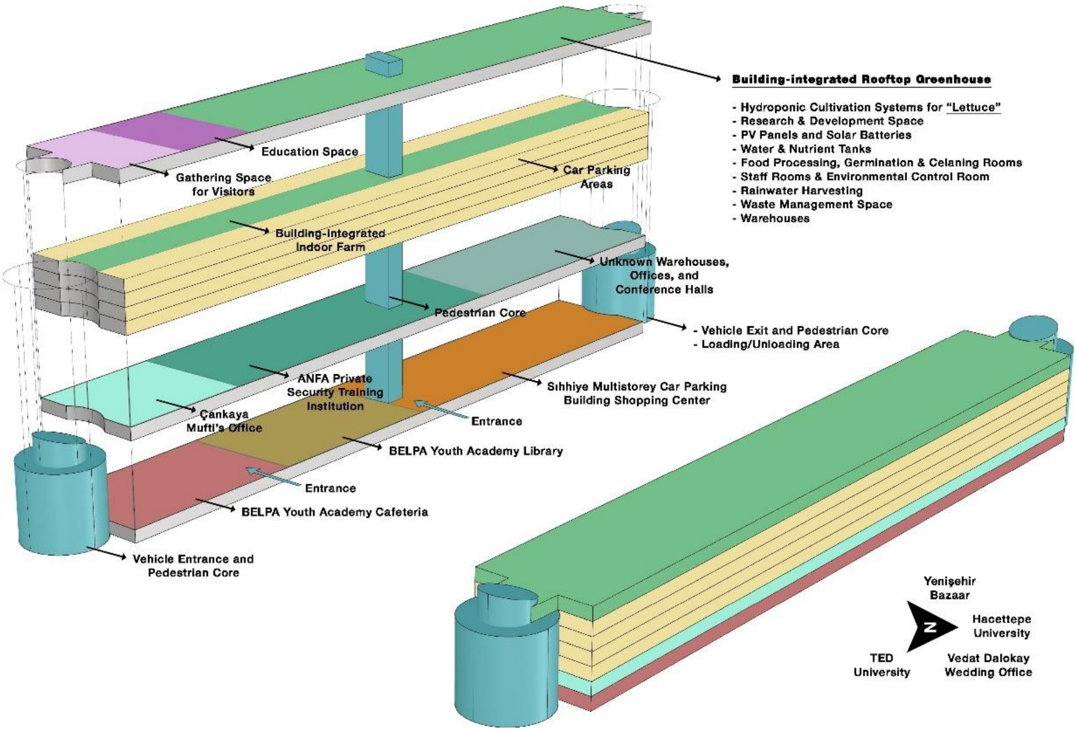


Figure 4.2 Spatial use diagram of Sıhhiye Multistorey Car Parking Building according to transformation scenario.

Every student, volunteer, and agriculture professional can use food production facilities in the building for their consumption, for selling their produce in Yenişehir Bazaar area, for sharing with the urban poor, or for leisure time activities. The bazaar area can be used as the local food market for the locally produced food in Sıhhiye Multistorey Car Parking Building, due to its readiness to sell products, its well-known location, and its proximity to the building. The selling can be governed by the Çankaya Municipality or Ankara Metropolitan Municipality with a relatively cheaper price, especially for people in need, students, disabled people, and elderly people. It ensures local food security, provides healthy food for people, and eliminates food miles. Moreover, the organic wastes from Yenişehir Bazaar area, BELPA Youth Academy Cafeteria, and BIA systems in the structure can be turned into compost to upcycle them as fertilizer for BIA systems.

There can also be "food gatherings" on the rooftop or on the public ground floor of the building for sharing locally produced foods and knowledge about the food production process. Moreover, education programs especially for children and elderly people can be conducted at the planned education space at the rooftop or ready-to-use education halls in the BELPA Youth Academy section. These education programs aim to spread awareness about environmental global problems, food-based distress, and local demands. As Ryan (2015) claims, children and students can also learn about cultivation, composting, gardening, vertical farming, greenhouse gardening, hydroponics, xeriscaping, etc.

Spaces of the transformation scenario are shown in floor plans and sections below from Figure 4.3 to Figure 4.5.

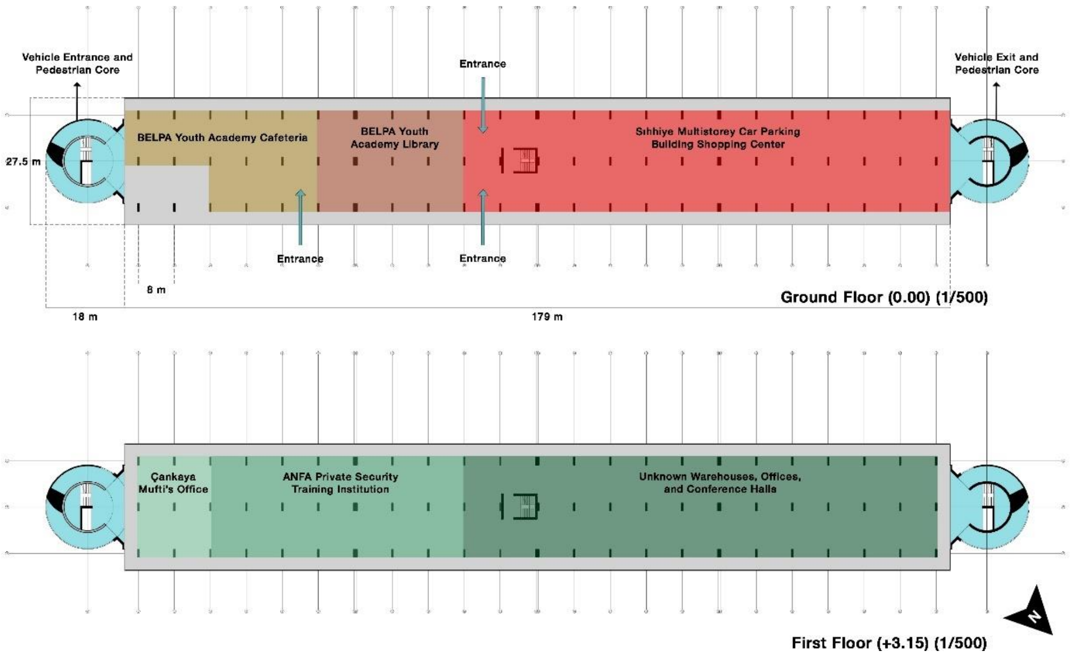


Figure 4.3 Current use of the ground and first floor of the building.

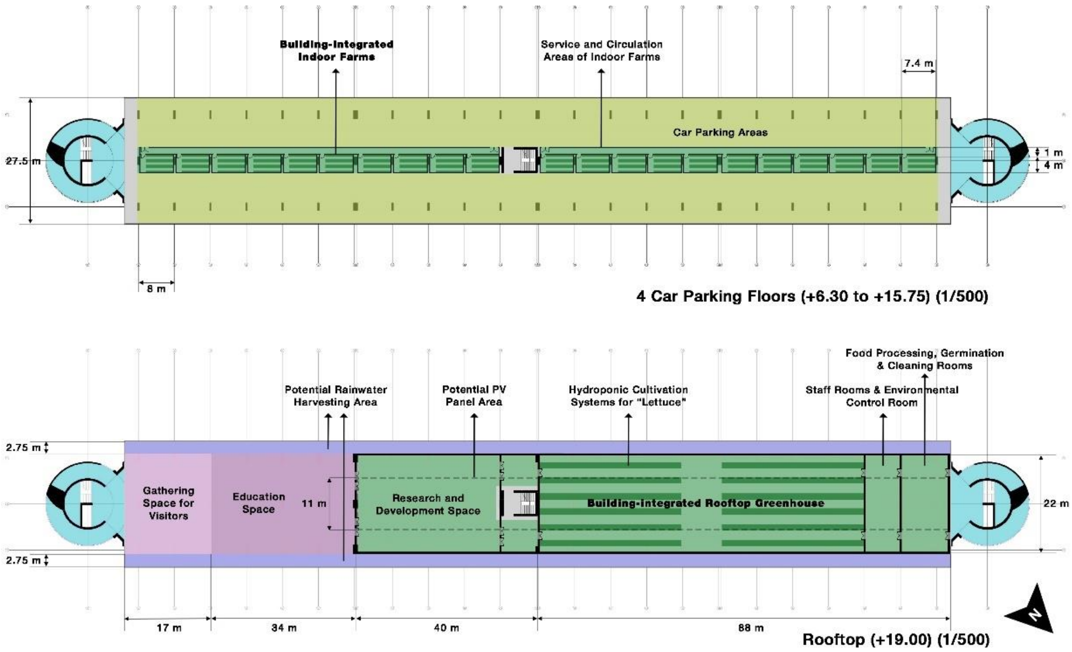


Figure 4.4 Proposed use of the car parking floors and rooftop of the building.

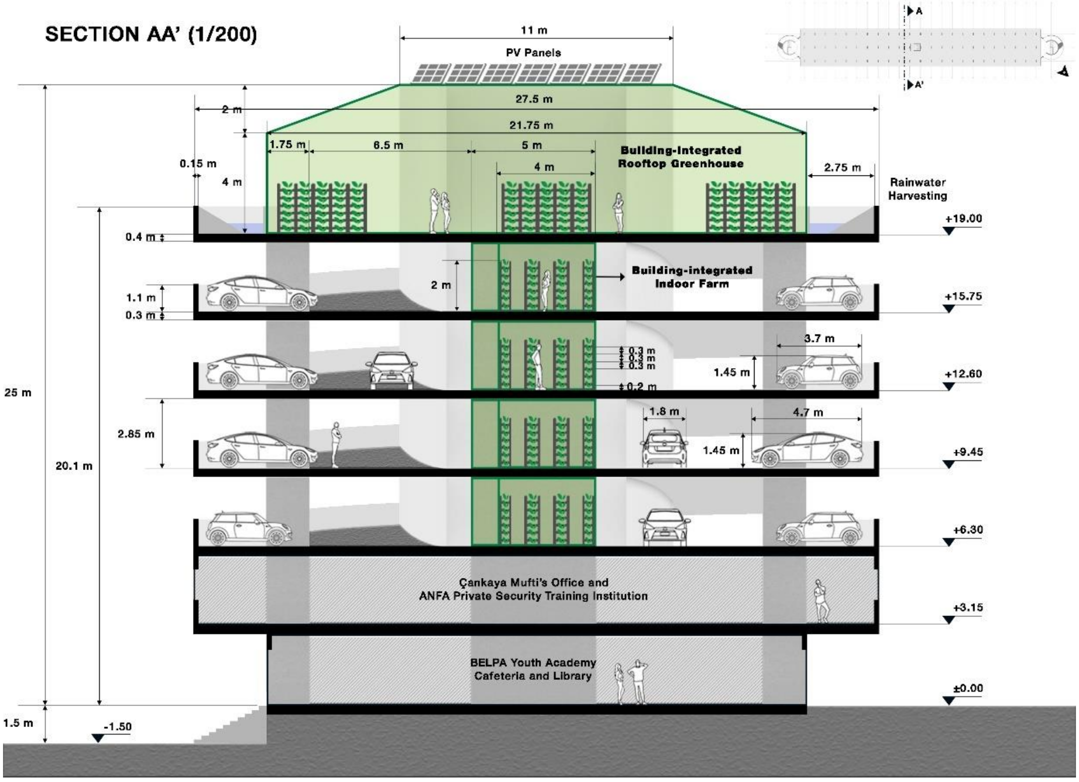


Figure 4.5 Proposed use of the car parking floors and rooftop of the building (Section AA').

While those social activities are happening, the community-based agriculture process can be sustained via renewable energy production with PVs at the top of the rooftop greenhouse for BIA system needs, rainwater harvesting at the rooftop for both irrigation and occupant uses, reutilizing concealed İncesu Stream for irrigation needs and rehabilitation of the stream, and reutilizing CO_2 from vehicles entering the building, occupants of the building, and the polluted air of Sıhhiye district to fertilize cultivated plants (Figure 4.6). Harvested rainwater and water from the stream are directed through the filtration system of the building before using them and rehabilitating the stream water to give it back to the stream. CO_2 from local sources is captured via carbon capture technology, and it is also directed through the related filtration process before pumping it into the cultivation spaces as fertilizer.

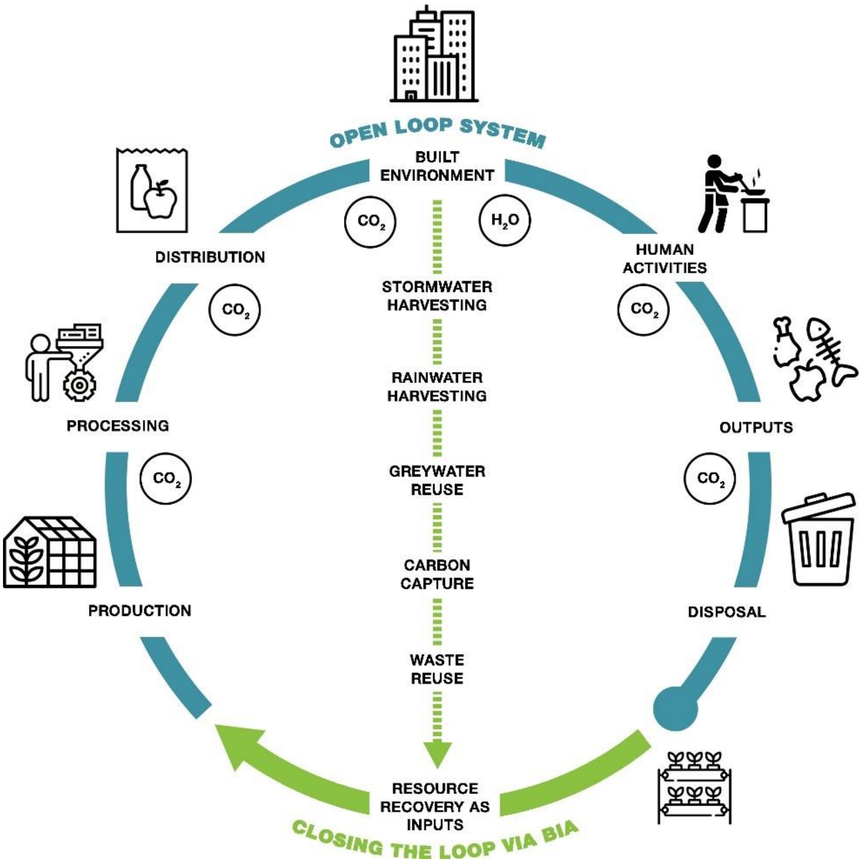


Figure 4.6 Closing the open loop systems via BIA systems in the proposed transformation scenario of the Sıhhiye Multistorey Car Park.

Contrary to the use of ETFE widely as greenhouse coverage material, which is toxic, Kozai et al. (2019) suggest the selection of solar glass or diffusive glass for the rooftop greenhouse to use natural light for the cultivation of the crops. Such glasses allow transmitting specific wavelengths into the greenhouse as diffused light. Direct sunlight is avoided due to excessive and unwanted heat gain that negatively affects crop yields and the food production process. Even though ETFE is lighter and cheaper than solar glass or diffusive glass, ETFE can be toxic with direct exposure to sunlight for the cultivation space and foods. Thus, relying on the load-bearing capabilities of the structure due to its design for bearing vehicular loads, solar glass or diffusive glass is chosen as the heavier but healthier option. The load-bearing capacity of the building is high due to the required stability for vehicular movement, vehicular loads, occupant loads, and tolerance for dead loads such as snow and stored goods. For per m², approximately 150-200 kg of vehicular load, 30-50 kg of occupant load, 40-50 kg of PV panel load, and the load of BIA systems are present in the transformation project. Thus, BIA systems with proper material choices and PV panels do not create static problems when they are compared with the existing vehicular and occupant loads. Especially the joint locations between the vehicular ramps and car parking floors do not have any structural cracks or deformation which is a also a sign for the existing structural stability. Moreover, structural design of the rooftop greenhouse should be done according to the PV panel weights and external loads.

The following sections describe the various possibilities of the scenario such as the local climate and characteristics of the location; food production capacity, food miles reduction, energy production and rainwater harvesting capacity; and carbon capture and air purification capacity.

4.3.1 Climatic Conditions

According to the Climate Consultant 6.0 software, the prevailing wind direction is northeast in Ankara. The range of temperature in Ankara is between 0 °C and 34 °C in summer and between -22 °C and 12 °C in winter. From the ground or İncesu Stream, heat pumps can be considered to decrease the need of energy for heating and cooling according to seasons because ground temperature in Ankara is suitable to use as a heat source: 5 to 15 °C at a depth of 4 meters. Humidity ranges in Ankara from 30% to 85% in summer, while from 50% to 90% in winter.

For the illumination range values according to the Climate Consultant 6.0 software, Ankara has a range of illumination from 5,000 to 40,000 lux in winter, whereas from 30,000 to 90,000 lux in summer. Around 10,000-15,000 lux is required for the optimum plant growth rate of lettuce (Brechner et al., 1996). Moreover, the sky coverage percentages are around 60% in winter and 25% in summer.

All the relevant charts from Climate Consultant software are given in Appendices E.

4.3.2 Food Production Capacity

For every car parking floor, 60 normal parking spaces and 2 parking spaces for disabled people are occupied with CEA-based BIA systems. The total 800 car parking lots, of which no more than 500 are used, decreased by 248 to 552 lots even if the middle axis of all four car parking floors is occupied with BIA systems. In another case only the 4th car parking floor is occupied by indoor farming units, this time the total 800 car parking lots decreased by 200 to 600 lots. In the second case, indoor farming units can also use natural light from the front and back of the building. Calculations are made according to the first case due to the ease of calculation with CEA conditions.

Indoor farming units are connected to each other with a buffer zone which is used as a service and circulation area. The buffer zone is located at the southwestern part of the car parking floor due to the prevailing wind direction of the location as northeast. Moreover, the buffer zone is restricted to enter; only responsible people, researchers, and assigned producers are allowed to use them to sustain healthy food production process. In the indoor farming units, vertically stacked shelves in the middle of them are wider because both sides of them are reachable (Figure 4.7). Accordingly, the estimated total area for food production in Sıhhiye Multistorey Car Parking Building according to the scenario design is about 1700 m² for the rooftop greenhouse (20 m width, 85 m length), and 2,368 m² for the indoor farming units (4 m width and 7.4 m length for a single unit, 20 units at each floor, 80 units for total) on the middle axis of car parking floors (Figure 4.7). Indoor farming units can also be located only at the 4th car parking floor. In this case, their area is 3,219 m² (7.4 m width, 21.75 m length, 20 units for the 4th floor). Those areas are approximately calculated according to the structural grid system to calculate possible food production capacity.

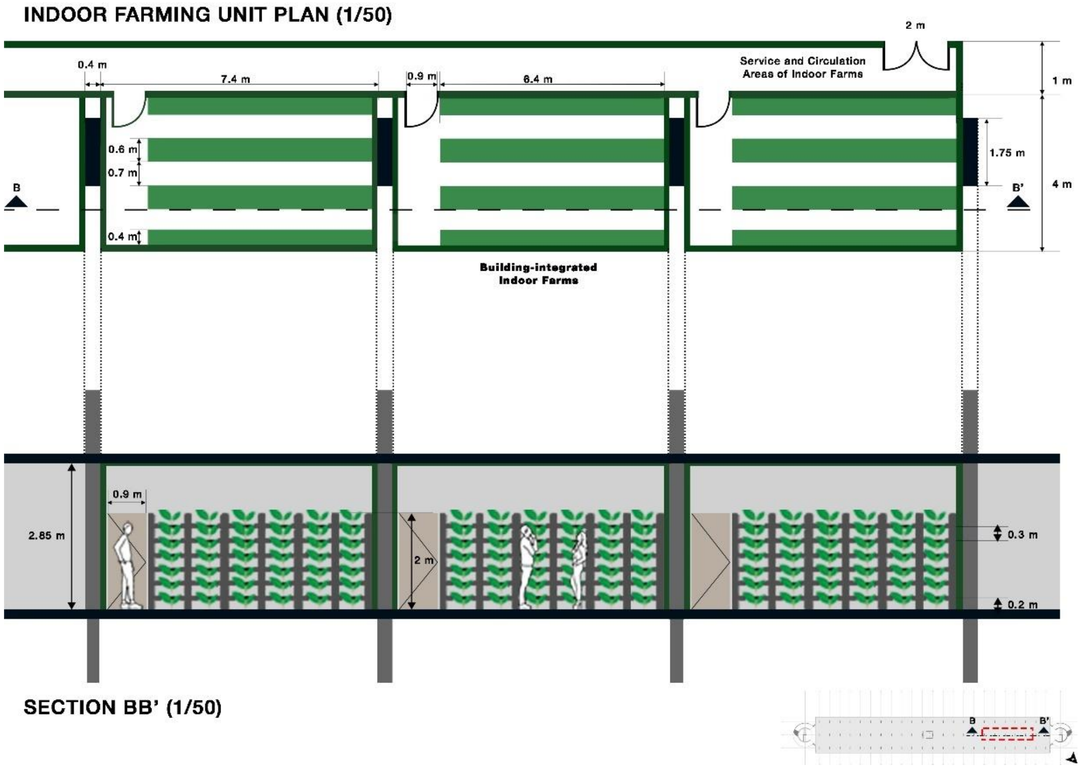
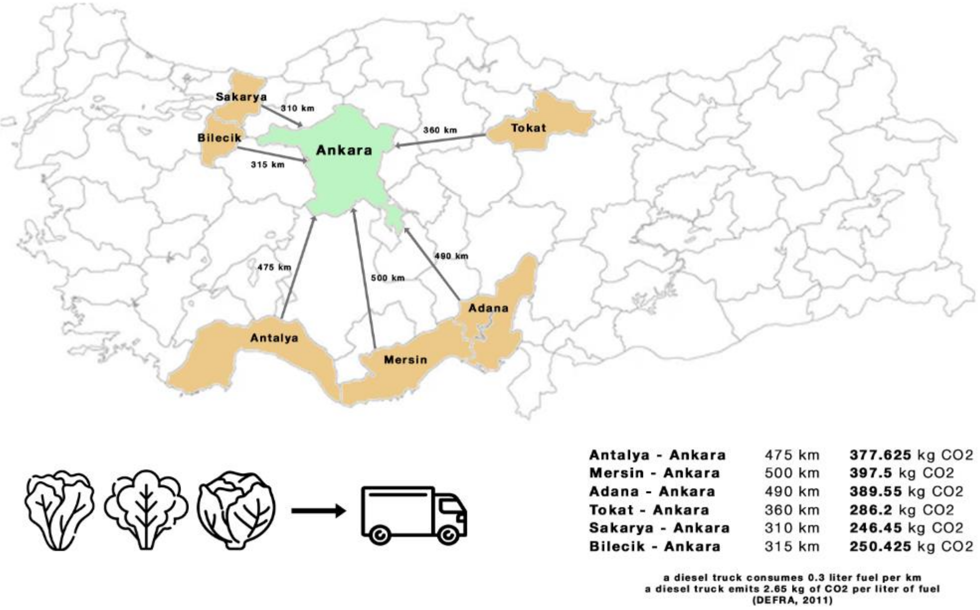


Figure 4.7 Indoor farming unit plan and section BB’ for the transformation project.

At the end of the scenario, a total area of 4,068 m² or 4,919 m² is occupied by BIA systems. For the potential food production capacity calculation, a rough average of those areas is selected as 4,500 m² (1,700 m² rooftop greenhouse, 2,800 m² indoor farming units). However, the selected footprint area cannot be used totally for food production only, due to necessary circulation and operation areas. Thus, the footprint area for food production is taken as the half of it, i.e. 2,250 m² (850 m² rooftop greenhouse area, 1,400 m² indoor farming units’ area). In the scenario, the design of the food production shelves can be considered as 6 vertically stacked hydroponic shelves with 30 cm between each (20 cm raise from the ground and a total 2 meters height of the shelve system) to produce as much as possible with a ceiling height of 3 meters. This design of shelves increases the food production area from 2,250 m² to 13,500 m² (5,100 m² for rooftop greenhouse, 8,400 m² for indoor farming units). Moreover, hydroponic systems can be preferred for the transformation project because they are cheaper, easier to construct, and more lightweight compared to aeroponic and aquaponic systems. According to Proksch (2016), in CEA conditions with hydroponics, the minimum crop yield per m² is around 45 kg for leafy greens, the average harvest cycle is around 25 days, and total amount of annual harvest cycles is around 12 times. According to the meta-analysis of the real-life examples of BIA systems in Turkey, the crop yield per m² is around 20 kg for lettuce. Thus, the average value for the crop yield per m² is taken as 30 kg, and the calculation of the potential food production capacity of the building is done as 360 kg.lettuce/m²/year value. According to the numerical data, Sıhhiye Multistorey Car Parking Building can produce 4,860,000 kg.lettuce/year with the transformation scenario. The number of shelves in the vertical farming units of BIA systems, passive design strategies, and other more efficient equipment use can change the assumed food production capacity values.

4.3.3 Food Miles

With the transformation of the vacant floors and rooftop of Sıhhiye Multistorey Car Parking Building into a food production facility, local food production is provided to sell in Yenişehir Bazaar or to consume for local needs. With this local production, food miles are eliminated for lettuce transportation from Antalya, Mersin, Adana, Sakarya, Bilecik, and Tokat which cities are the biggest lettuce producers according to turktarim.gov.tr (2024) (Figure 4.8). To calculate the eliminated amount of food miles roughly, DEFRA (2011) claims estimated numerical values such as a diesel truck consumption of 0.3 liter fuel per km and a diesel truck emission of 2.65 kg of CO_2 per liter of fuel. Therefore, in the case of one diesel truck of lettuce transportation through Ankara from all those cities, total food miles are calculated as 2,450 km (Figure 4.8). With those food miles, a total of 735 liters of fuel are consumed, and 1,947.75 kg of CO_2 is emitted. On the other hand, an average distance between producer cities and Ankara can be taken as 400 km and the total transportation distance can be taken as 800 km (delivery and return) to calculate the required food miles and emitted CO_2 amount for the potential food production capacity of BIA systems in the scenario as 4,860,000 kg.lettuce/year. For this calculation, the carrying capacity of one diesel truck per transportation is taken 15,000 kg as an average (Wellpack, 2024). Thus, there is a need for 324 diesel trucks annually to deliver 4,860,000 kg.lettuce/year to Ankara which must travel a total of 259,200 km, consume 77,760 liters of fuel, and emit 206,064 kg of CO_2. All those consumption and emission values are eliminated by local food production by BIA systems in the Sıhhiye Multistorey Car Park.



Antalya - Ankara	475 km	**377.625** kg CO2
Mersin - Ankara	500 km	**397.5** kg CO2
Adana - Ankara	490 km	**389.55** kg CO2
Tokat - Ankara	360 km	**286.2** kg CO2
Sakarya - Ankara	310 km	**246.45** kg CO2
Bilecik - Ankara	315 km	**250.425** kg CO2

a diesel truck consumes 0.3 liter fuel per km
a diesel truck emits 2.65 kg of CO2 per liter of fuel
(DEFRA, 2011)

Figure 4.8 Food miles for transporting lettuce from other cities to Ankara. (data from DEFRA, 2011; information from turktarim.gov.tr)

4.3.4 Energy Production Capacity with PVs

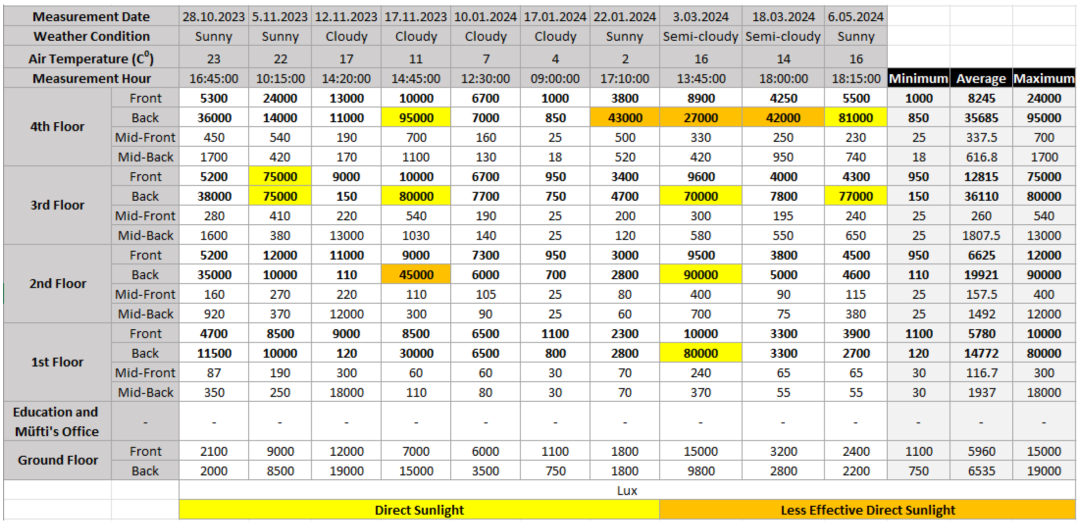
For lettuce production, the optimal indoor dry bulb temperature interval for the growth of the crop is mentioned as 19 to 24 °C by Brechner et al. (1996). As they indicated (1996), water temperature should be no more or less than 25 °C, and relative humidity should be between 50% and 70% because lesser humidity makes the cultivation process difficult while more humidity creates fungi problems with condensation of water and less water intake from roots. Brechner et al. (1996) also claimed that with an adequate amount of lighting supply, 1500 ppm of CO_2 level is optimal for optimal growth; otherwise, ambient air with 400 ppm CO_2 level is proper for lettuce cultivation with daylight conditions (Table 4.4). According to Kozai et al. (2019), CO_2 value can be between 700-1,000 ppm for an optimal growth rate with a CO_2 enrichment system.

Table 4.4 Optimal set-points for hydroponic lettuce cultivation. (adapted from Brechner et al., 1996)

Optimal Set-points for Hydroponic Lettuce Cultivation	
Air Temperature	24 °C Day / 19 °C Night
Water Temperature	25 °C
Relative Humidity	50%<RH<70%
Carbon Dioxide	1500 ppm (with adequate light), 400 ppm (ambient)
Light	17 mole m^2/day (natural and artificial) (the day equals to 16 hours of light period and 8 hours of dark period)
Dissolved Oxygen	7 mg/L or ppm
pH	5.6-6

Calculations are made to determine the consumed electricity for artificial lighting of BIA systems in the transformation project of Sıhhiye Multistorey Car Parking Building. According to Both et al. (1994) and Brechner et al. (1996), the amount of total lighting (both natural and artificial) for optimal hydroponic lettuce cultivation is 17 mole.m^2/day (Table 4.4). It must be noted that daily need of 17 mole.m^2 is a total amount for 16-18 (16 is taken for calculations) hours of light; there is also an essential 6-8 (8 is taken for calculations) hours of dark period for leafy greens (Brechner et al., 1996; Kozai et al., 2019). For the rooftop greenhouse, this amount of lighting can be provided via both natural and artificial sources of light. However, according to the local measurements with luxmeter, for the indoor farming units at the middle axis of the car parking floors cannot have enough light from both the front and back of the building (Table 4.5); because Sharakshane (2018) claims that 1,000 lx is equivalent to 15 µmole.m^2/second (1,296,000 µmole.m^2/day) which is also equal to 1.296 mole.m^2/day and 0.864 mole.m^2/16hours. According to the lux measurements, the average lx value from the middle axis of car parking floors is no more than 1,000 lx which is also not enough when 0.864 mole.m^2/16hours is compared with 17 mole.m^2/16hours as prescribed by Brechner et al. (1996). However, according to the lux measurements from the northeast (front) and southwest (back) facades of the building, a minimum of 1,000 lux and an average of 8,000 lux can be sustained via daylight, which means more than 8,000 lux in average for the rooftop greenhouse (Table 4.5). Thus, there must be 16 hours of artificial lighting support for indoor farming units for optimal growth, while the rooftop greenhouse requires less LED support due to the present daylight option.

Table 4.5 Daylight data gathered through lux-meter in Sıhhiye Multistorey Car Parking Building is presented in lux units for each floor.



Measurement Date		28.10.2023	5.11.2023	12.11.2023	17.11.2023	10.01.2024	17.01.2024	22.01.2024	3.03.2024	18.03.2024	6.05.2024			
Weather Condition		Sunny	Sunny	Cloudy	Cloudy	Cloudy	Cloudy	Sunny	Semi-cloudy	Semi-cloudy	Sunny			
Air Temperature (C^0)		23	22	17	11	7	4	2	16	14	16			
Measurement Hour		16:45:00	10:15:00	14:20:00	14:45:00	12:30:00	09:00:00	17:10:00	13:45:00	18:00:00	18:15:00	Minimum	Average	Maximum
4th Floor	Front	5300	24000	13000	10000	6700	1000	3800	8900	4250	5500	1000	8245	24000
	Back	36000	14000	11000	95000	7000	850	43000	27000	42000	81000	850	35685	95000
	Mid-Front	450	540	190	700	160	25	500	330	250	230	25	337.5	700
	Mid-Back	1700	420	170	1100	130	18	520	420	950	740	18	616.8	1700
3rd Floor	Front	5200	75000	9000	10000	6700	950	3400	9600	4000	4300	950	12815	75000
	Back	38000	75000	150	80000	7700	750	4700	70000	7800	77000	150	36110	80000
	Mid-Front	280	410	220	540	190	25	200	300	195	240	25	260	540
	Mid-Back	1600	380	13000	1030	140	25	120	580	550	650	25	1807.5	13000
2nd Floor	Front	5200	12000	11000	9000	7300	950	3000	9500	3800	4500	950	6625	12000
	Back	35000	10000	110	45000	6000	700	2800	90000	5000	4600	110	19921	90000
	Mid-Front	160	270	220	110	105	25	80	400	90	115	25	157.5	400
	Mid-Back	920	370	12000	300	90	25	60	700	75	380	25	1492	12000
1st Floor	Front	4700	8500	9000	8500	6500	1100	2300	10000	3300	3900	1100	5780	10000
	Back	11500	10000	120	30000	6500	800	2800	80000	3300	2700	120	14772	80000
	Mid-Front	87	190	300	60	60	30	70	240	65	65	30	116.7	300
	Mid-Back	350	250	18000	110	80	30	70	370	55	55	30	1937	18000
Education and Müfti's Office	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ground Floor	Front	2100	9000	12000	7000	6000	1100	1800	15000	3200	2400	1100	5960	15000
	Back	2000	8500	19000	15000	3500	750	1800	9800	2800	2200	750	6535	19000
								Lux						
		Direct Sunlight							Less Effective Direct Sunlight					

For the potential need for artificial lighting equipment calculation, a rough average of BIA system areas is selected as 4,500 m^2, usable area as 2,250 m^2, and food production area with 6 layers of vertically stacked shelves as 13,500 m^2 (5,100 m^2 for rooftop greenhouse, 8,400 m^2 for indoor farming units), like the area assumption in section 4.2.2. The amount of kWh electricity consumption for 1 mole.m^2/day lighting value is 0.005511 kWh.m^2/day if the wavelength of the light is between 305-

2,800 nanometers (support.30mhz.com) (the wavelength of LED light is mostly between 380 (violet) to 750 (red) nanometers as the visible light spectrum), and it equals to 0.003674 kWh.m^2/16hours for the calculation of 16 hours of light period for optimum growth of lettuce. Therefore, in a condition that the lighting requirements is fulfilled only by LEDs without any natural light use to sustain the optimal lighting intensity for lettuce production as 17 mole.m^2/16hours, LEDs consume 0.062463 kWh.m^2/16hours. Total electricity consumption by LEDs for the approximate 13,500 m^2 of BIA system area with only artificial lighting is calculated as 843.2539 kWh/16hours. This daily electricity consumption requirement for artificial lighting systems is for the 16 hours of lighting needed for the optimal growth of the hydroponic lettuce. According to Kozai (2013), the electricity consumed in average plant factories for artificial lighting sources is approximately equal to 80% of the total electricity consumption; the rest is for heating-cooling, mechanical ventilation, filtration, irrigation, and automation. Thus, an approximate calculation can be made for the transformation project's BIA systems' daily electricity need as 1,054.0673 kWh/day.

For potential PV energy production calculations, PVs are chosen as mono-crystalline panels with 21% efficiency. According to Koçer et al. (2016), the optimal tilt degree of PVs in Ankara is calculated as 34°, the interval of optimum tilt degrees can differ from 1° to 67° according to the months. According to PVWatts calculations for the focus building, made with the help of Ataberk Yılmaz, the best orientation of PVs with a 34° tilt is the total south (180 azimuth) (Figure 4.9 and Figure 4.10). However, the other two orientation options, which are southeast (142 azimuth, parallel to the structure) and southwest (232 azimuth, parallel to the structure) are also very similar in terms of electricity production capacity. Calculations demonstrate the electricity production of 1 m^2 PV panel area annually as between 313.83 kWh/m^2 and 344.28 kWh/m^2. Thus, 344.28 kWh/m^2 is selected for the calculations and for making an estimation about the energy production capacity.

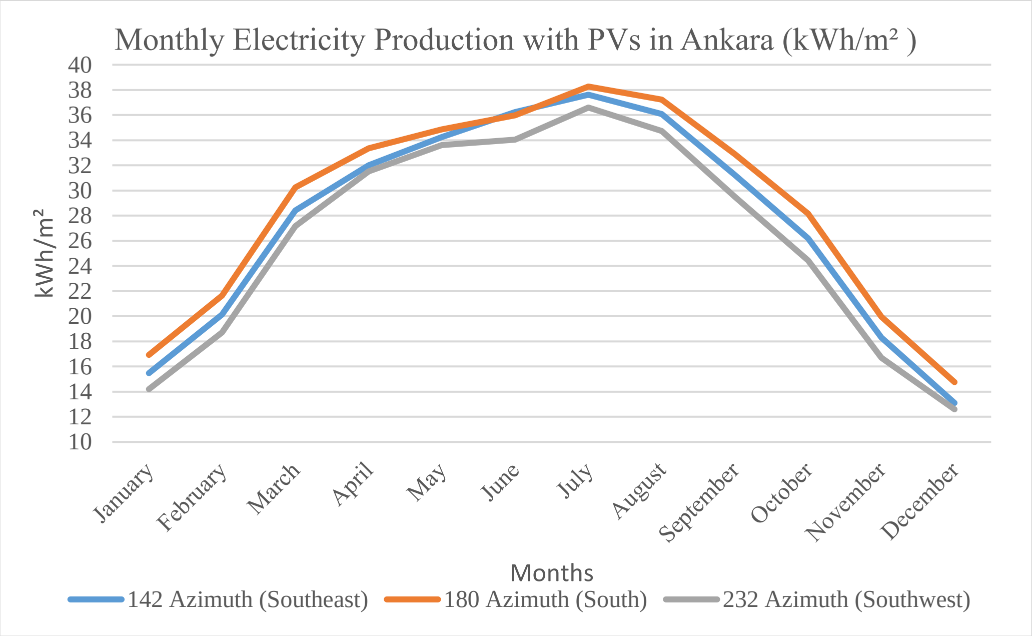


Figure 4.9 Monthly PV electricity production capacity (kWh/m²) in Ankara according to PVWatts (calculated by Ataberk Yılmaz)

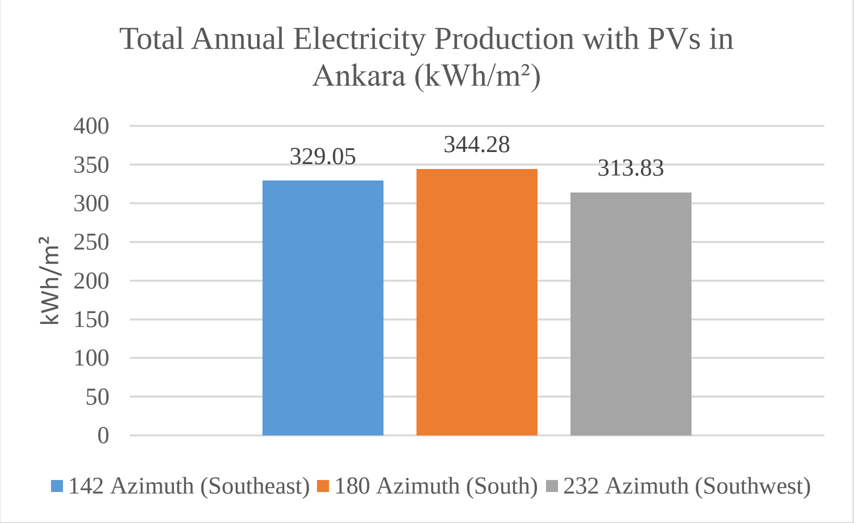
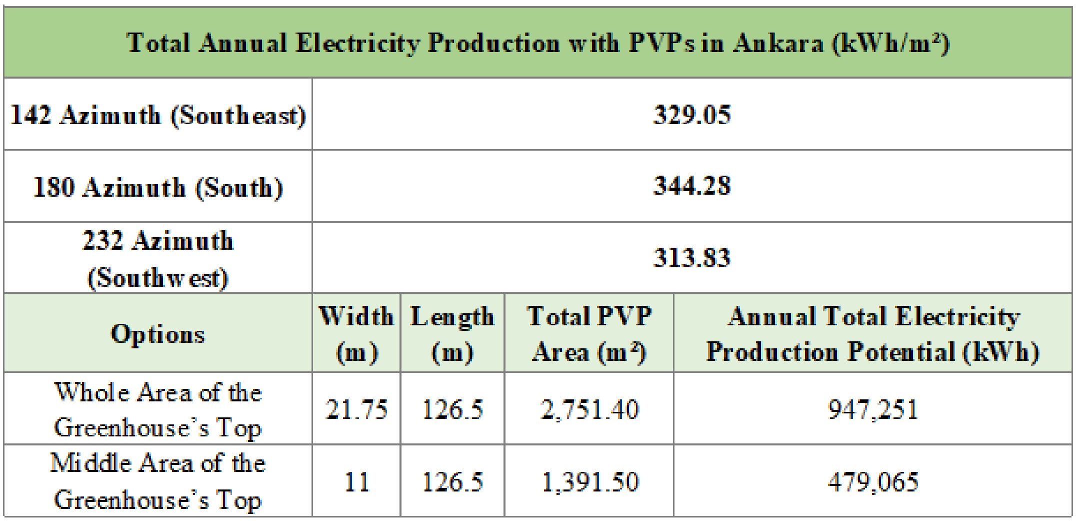


Figure 4.10 Total annual PV electricity production capacity (kWh/m²) in Ankara according to PVWatts (calculated by Ataberk Yılmaz)

For the calculations, the potential rooftop area for PVs is selected as 1,391.5 m² (11 m width and 126.5 m length of the middle of the greenhouse's top). With all top surfaces of the rooftop greenhouse, the potential area for PVs can be increased to 2,751.375 m² (21.75 width and 126.5 m length). However, for the calculation, the first option is considered as 1,391.5 m². With the selected value and potential rooftop area for PVs, the annual electricity production capacity of the building via PVs is about 479,065 kWh (Table 4.6).

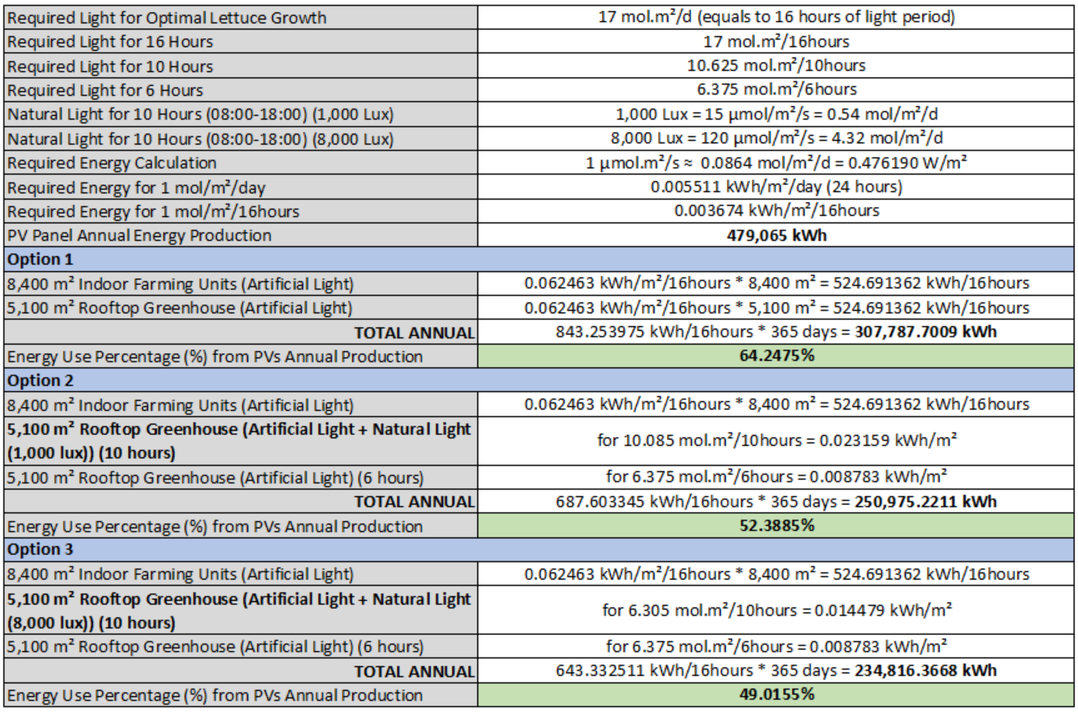
Table 4.6 Annual total electricity production potential in Ankara (kWh/m²).



Total Annual Electricity Production with PVPs in Ankara (kWh/m²)				
142 Azimuth (Southeast)	**329.05**			
180 Azimuth (South)	**344.28**			
232 Azimuth (Southwest)	**313.83**			
Options	**Width (m)**	**Length (m)**	**Total PVP Area (m²)**	**Annual Total Electricity Production Potential (kWh)**
Whole Area of the Greenhouse's Top	21.75	126.5	2,751.40	947,251
Middle Area of the Greenhouse's Top	11	126.5	1,391.50	479,065

The calculated daily artificial lighting system electricity needed for the 13,500 m² BIA food production area is 843.2539 kWh for the lighting need period of 16 hours for hydroponic lettuce. Thus, the annual total energy requirement for the artificial lighting was calculated as 307,787.7009 kWh which corresponds to 64.2475% of the annual electricity production capacity of the building via PVs as 479,065 kWh. If 10 hours of daylight (10 hours of the required 16 hours lighting period between 08.00-18.00) is used for the rooftop greenhouse with the measured minimum of 1,000 lux, the energy demand can be decreased by 56,812.4798 kWh and 52.3885% of the PVs annual production becomes adequate to fulfill the demand, whereas the use of daylight with an average 8,000 lux for the rooftop greenhouse can further mitigate the requirement by 16,158.8543 kWh to meet the demand from 49.0155% of the annual PVs production (Table 4.7). The rest of the produced electricity by PV panels can be used for occupant needs in the building, be stored in solar batteries for further needs of BIA systems and be sold to the government's electricity system.

Table 4.7 Required energy amounts of BIA systems in the proposed transformation project.



Required Light for Optimal Lettuce Growth	17 mol.m^2/d (equals to 16 hours of light period)
Required Light for 16 Hours	17 mol.m^2/16hours
Required Light for 10 Hours	10.625 mol.m^2/10hours
Required Light for 6 Hours	6.375 mol.m^2/6hours
Natural Light for 10 Hours (08:00-18:00) (1,000 Lux)	1,000 Lux = 15 µmol/m^2/s = 0.54 mol/m^2/d
Natural Light for 10 Hours (08:00-18:00) (8,000 Lux)	8,000 Lux = 120 µmol/m^2/s = 4.32 mol/m^2/d
Required Energy Calculation	1 µmol.m^2/s ≈ 0.0864 mol/m^2/d = 0.476190 W/m^2
Required Energy for 1 mol/m^2/day	0.005511 kWh/m^2/day (24 hours)
Required Energy for 1 mol/m^2/16hours	0.003674 kWh/m^2/16hours
PV Panel Annual Energy Production	**479,065 kWh**
Option 1	
8,400 m^2 Indoor Farming Units (Artificial Light)	0.062463 kWh/m^2/16hours * 8,400 m^2 = 524.691362 kWh/16hours
5,100 m^2 Rooftop Greenhouse (Artificial Light)	0.062463 kWh/m^2/16hours * 5,100 m^2 = 524.691362 kWh/16hours
TOTAL ANNUAL	843.253975 kWh/16hours * 365 days = **307,787.7009 kWh**
Energy Use Percentage (%) from PVs Annual Production	**64.2475%**
Option 2	
8,400 m^2 Indoor Farming Units (Artificial Light)	0.062463 kWh/m^2/16hours * 8,400 m^2 = 524.691362 kWh/16hours
5,100 m^2 Rooftop Greenhouse (Artificial Light + Natural Light (1,000 lux)) (10 hours)	for 10.085 mol.m^2/10hours = 0.023159 kWh/m^2
5,100 m^2 Rooftop Greenhouse (Artificial Light) (6 hours)	for 6.375 mol.m^2/6hours = 0.008783 kWh/m^2
TOTAL ANNUAL	687.603345 kWh/16hours * 365 days = **250,975.2211 kWh**
Energy Use Percentage (%) from PVs Annual Production	**52.3885%**
Option 3	
8,400 m^2 Indoor Farming Units (Artificial Light)	0.062463 kWh/m^2/16hours * 8,400 m^2 = 524.691362 kWh/16hours
5,100 m^2 Rooftop Greenhouse (Artificial Light + Natural Light (8,000 lux)) (10 hours)	for 6.305 mol.m^2/10hours = 0.014479 kWh/m^2
5,100 m^2 Rooftop Greenhouse (Artificial Light) (6 hours)	for 6.375 mol.m^2/6hours = 0.008783 kWh/m^2
TOTAL ANNUAL	643.332511 kWh/16hours * 365 days = **234,816.3668 kWh**
Energy Use Percentage (%) from PVs Annual Production	**49.0155%**

4.3.5 Rainwater Harvesting Capacity

For the water needs of irrigation systems of BIA systems in Sıhhiye Multistorey Car Parking Building, rainwater harvesting, stormwater harvesting, greywater reuse, and reutilization of the stream water of İncesu Stream are planned for the scenario (Figure 4.11). After proper filtration and sterilization processes, the polluted water of the stream can be directed through the building for the irrigation needs of BIA systems and the daily water needs of occupants of the building. After those processes, water can also be redirected through the stream as clean water for rehabilitating the stream and mitigating the smell from the manholes in the area. Moreover, the stream can be used as a heat pump for decreasing the heating and cooling load of BIA systems in the building. Other harvested and reused water sources are also pumped to the BIA systems with fertilizer-injection after proper purification and filtration processes.

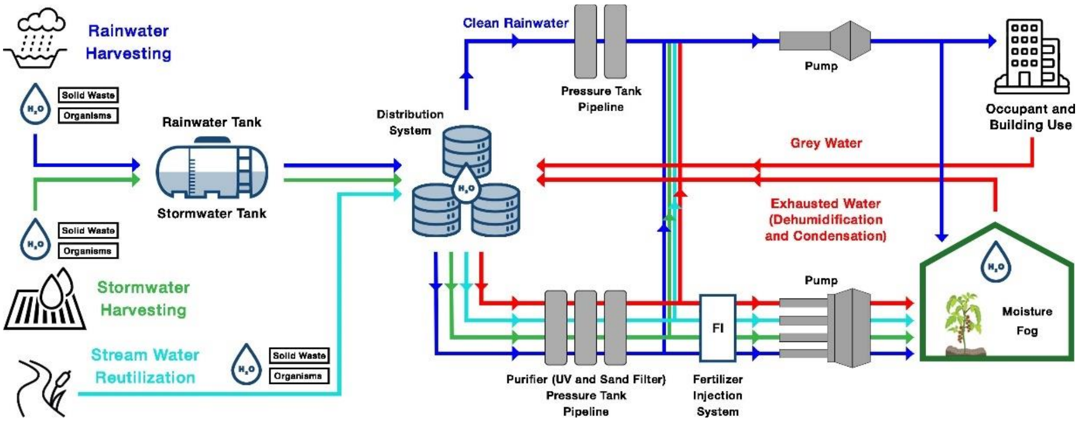


Figure 4.11 Water sources and cycles for BIA systems.

Aksu Street, which is in front of the Sıhhiye Multistorey Car Parking Building, and around the structure faces floods when excessive amounts of rain falls (Figure 4.12 and Figure 4.13). The floods are caused by both sudden and extreme rainfalls, which are increased with climate change, because the infrastructure is not capable of draining that amount of water, and the concealed İncesu Stream is prone to overflowing during rainy days with its limited concrete conduit capacity for its natural flow. Thus, the reutilizing of İncesu Stream for irrigation and occupant needs, and rainwater harvesting at the rooftop can mitigate the stress of flood and the load of rainfalls by supplementing the infrastructure.

Figure 4.12 Flood in between Yenişehir Bazaar and Sıhhiye Mutlistorey Car Parking Building. (trthaber.com)

Figure 4.13 Flood near Sıhhiye Mutlistorey Car Parking Building. (liderhaber.com.tr)

For the potential rainwater harvesting capability calculations, monthly total rainfall averages for Ankara as mm/m² are taken from the Meteorology Department's website (mgm.gov.tr) (Figure 4.14). According to those averages, the annual average for Ankara is calculated as 392.4 mm/m² (1 mm/m² water equals 1 liter of water). For the rainwater harvesting area calculation, there are two situations such as a calculation with the whole area of the rooftop due to the drainage of water from the top of the rooftop greenhouse and only two sides of the rooftop area near the greenhouse. For the whole rooftop, the area is calculated as 4,922.5 m² (27.5 m width and 179 m length) whereas the area for the sides of the greenhouse is calculated as 984.5 m² (2.75 m width and 179 m length for 2 sides of the greenhouse each). Therefore, the total rainwater harvesting capacity is between 386,317.8 liters and 1,931,589 liters (Table 4.8). According to Proksch (2016), the need for irrigation water per kg lettuce is approximately 15 liters. With the potential food production capacity as 4,860,000 kg.lettuce/year in the scenario, the irrigation water need can be calculated as 72,900,000 liters/year.

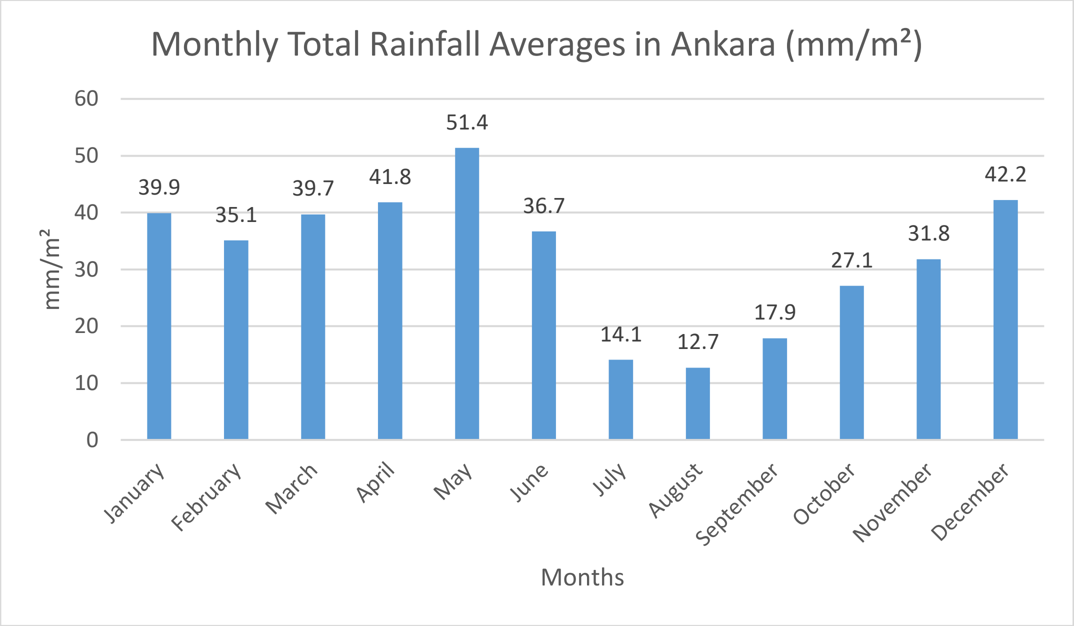


Figure 4.14 Monthly total rainfall averages in Ankara (mm/m^2). (mgm.gov.tr)

Table 4.8 Annual total rainwater harvest potential in Ankara (mm/m^2). (data taken from mgm.gov.tr)

Annual total rainfall average for Ankara (mm/m^2)				
392.4				
Options	**Width (m)**	**Length (m)**	**Total Rainwater Harvesting Area (m^2)**	**Annual Total Rainwater Harvest Potential (L)**
Whole Rooftop Collection Area	27.5	179	4,922.50	1,931,589
2 Lines of Collection Areas	5.5	179	984.5	386,317.80

4.3.6 Carbon Capture and Air Purification Capacity

The structure was designed to bear vehicular loads; thus, it is suitable for locating light structures and equipment of BIA systems in and on the building. Moreover, the nature of the structure as a car parking area can be used as an advantage for BIA systems. Sıhhiye is known for its polluted air; the building is also a source of CO_2 emission due to vehicles entering the structure. CO_2, which is emitted by the occupants of the building, vehicles that enter and exit the building, and existing pollution of the air can be utilized for increasing crop yields and food production efficiency. Carbon capture technology allows fertilization of the agricultural system with CO_2 after proper filtration of the air to extract only CO_2 from the ambient air instead of toxic gases from vehicles.

Sıhhiye and Ulus districts have the most polluted air in Ankara except the industrial zones of the city such as Sincan, Törekent, and Siteler, and the waste collection center in Mamak. The reasons behind the air pollution are being highly populated areas, being transportation center of Ankara, the lack of green areas in the area, proximity to Siteler and Mamak, and the topography of the area as a “bowl” with lower altitude then the surrounding districts.

According to the Ministry of Environment, Urbanism and Climate Change (havaizleme.gov.tr, 2023-2024), the air pollution can be examined via air quality index (AQI or HKI in Turkish). Between 50-100 AQI, the quality of the air can be identified as medium. Sıhhiye District is averagely classified in the medium range of the air quality (Figure 4.15 and Figure 4.16).

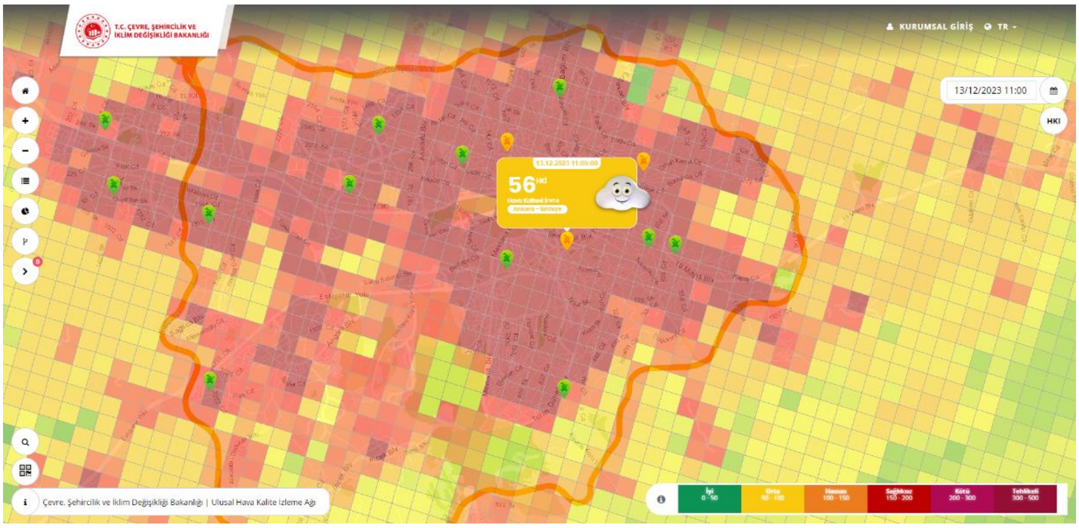


Figure 4.15 Air quality index (AQI) of Sıhhiye District with population data. (Retrieved from havaizleme.gov.tr, 2023)

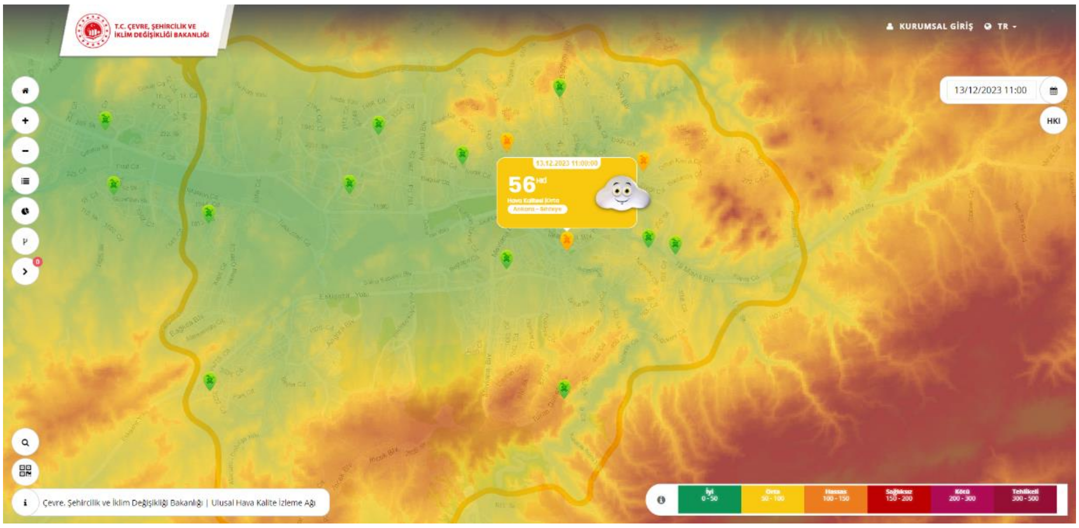


Figure 4.16 Air quality index (AQI) of Sıhhiye District with topography data. (Retrieved from havaizleme.gov.tr, 2023)

In the transformation scenario, BIA systems can be helpful to purify the air in the location by carbon capture technologies to fertilize plants in CEA conditions and adding green areas to the location. To understand the carbon capture potentials of the Sıhhiye Multistorey Car Parking Building and BIA systems in it from CO_2 of the location, of the car parking floors of the building, and of the Youth Academy Cafeteria, data loggers were deployed to measure the relative humidity (RH %), temperature (°C), and CO_2 concentration (ppm). Furthermore, with those measurements and vehicle entry-exit values from BELTAŞ (2023-2024), possible correlations were examined to calculate CO_2 capture and air purification capabilities of the scenario. Therefore, before the deployment of data loggers on the car parking floors of the building, the use pattern of it by the vehicles was investigated to clarify some of the reasons behind the potential correlations between CO2, RH, temperature, and vehicle entry-exit values of car parking floors.

From the entry/exit data obtained from the municipality, it can be indicated that the car parking is used more in the afternoon between 1:30 pm and 5 pm (Figure 4.17). This indication claims that outsiders, who are present in the area for bazaar, wedding ceremonies, and hospitals, use the car parking lots more than people working around.

Additionally, the distribution of the total number of vehicles using the car park between 15.07.2023 and 30.09.2023 is given in Figure 4.18.

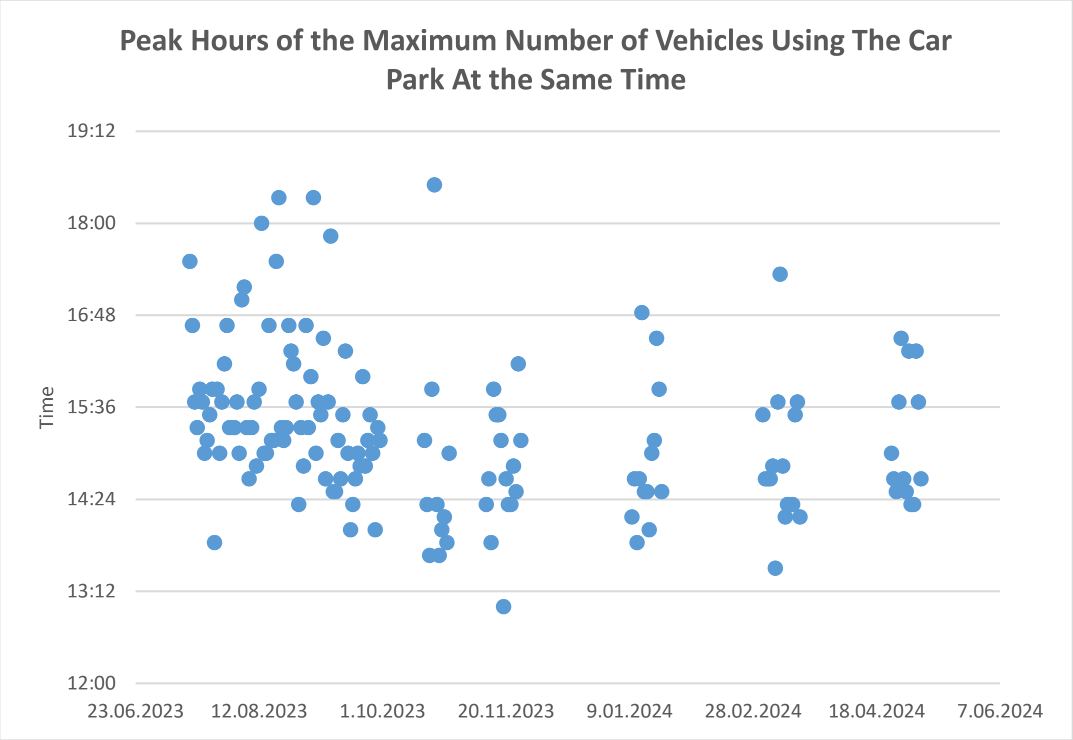


Figure 4.17 Scatter diagram showing the times when maximum number of vehicles are present in the car park during the study period.

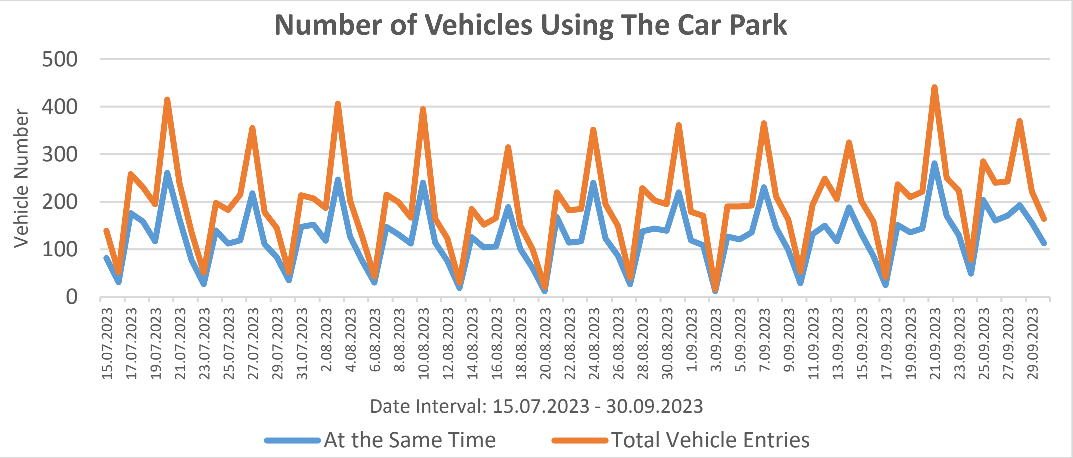


Figure 4.18 Distribution of the number of vehicles using the car park between 15.07.2023 and 30.09.2024.

According to the vehicle entry and exit data from BELTAŞ (2023-2024), the pattern of vehicular use of the building can be investigated. Due to the high society bazaars on Thursdays in Yenişehir Bazaar area, every Thursday between 15.07.2023 and 06.05.2024 dates have the highest number of vehicles that enter the structure for car parking; on the other hand, Sundays are the days that the structure is least used for every week.

Between 15.07.2023 and 06.05.2024, Sıhhiye Multistorey Car Park hosted 557 cars on a Thursday as the maximum value for the cars used the building at the same time (Figure 4.19). This value demonstrates the maximum demand for the car parking lots of the building that has 800 of them. Moreover, the minimum demand for the building was observed as 12 cars on a Sunday. On the other hand, the building was used by 841 cars on a Thursday as the maximum value, whereas it was used only by 16 cars on a Sunday as the minimum value (Figure 4.20).

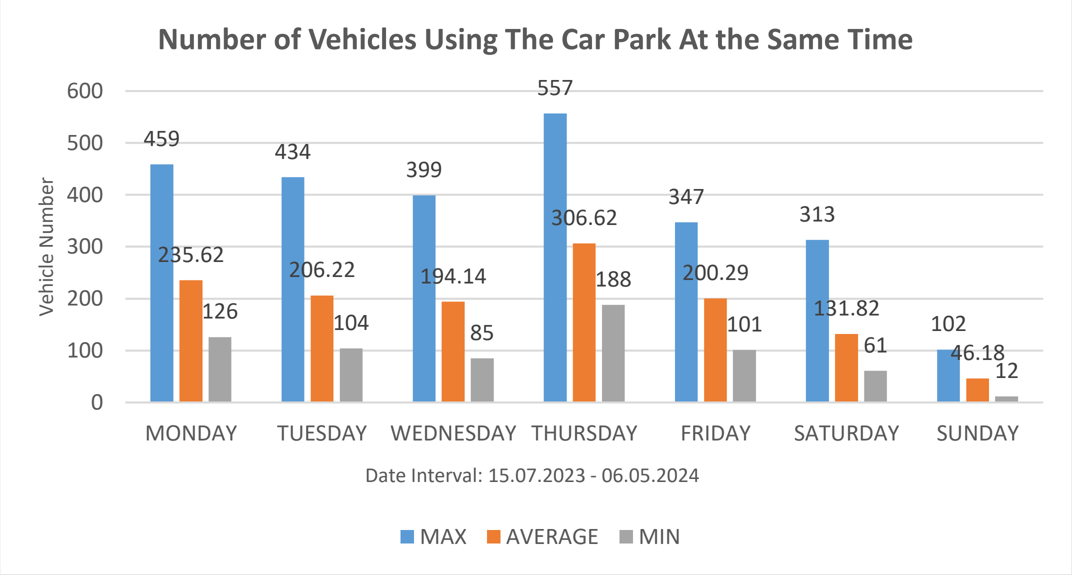


Figure 4.19 Number of vehicles using the car park at the same time. (15.07.2023-06.05.2024)

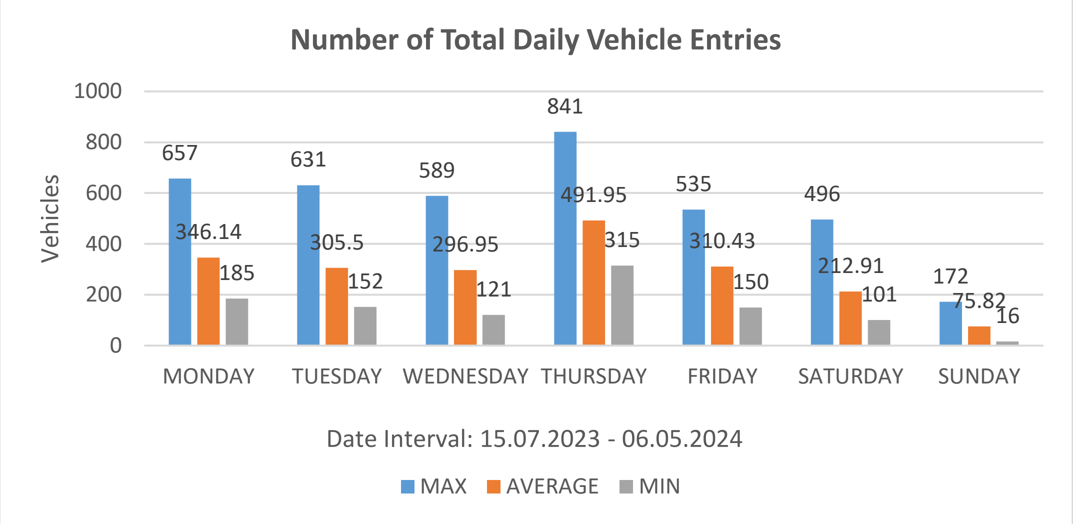


Figure 4.20 Number of total daily vehicle entries. (15.07.2023-06.05.2024)

After the investigation of vehicle use pattern of the building via vehicle entry-exit data from BELTAŞ (2023-2024), data loggers were deployed to the selected cable trays for standardizing the logging sessions and for their safety because they were left alone as totally unprotected for more than a week for each logging session (Table 4.9).

Table 4.9 Deployment information of data loggers.

First Deployment				
Deployment Date / Time	18.10.2023 / 15:30			
Collecting Date / Time	28.10.2023 / 16:45			
Deployment Location	Middle of the Structure, Near Core			
Deployed Floor	1st Floor	2nd Floor	3rd Floor	4th Floor
HOBOware Number	**EQ05**	**EQ07**	**EQ08**	**EQ09**
Second Deployment				
Deployment Date / Time	12.11.2023 / 14:00			
Collecting Date / Time	26.11.2023 / 16:40			
Deployment Location	Middle of the Structure, Near Core			
Deployed Floor	1st Floor	2nd Floor	3rd Floor	4th Floor
HOBOware Number	**EQ05**	**EQ07**	**EQ06**	**EQ09**
Third Deployment				
Deployment Date / Time	10.01.2024 / 12:30			
Collecting Date / Time	22.01.2024 / 17:10			
Deployment Location	Vehicle Entrance, Near Core			
Deployed Floor	1st Floor	2nd Floor	3rd Floor	4th Floor
HOBOware Number	**EQ09**	**EQ08**	**EQ06**	**EQ05**
Fourth Deployment				
Deployment Date / Time	03.03.2024 / 13:45			
Collecting Date / Time	18.03.2024 / 18:00			
Deployment Location	Vehicle Entrance, Near Core			
Deployed Floor	1st Floor	2nd Floor	3rd Floor	4th Floor
HOBOware Number	**EQ06**	**EQ07**	**EQ09**	**EQ08**
Fifth Deployment				
Deployment Date / Time	24.04.2024 / 18:15			
Collecting Date / Time	06.05.2024 / 18:15			
Deployment Location	Vehicle Entrance, Near Core			
Deployed Floor	1st Floor	2nd Floor	3rd Floor	4th Floor
HOBOware Number	**EQ09**	**EQ06**	**EQ08**	-

All data was recorded as **10 minutes' intervals**.

First Cafeteria Logging					
Deployment Date / Time	10.01.2024 / 11:40				
Collecting Date / Time	10.01.2024 / 12:20				
Deployment Location	Cafeteria				
Deployed Floor	Ground Floor				
HOBOware Number	**EQ09**	**EQ08**	**EQ06**	**EQ05**	-
Second Cafeteria Logging					
Deployment Date / Time	03.03.2024 / 13:15				
Collecting Date / Time	03.03.2024 / 13:55				
Deployment Location	Cafeteria				
Deployed Floor	Ground Floor				
HOBOware Number	**EQ06**	**EQ07**	**EQ09**	**EQ08**	-
Third Cafeteria Logging					
Deployment Date / Time	16.05.2024 / 14:25				
Collecting Date / Time	16.05.2024 / 16:25				
Deployment Location	Cafeteria				
Deployed Floor	Ground Floor				
HOBOware Number	**EQ05**	**EQ06**	**EQ07**	**EQ08**	**EQ09**

For the first and second deployment, the data loggers were deployed near to the middle core of the structure to examine the effects of both vehicular entries and exits on CO2 concentrations. For the other three deployments, the data loggers were deployed near to the entrance core and vehicular ramps to investigate the effects of vehicular movement on CO2 more precisely because every vehicle must pass by the deployed loggers. For those logging sessions, only the effects of vehicular entries on CO2 concentrations can be considered for further analysis.

The data loggers were not used in the same order for each floor and each logging session because some of the loggers developed different faults at different logging sessions, and they were changed accordingly.

There were also three data logger deployments for the Youth Academy Cafeteria to understand the interior conditions and the amount of interior CO2 concentrations. BELPA did not allow long time deployment of the data loggers in the cafeteria interior; but permitted data logging the author was present in the cafeteria for studying. Thus, the number of interior data logging sessions are limited, and their durations are shorter than the logging sessions in the car parking floors.

First Deployment of Data Loggers

The first deployment of data loggers was between 18.10.2023 and 28.10.2023. However, for the first two car parking floors, EQ05 and EQ07 logged the data until 24.10.2023 at 2.30 AM. Therefore, the graphs about the first deployment were made accordingly, until 24.10.2023 at 2.30 AM (from Figure 4.21 to Figure 4.24).

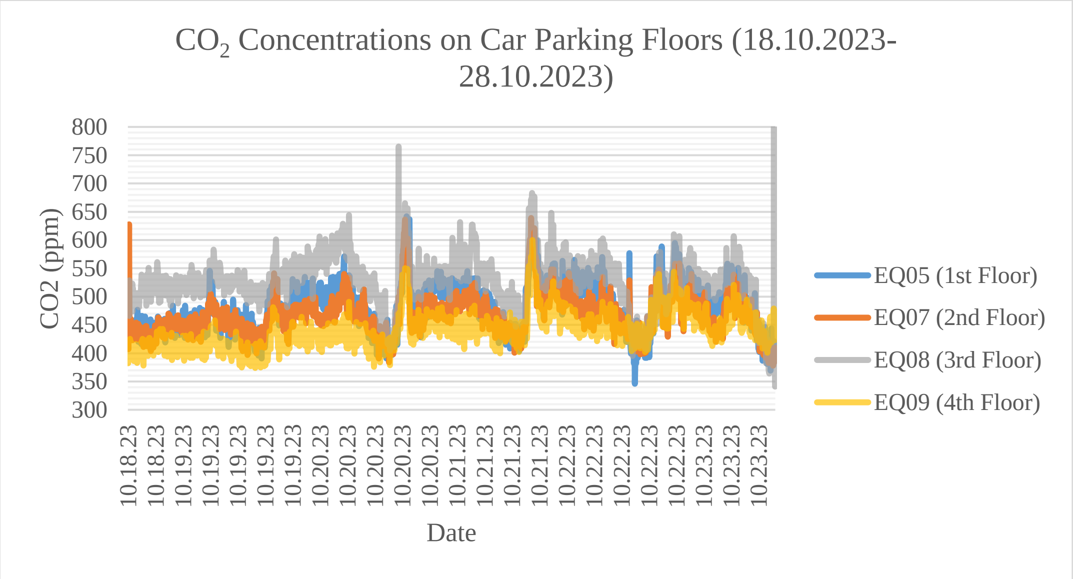


Figure 4.21 CO2 concentrations on car parking floors (18.10.2023-28.10.2023)

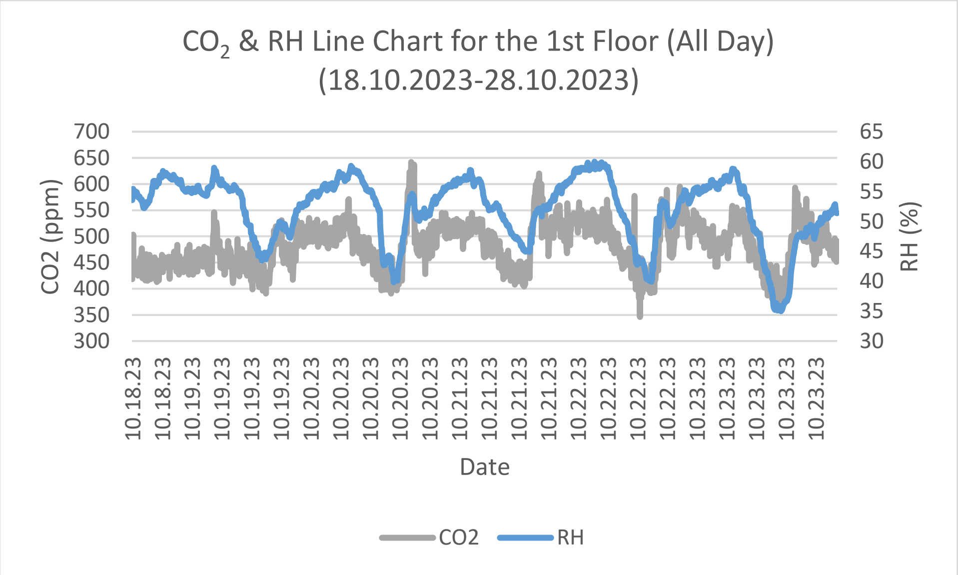


Figure 4.22 CO$_2$ & RH line chart for the 1st floor (All Day) (18.10.2023-28.10.2023)

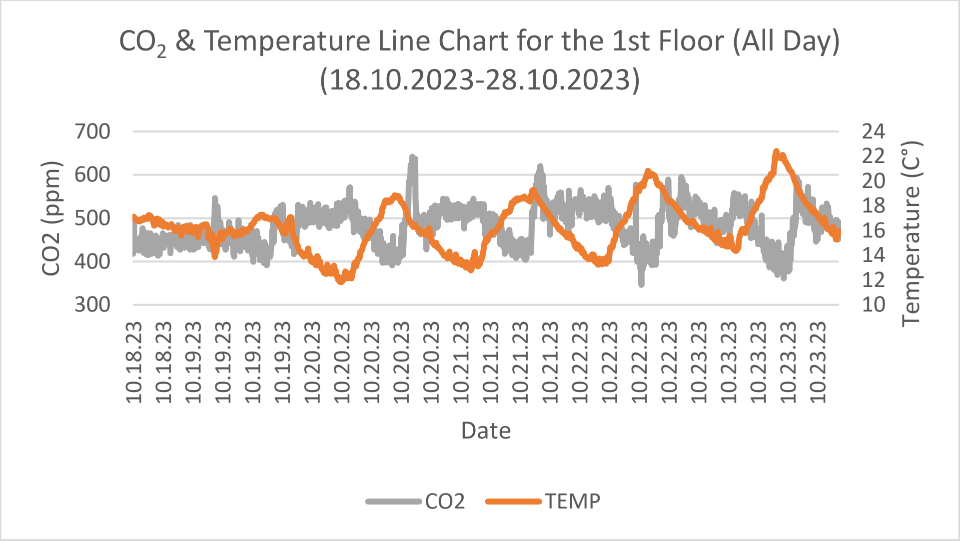


Figure 4.23 CO_2 & Temperature line chart for the 1st floor (All Day) (18.10.2023-28.10.2023)

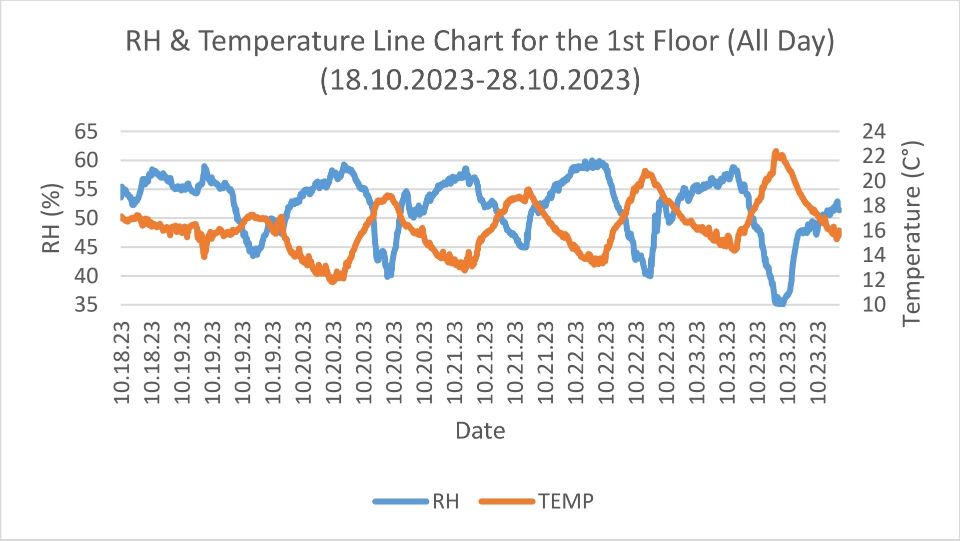


Figure 4.24 RH & Temperature line chart for the 1st floor (All Day) (18.10.2023-28.10.2023)

There is no point comparing CO_2 concentrations with vehicle entry-exit data on the 3rd or 4th floor since there were no cars there; only 1st and 2nd floors are used for car parking. Moreover, the number of vehicle entries and exits are a total value for the whole building from BELTAŞ (2023-2024), and the way of their distribution to the car parking floors is not known. Thus, the total vehicle entry-exit numbers for the

2nd floor are also not reliable for correlation chart with CO_2 concentrations. That is why data from the entry point of the building was investigated for the last three data logging sessions, and correlation charts for the 1st floor were demonstrated in this research that are more valid for establishing a relationship. Furthermore, the graphs were made for the durations of all day, between 07.00-23.00 as the working hours of the building's car parking floors, and between 07.00-19.00 as the peak hours of the carpark to demonstrate clear indications about the potential relationships between different data sets.

The data from October 2023 shows that correlation is not significant between the number of vehicle entries or exits and the CO_2 concentration recorded on each floor (Figure 4.25 and Figure 4.26). On the other hand, there is a quite strong relationship between CO_2 and RH as well as CO_2 and temperature, which shows a positive trend for RH and a negative trend for temperature (Figure 4.27 to 4.30). It is expected according to the literature because CO_2 concentration in ambient air has a positive correlation with relative humidity and a negative correlation with temperature (Liu et al., 2017) (Hamidu et al., 2022). In higher temperatures, CO_2 concentration in a unit volume decreases due to its physical aspects as a gas.

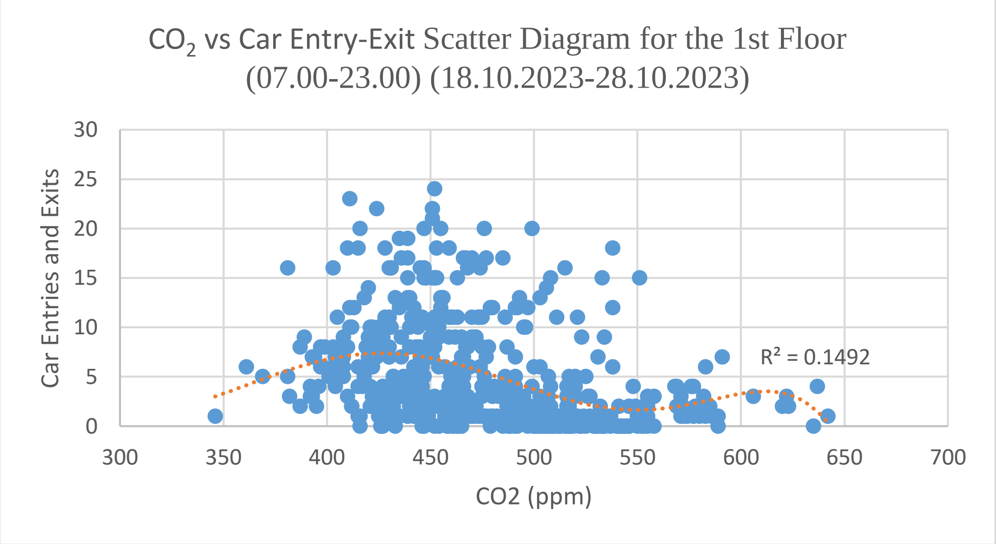


Figure 4.25 CO_2 vs Car Entry-Exit scatter diagram for the 1st floor (07.00-23.00) (18.10.2023-28.10.2023)

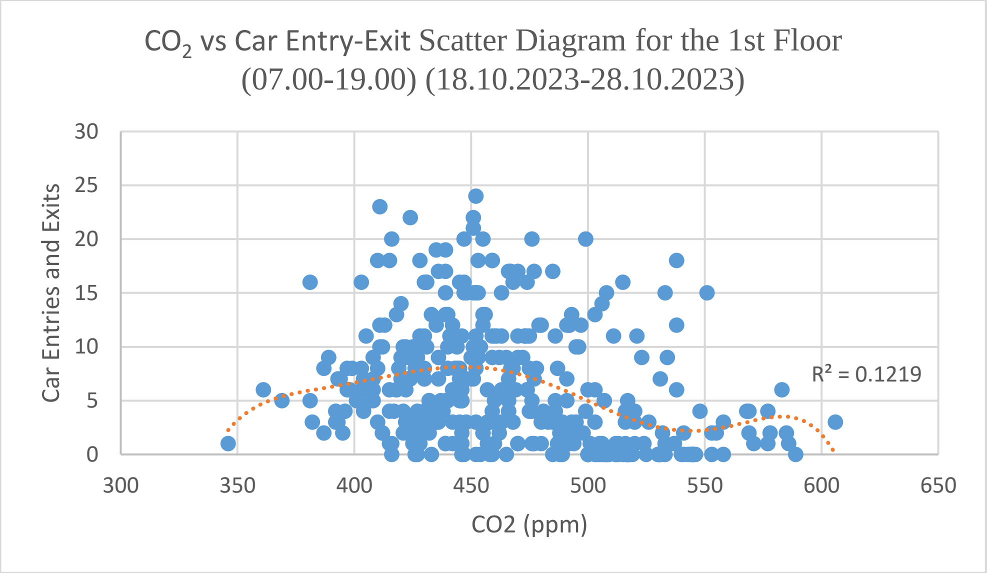


Figure 4.26 CO$_2$ vs Car Entry-Exit scatter diagram for the 1st floor (07.00-19.00) (18.10.2023-28.10.2023)

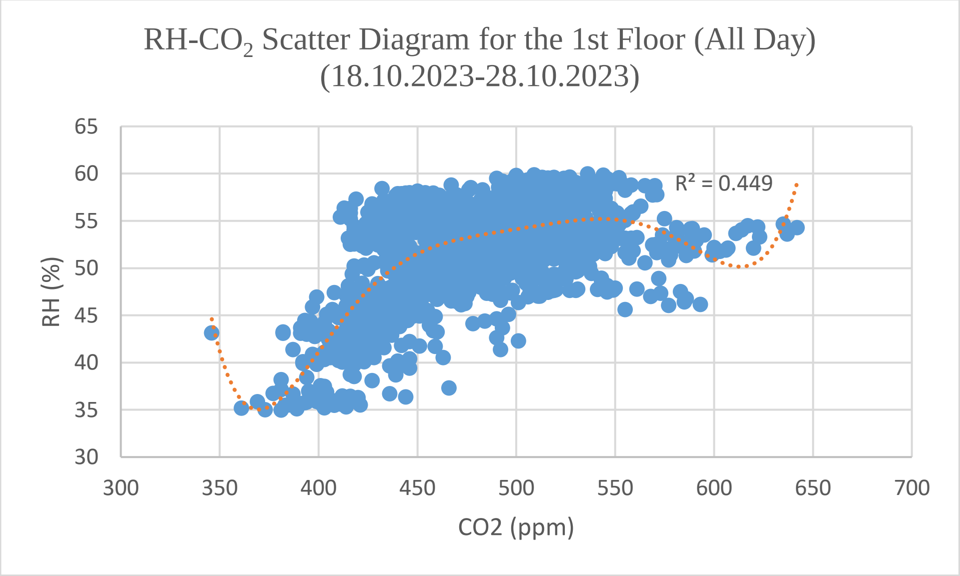


Figure 4.27 RH-CO$_2$ scatter diagram for the 1st floor (All Day) (18.10.2023-28.10.2023)

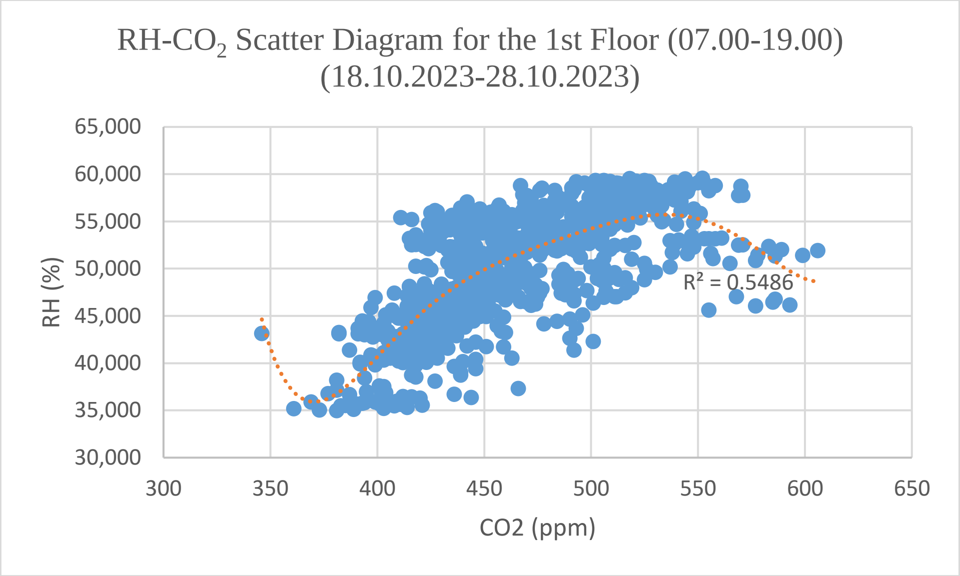


Figure 4.28 RH-CO$_2$ scatter diagram for the 1st floor (07.00-19.00) (18.10.2023-28.10.2023)

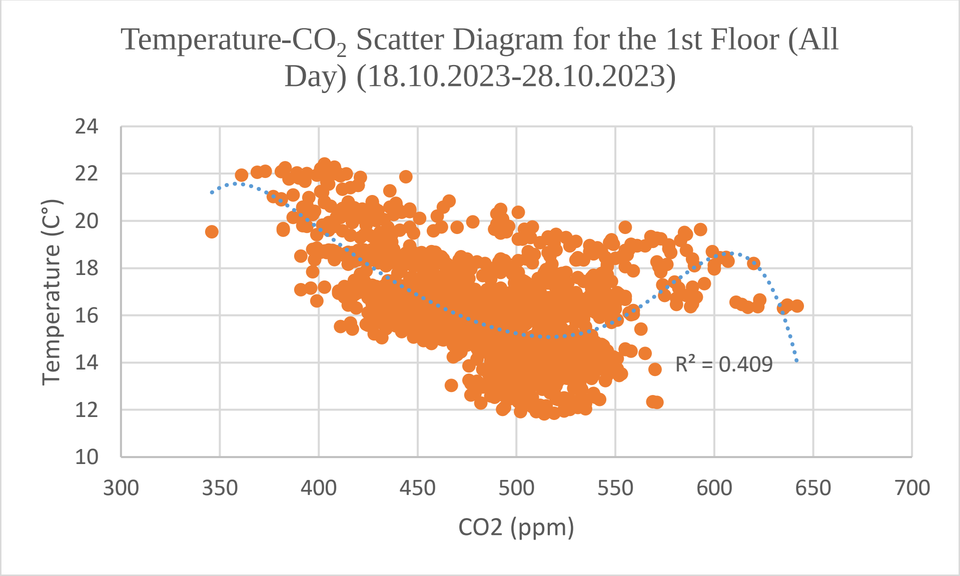


Figure 4.29 Temperature-CO$_2$ scatter diagram for the 1st floor (All Day) (18.10.2023-28.10.2023)

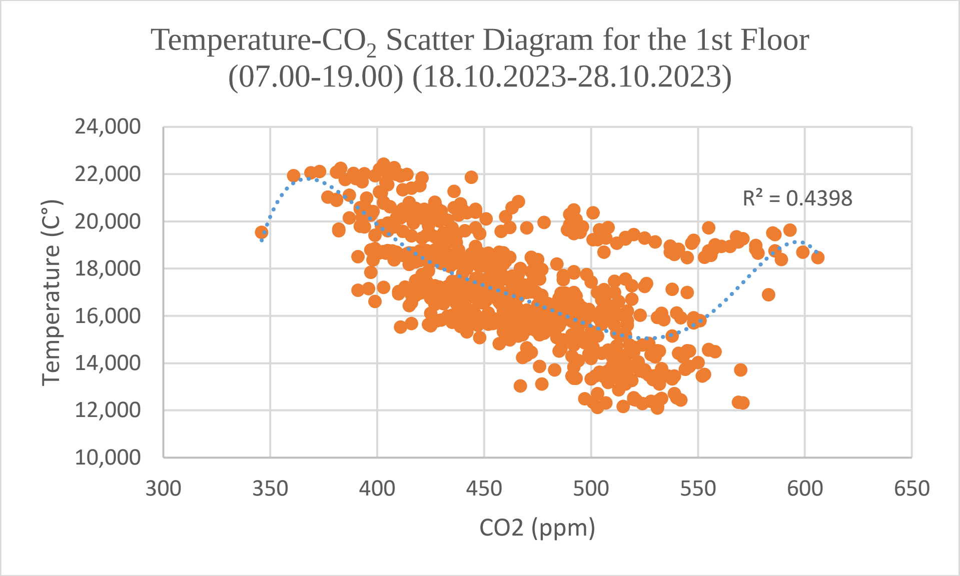


Figure 4.30 Temperature-CO_2 scatter diagram for the 1st floor (07.00-19.00) (18.10.2023-28.10.2023)

Those results indicate that the source of CO_2 may be the surrounding vehicular activity or the built environment more than the vehicles moving in the building; because Aksu Street in front of the building is a heavily used road, and as the temperatures dropped (and RH rose), heating was turned on in the neighborhood buildings causing an increase in the amount of CO_2 in the air by the exhausted heating system outputs. Since the amount of CO_2 was recorded as the highest on the 3rd floor whereas the 1st and 2nd floors were expected to have higher CO_2 concentrations, it can be claimed the increase of CO_2 at higher levels due to the chimneys and exhausted air of heating systems. As can be expected, the 4th floor has the lowest amounts of CO_2 due to the absence of vehicles and more natural ventilation without any obstructions.

Moreover, since the building is open from all sides of the car parking floors, the wind can be effective at dispelling the buildup of CO_2 in the building as a natural ventilation source. The lack of correlation between vehicular movement and CO_2 concentrations can be caused by the wind flow.

In order to see whether the vehicle entry and exit numbers made a difference or not, the minimum amount of CO_2 value was subtracted from the data for creating a threshold, and a scatter diagram was drawn but still no significant correlation could be found (Figure 4.31 and Figure 4.32).

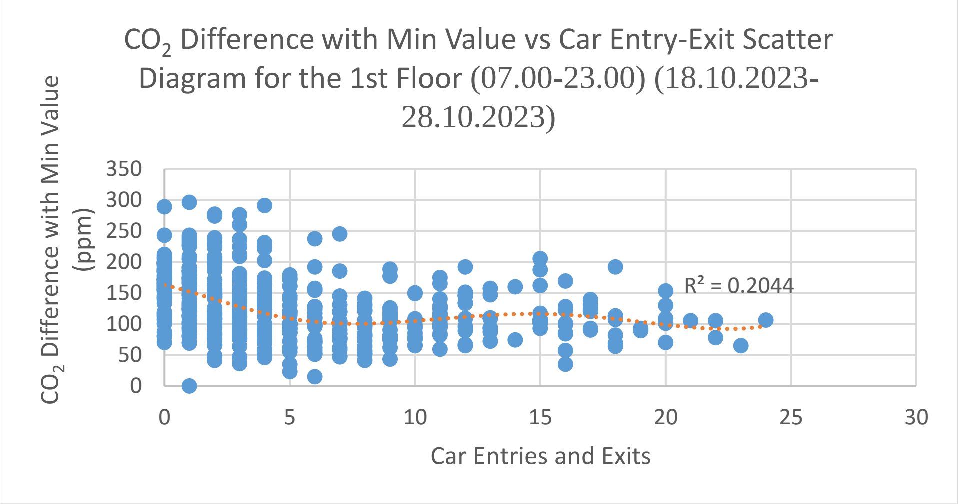


Figure 4.31 CO_2 difference with min value vs car entry-exit scatter diagram for the 1st floor (07.00-23.00) (18.10.2023-28.10.2023)

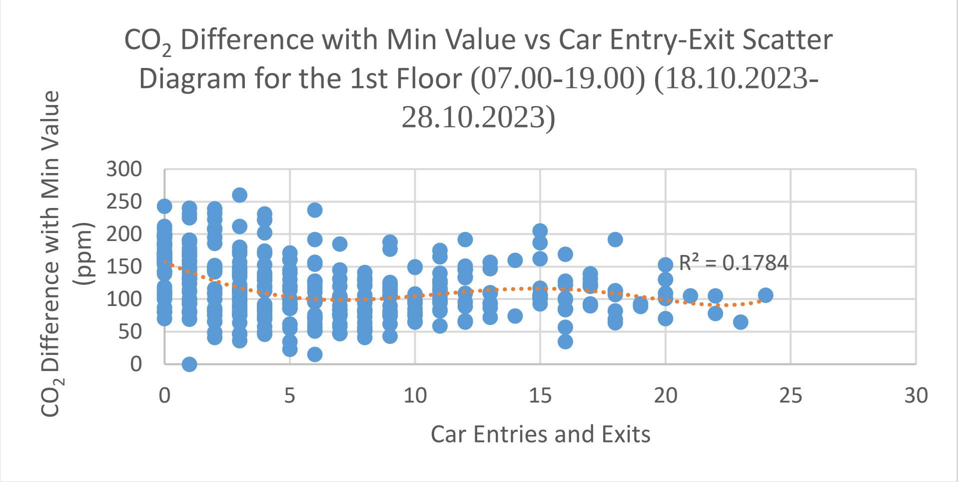


Figure 4.32 CO_2 difference with min value vs car entry-exit scatter diagram for the 1st floor (07.00-19.00) (18.10.2023-28.10.2023)

Second Deployment of Data Loggers

According to the combined data sets for the 4 floors in November, it was indicated that again the 4th floor has the least and 3rd floor has the highest amount of CO_2 (Figure 4.33). The correlation between CO_2 concentrations and RH is still considerable but lower than the first deployment results. Moreover, again there is no correlation between the number of cars and the CO_2 value.

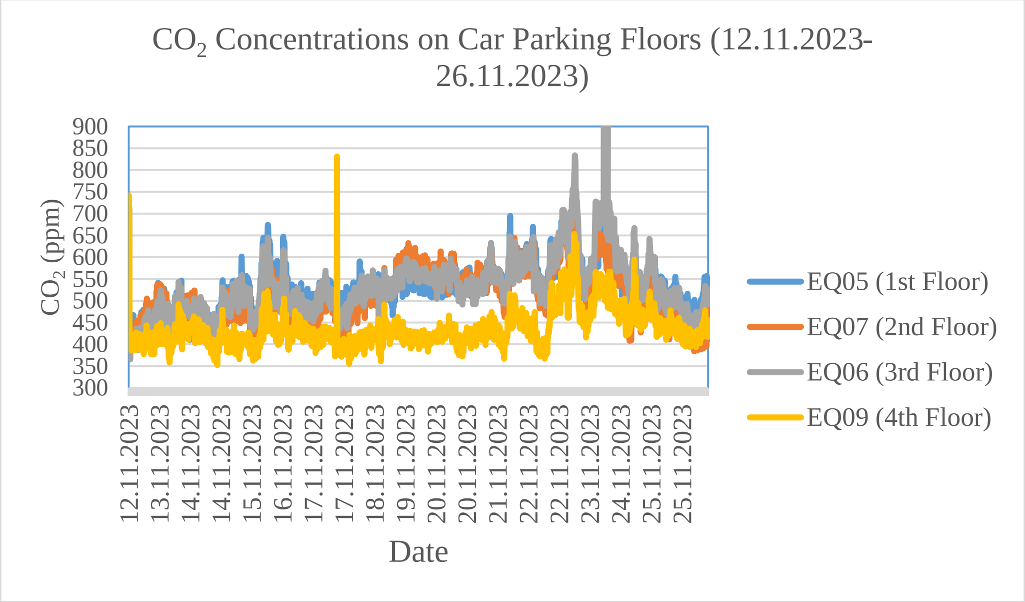


Figure 4.33 CO_2 concentrations on car parking floors (12.11.2023-26.11.2023)

Third Deployment of Data Loggers

For the third deployment, CO_2 levels were the lowest on the 1st and 4th floor at different times. The 2nd and 3rd floors had higher CO_2 concentrations; this may be caused by heating systems of surrounding buildings due to the cold weather of January (Figure 4.34). Moreover, since highest levels are recorded during the evening hours, when there are no car entries and exits, it can be assumed that the increased CO_2 levels occurred due to the environmental loads from the heating in the surrounding buildings as well as the CO_2 being released at night from the dense vegetation in Kurtuluş Park across the road and the Abdi İpekçi Park nearby. The correlation between RH and CO_2 values are also considerable in this data logging session (Figure 4.35).

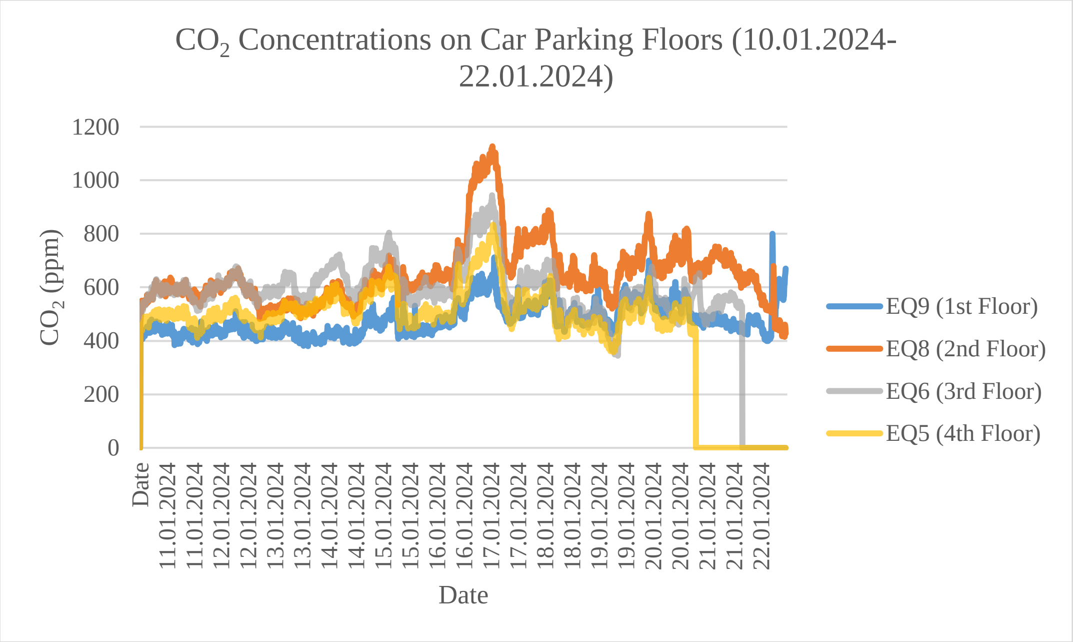


Figure 4.34 CO_2 concentrations on car parking floors (10.01.2024-22.01.2024)

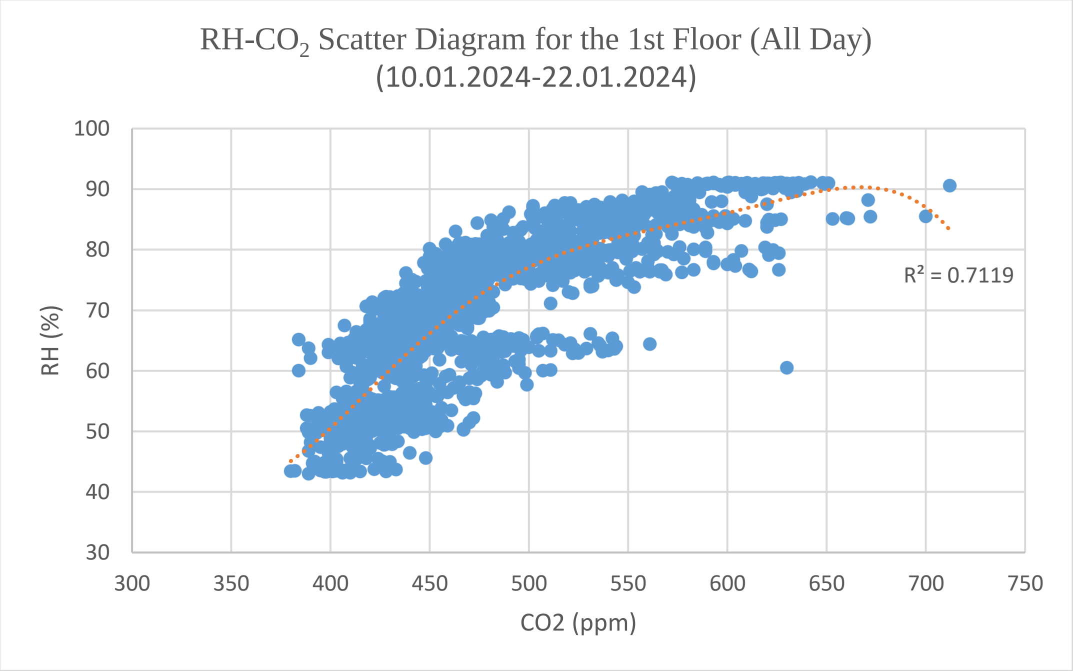


Figure 4.35 RH-CO_2 scatter diagram for the 1st floor (All Day) (10.01.2024-22.01.2024)

Fourth Deployment of Data Loggers

In the fourth deployment, EQ08 data logger on the 4th floor developed a fault and did not record any data. On the other hand, the combined data for the 3 other floors demonstrated the CO_2 levels as expected; they were highest on the 1st floor due to vehicle entries and lowest on the 3rd floor with no vehicular movement (Figure 4.36). Nevertheless, the relationship between the number of car entries and the CO_2 levels were not significant according to correlation tests (Appendices F). For this deployment in March, the weather became hotter, and there was no effect of heating system of surrounding buildings on CO_2 concentrations. Moreover, the logged CO_2 values are lower than the previous deployments because when the temperature is high or in warmer seasons, plants use more CO_2 for photosynthesis (EPA, 2024), and the correlation between CO_2 and temperature is negative.

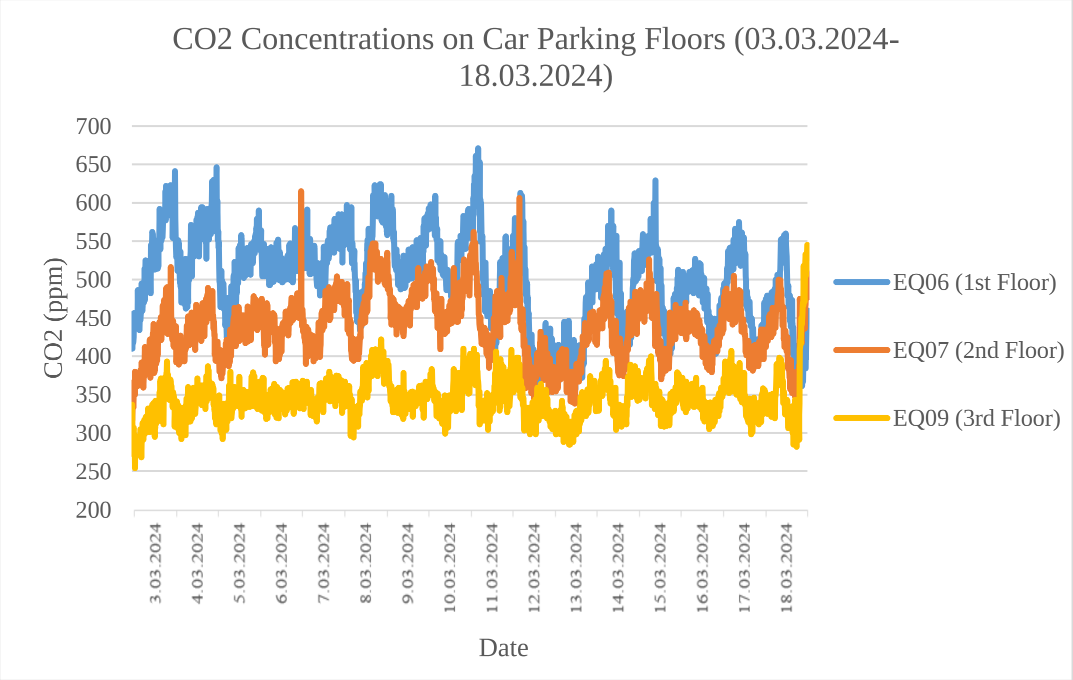


Figure 4.36 CO2 concentrations on car parking floors (03.03.2024-18.03.2024)

Fifth Deployment of Data Loggers

According to the combined dataset for the 3 floors in April and May as the latest deployment, it can be observed that the 2nd floor had lower CO_2 than the 1st floor as expected due to the car parking intensity on the 1st floor, but the highest levels were recorded on the 3rd floor (Figure 4.37). During this period too, there is no significant correlation between the number of car entries and the CO_2 changes (Table 4.10).

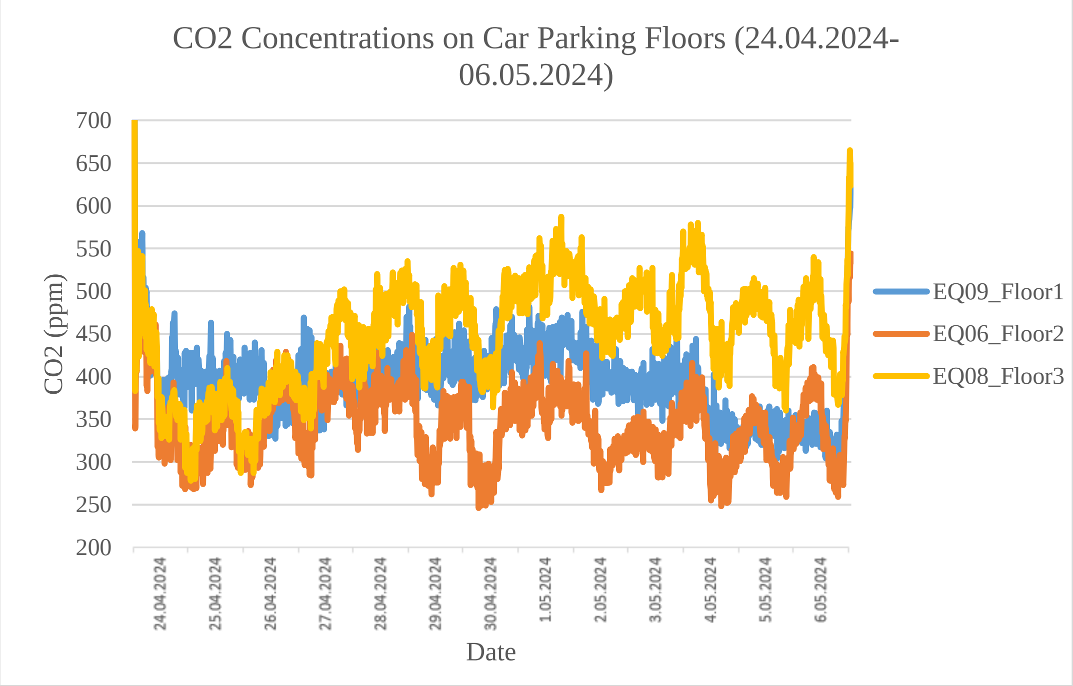
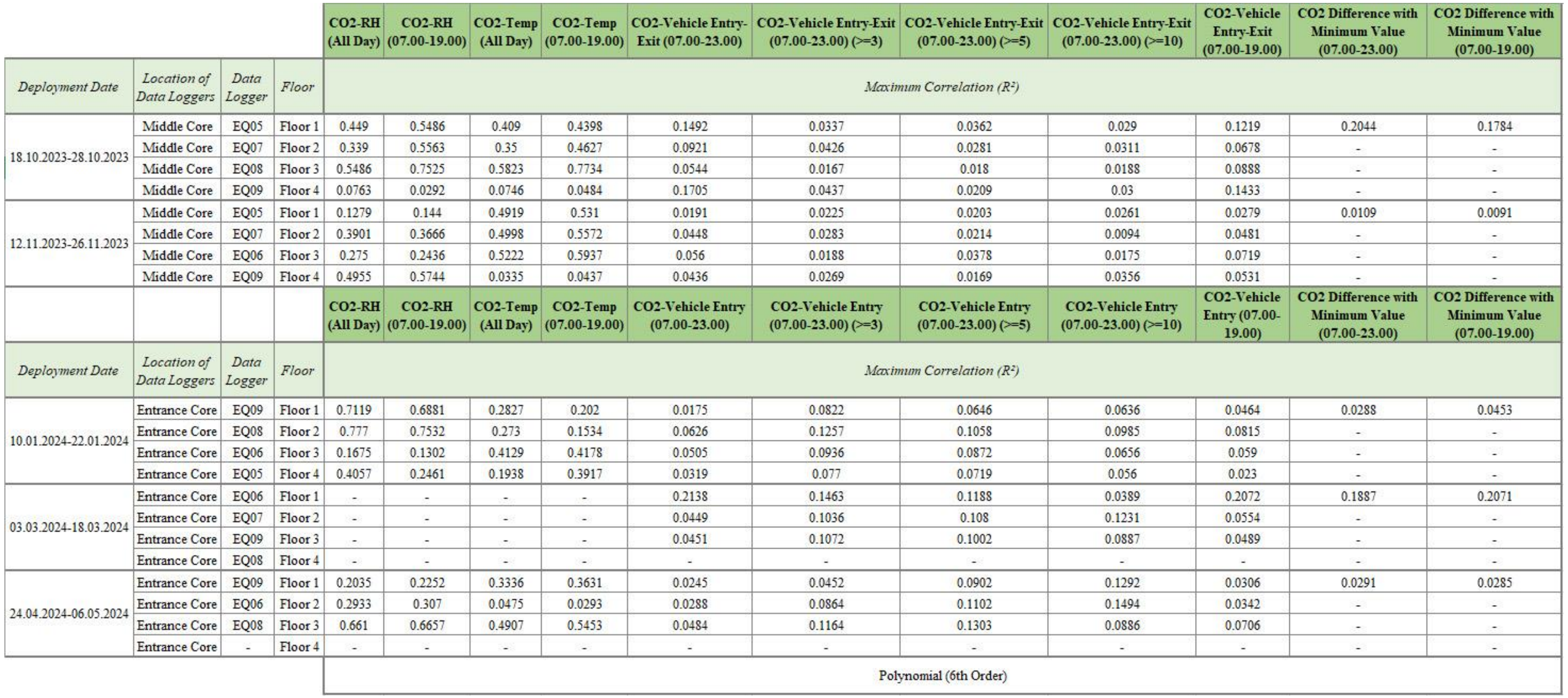


Figure 4.37 CO2 concentrations on car parking floors (24.04.2024-06.05.2024)

Table 4.10 CO2-RH, CO2-Temperature, and CO2-Vehicle Entry correlation values.



				CO2-RH (All Day)	**CO2-RH (07.00-19.00)**	**CO2-Temp (All Day)**	**CO2-Temp (07.00-19.00)**	**CO2-Vehicle Entry-Exit (07.00-23.00)**	**CO2-Vehicle Entry-Exit (07.00-23.00) (>=3)**	**CO2-Vehicle Entry-Exit (07.00-23.00) (>=5)**	**CO2-Vehicle Entry-Exit (07.00-23.00) (>=10)**	**CO2-Vehicle Entry-Exit (07.00-19.00)**	**CO2 Difference with Minimum Value (07.00-23.00)**	**CO2 Difference with Minimum Value (07.00-19.00)**
Deployment Date	*Location of Data Loggers*	*Data Logger*	*Floor*	*Maximum Correlation (R^2)*										
18.10.2023-28.10.2023	Middle Core	EQ05	Floor 1	0.449	0.5486	0.409	0.4398	0.1492	0.0337	0.0362	0.029	0.1219	0.2044	0.1784
	Middle Core	EQ07	Floor 2	0.339	0.5563	0.35	0.4627	0.0921	0.0426	0.0281	0.0311	0.0678	-	-
	Middle Core	EQ08	Floor 3	0.5486	0.7525	0.5823	0.7734	0.0544	0.0167	0.018	0.0188	0.0888	-	-
	Middle Core	EQ09	Floor 4	0.0763	0.0292	0.0746	0.0484	0.1705	0.0437	0.0209	0.03	0.1433	-	-
12.11.2023-26.11.2023	Middle Core	EQ05	Floor 1	0.1279	0.144	0.4919	0.531	0.0191	0.0225	0.0203	0.0261	0.0279	0.0109	0.0091
	Middle Core	EQ07	Floor 2	0.3901	0.3666	0.4998	0.5572	0.0448	0.0283	0.0214	0.0094	0.0481	-	-
	Middle Core	EQ06	Floor 3	0.275	0.2436	0.5222	0.5937	0.056	0.0188	0.0378	0.0175	0.0719	-	-
	Middle Core	EQ09	Floor 4	0.4955	0.5744	0.0335	0.0437	0.0436	0.0269	0.0169	0.0356	0.0531	-	-

				CO2-RH (All Day)	**CO2-RH (07.00-19.00)**	**CO2-Temp (All Day)**	**CO2-Temp (07.00-19.00)**	**CO2-Vehicle Entry (07.00-23.00)**	**CO2-Vehicle Entry (07.00-23.00) (>=3)**	**CO2-Vehicle Entry (07.00-23.00) (>=5)**	**CO2-Vehicle Entry (07.00-23.00) (>=10)**	**CO2-Vehicle Entry (07.00-19.00)**	**CO2 Difference with Minimum Value (07.00-23.00)**	**CO2 Difference with Minimum Value (07.00-19.00)**
Deployment Date	*Location of Data Loggers*	*Data Logger*	*Floor*	*Maximum Correlation (R^2)*										
10.01.2024-22.01.2024	Entrance Core	EQ09	Floor 1	0.7119	0.6881	0.2827	0.202	0.0175	0.0822	0.0646	0.0636	0.0464	0.0288	0.0453
	Entrance Core	EQ08	Floor 2	0.777	0.7532	0.273	0.1534	0.0626	0.1257	0.1058	0.0985	0.0815	-	-
	Entrance Core	EQ06	Floor 3	0.1675	0.1302	0.4129	0.4178	0.0505	0.0936	0.0872	0.0656	0.059	-	-
	Entrance Core	EQ05	Floor 4	0.4057	0.2461	0.1938	0.3917	0.0319	0.077	0.0719	0.056	0.023	-	-
03.03.2024-18.03.2024	Entrance Core	EQ06	Floor 1	-	-	-	-	0.2138	0.1463	0.1188	0.0389	0.2072	0.1887	0.2071
	Entrance Core	EQ07	Floor 2	-	-	-	-	0.0449	0.1036	0.108	0.1231	0.0554	-	-
	Entrance Core	EQ09	Floor 3	-	-	-	-	0.0451	0.1072	0.1002	0.0887	0.0489	-	-
	Entrance Core	EQ08	Floor 4	-	-	-	-	-	-	-	-	-	-	-
24.04.2024-06.05.2024	Entrance Core	EQ09	Floor 1	0.2035	0.2252	0.3336	0.3631	0.0245	0.0452	0.0902	0.1292	0.0306	0.0291	0.0285
	Entrance Core	EQ06	Floor 2	0.2933	0.307	0.0475	0.0293	0.0288	0.0864	0.1102	0.1494	0.0342	-	-
	Entrance Core	EQ08	Floor 3	0.661	0.6657	0.4907	0.5453	0.0484	0.1164	0.1303	0.0886	0.0706	-	-
	Entrance Core	-	Floor 4	-	-	-	-	-	-	-	-	-	-	-
				Polynomial (6th Order)										

Youth Academy Cafeteria Loggings

According to the data logging sessions and gathered data from Youth Academy Cafeteria measurements, the acceptable CO_2 range of 400-500 ppm for indoor conditions is exceeded (from Figure 4.38 to Figure 4.40). There is no air conditioning in the cafeteria section; instead, there are two stand-alone devices that are only available for heating and/or cooling the interior space. Only the entrance door, a side-entrance door, and a few operable windows provide natural ventilation when they are opened, while there is no cross ventilation. Especially on colder days, those doors are kept closed, and CO_2 ppm values exceed even the range of 1000-1200 ppm (Figure 4.38 and Figure 4.39; Table 4.11). Thus, using the emitted CO_2 by the occupants also helps to purify the indoor air and to increase indoor air quality for providing a healthy working environment for students.

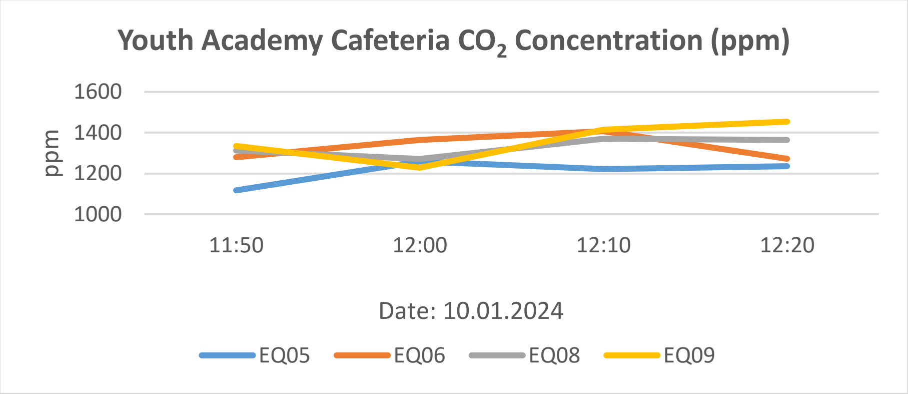


Figure 4.38 CO_2 concentration in Youth Academy Cafeteria. (10.01.2024)

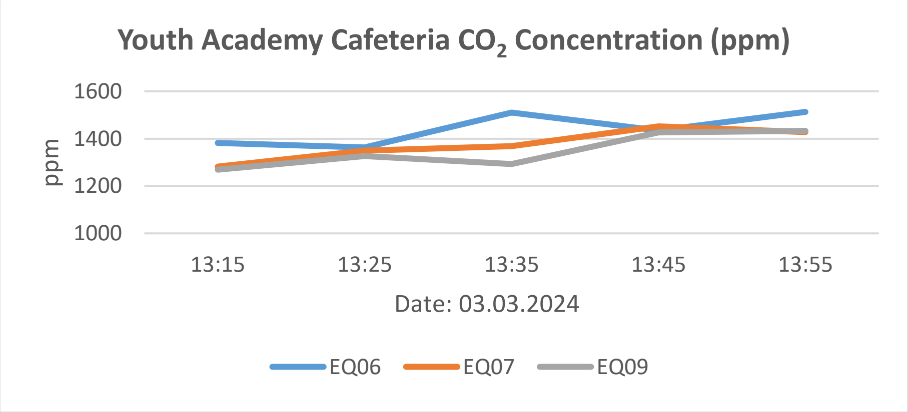


Figure 4.39 CO_2 concentration in Youth Academy Cafeteria. (03.03.2024)

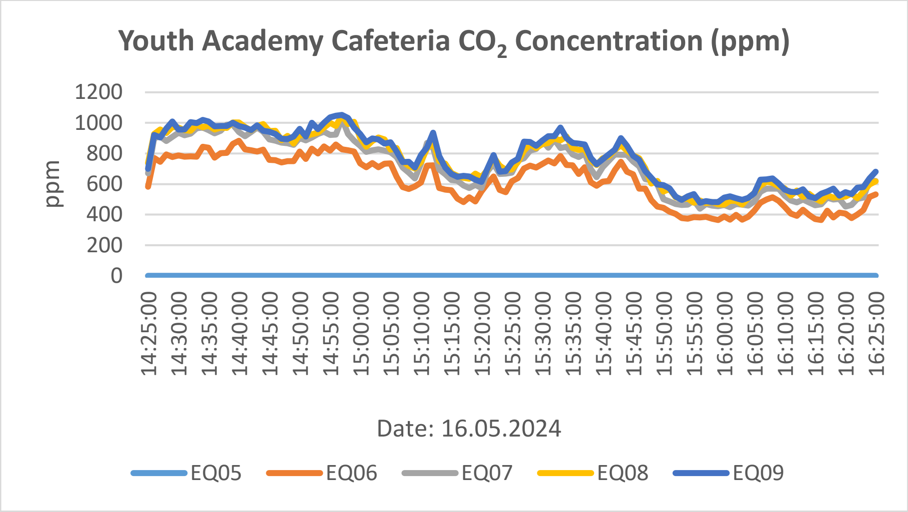


Figure 4.40 CO_2 concentration in Youth Academy Cafeteria. (16.05.2024)

Table 4.11 CO_2 concentration in Youth Academy Cafeteria. (2024)

Sıhhiye Multistorey Car Parking Building Youth Academy Cafeteria CO2 Concentration (ppm)			
Date of Data Logging	10.01.2024	3.03.2024	16.05.2024
Maximum CO2 (ppm)	1454	1513	1052
Minimum CO2 (ppm)	1117	1269	365
Average CO2 (ppm)	1306.5	1388.8	714.3

Brechner et al. (1996) claim that with adequate amount of lighting supply, 1500 ppm of CO_2 level is optimal for the growth of hydroponic lettuce; otherwise, ambient air with 400 ppm CO_2 level is proper for lettuce cultivation with daylight conditions. On the other hand, Wand et al. (2022) generalize the optimal value of CO_2 for crops between 700 and 1200 (Figure 4.41). The artificial lighting supply can increase the CO_2 absorption rate with increasing net photosynthesis rate (NPR) because as Shao et al. (2021) claim vertical farming vegetables can absorb up to 9.2 times higher CO_2 than vegetables in conventional fields due to the higher NPR. According to that information, the use of ambient air of Sıhhiye district is adequate for lettuce cultivation with daylight because the ambient air has 400-500 ppm CO_2 on average. However, there can be CO_2 support via carbon capturing to enhance the crop yields and air purification capacities of the crops.

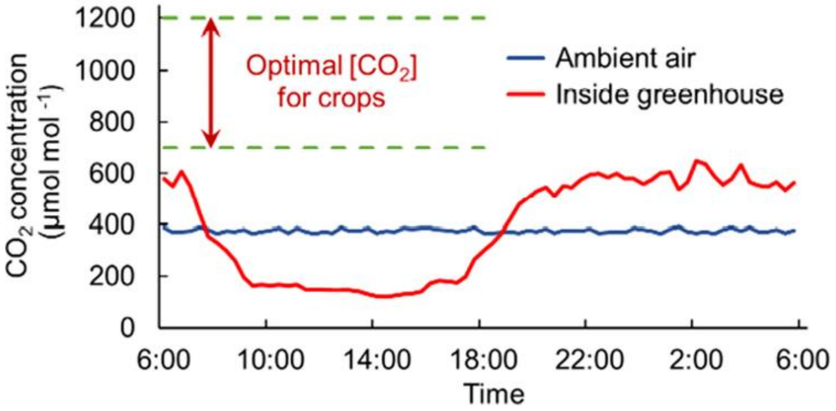


Figure 4.41 Schematic diagram of CO_2 concentration level of ambient air, greenhouse, and optimal crop growth scenario. (Wang et al., 2022)

Analysis of the Youth Academy Cafeteria and car parking floors of the structure shows that CO_2 from the occupants, from the cafeteria activities, from the car parking floors, and from the ambient air can be captured via carbon capture technology to reutilize in BIA units as fertilizers after a proper air filtration process (Figure 4.42).

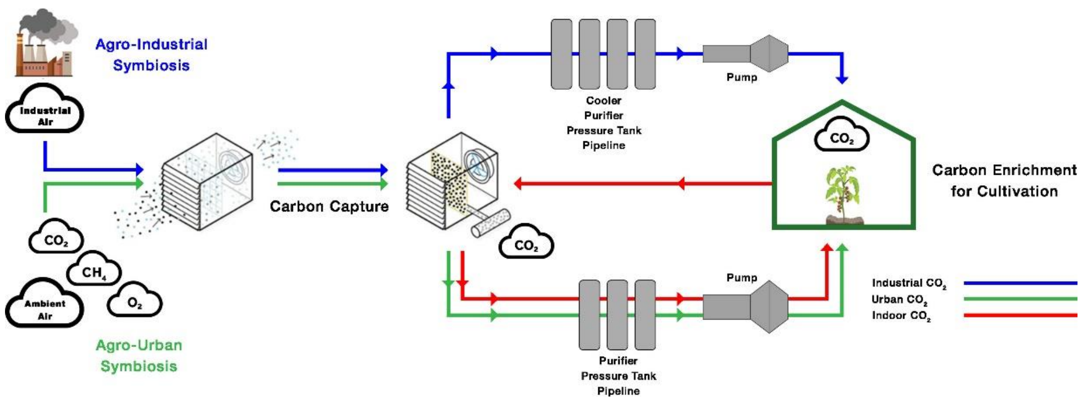


Figure 4.42 Carbon capture schematic diagram. (Redrawn by the author, based on information from Wang et al., 2022)

To calculate the potential air purification capacity of hydroponic lettuces and the BIA systems in Sıhhiye Multistorey Car Parking Building, the CO_2 absorption rate of a lettuce is taken as 20.22 µmole/m².s (20.22 µmole/m².s= 72,792 µmole/m².h = 1,747,008 µmole/m².d) (Zhou et al., 2020).

To simplify and understand the gathered data as ppm values of CO_2 and µmole values of CO_2, ppm can be turned into µmole. Ppm is often used to express the concentration of a gas in the air, specifically in terms of the number of molecules of that gas per million molecules of air. 1 ppm of CO_2 means 1 molecule of CO_2 per 1,000,000 molecules of air. For gases, it's often useful to consider a volume of 1 m^3 of air, which contains approximately 1,000,000 cm^3. According to the ideal gas law for context, at standard temperature and pressure (STP: 0°C and 1 atm), 1 mole of an ideal gas occupies 22.414 liters (or $22.414 \times 1{,}000\ cm^3 = 22{,}414\ cm^3$). Therefore, 1 m^3 (1,000,000 cm^3) of air at STP contains approximately $1{,}000{,}000\ cm^3 / 22{,}414\ cm^3 = 44.64$ moles of air. Therefore, 1 ppm of CO_2 corresponds to 44.64 moles of air / $1{,}000{,}000 = 4.464 \times 10^{-5}$ moles (44.64 µmole) of CO_2.

For the exhausted CO_2 from the occupants of the Youth Academy Cafeteria, its floor area is taken roughly as 800 m^2. Thus, the approximate volume of the cafeteria is 2,400 m^3 with 3 meters of ceiling height. With the measured indoor CO_2 concentration data, an approximate 800-1000 ppm CO_2 value can be considered for the interior, total µmole CO_2 in the cafeteria can be calculated as, from 85,708,800 to 107,136,000 µmole.

According to Zhou et al. (2020), hydroponic lettuces can purify 1,747,008 µmole/m^2.d of CO_2 which equals to 5,241,024 µmole/m^3.d due to the number of shelves for lettuces as 3 in 1 meter height with at least 30 cm between each shelve. For 2,250 m^2 food production floor area of BIA systems (without circulation and service areas), there is a volume of 4,500 m^3 at least with 6 shelves per m^2. Thus, the BIA systems in the scenario can purify the air with absorbing 23,584,608,000 µmole of CO_2 daily (23,584.608 mole) which value is higher than conventional field lettuce due to vertically stacked shelves and more CO_2 absorption rate due to higher NPR as Shao et al. (2021) claim. If the interior CO_2 concentration of Youth Academy Cafeteria is accepted as 1000 ppm in average (107,136,000 µmole), BIA systems in the scenario can decrease it easily to 400 ppm CO_2 as a healthy indoor condition while using the absorbed CO2 for food production.

Carbon (C) has a molar mass of approximately 12 g/mole, whereas oxygen (O) has approximately 16 g/mole. CO_2 has one carbon atom and two oxygen atoms; therefore, the weight of 1 mole of CO_2 in kilograms is 0.044 kg. According to the molar mass of CO2, BIA methods in Sıhhiye Multistorey Car Parking Building can absorb 1,037.72 kg of CO_2 per day which equals to 378,768.80 kg per year.

All calculations regarding food production capacity, food miles, energy production capacity, rainwater harvesting capacity, air purification with CO_2 capture capacity were made with the assumption of CEA use conditions in Sıhhiye Multistorey Car Parking Building. There can be issues to compromise for making those systems more "natural" and efficient in energy use such as the decrease of crop yields, less focus on the health of the food, use of natural ventilation, use of daylight to decrease the energy demand, no filtration of air and water.

At the end of analyses and results of the transformation project of Sıhhiye Multistorey Car Parking Building regarding food production, food miles, rainwater harvesting, renewable energy production, and CO_2 capture, a conceptual section design of the building is shaped that includes symbiosis strategies to provide circularity in the system (Figure 4.43). In the section, potential inputs and outputs of the BIA systems as the rooftop greenhouse and indoor farming units on the car parking floors are demonstrated. Moreover, local symbiotic potentials such as reutilizing İncesu Stream, using organic wastes of Yenişehir Bazaar area, rainwater harvesting, and CO_2 capture from both vehicles and occupants are shown to explain their relationship with the building.

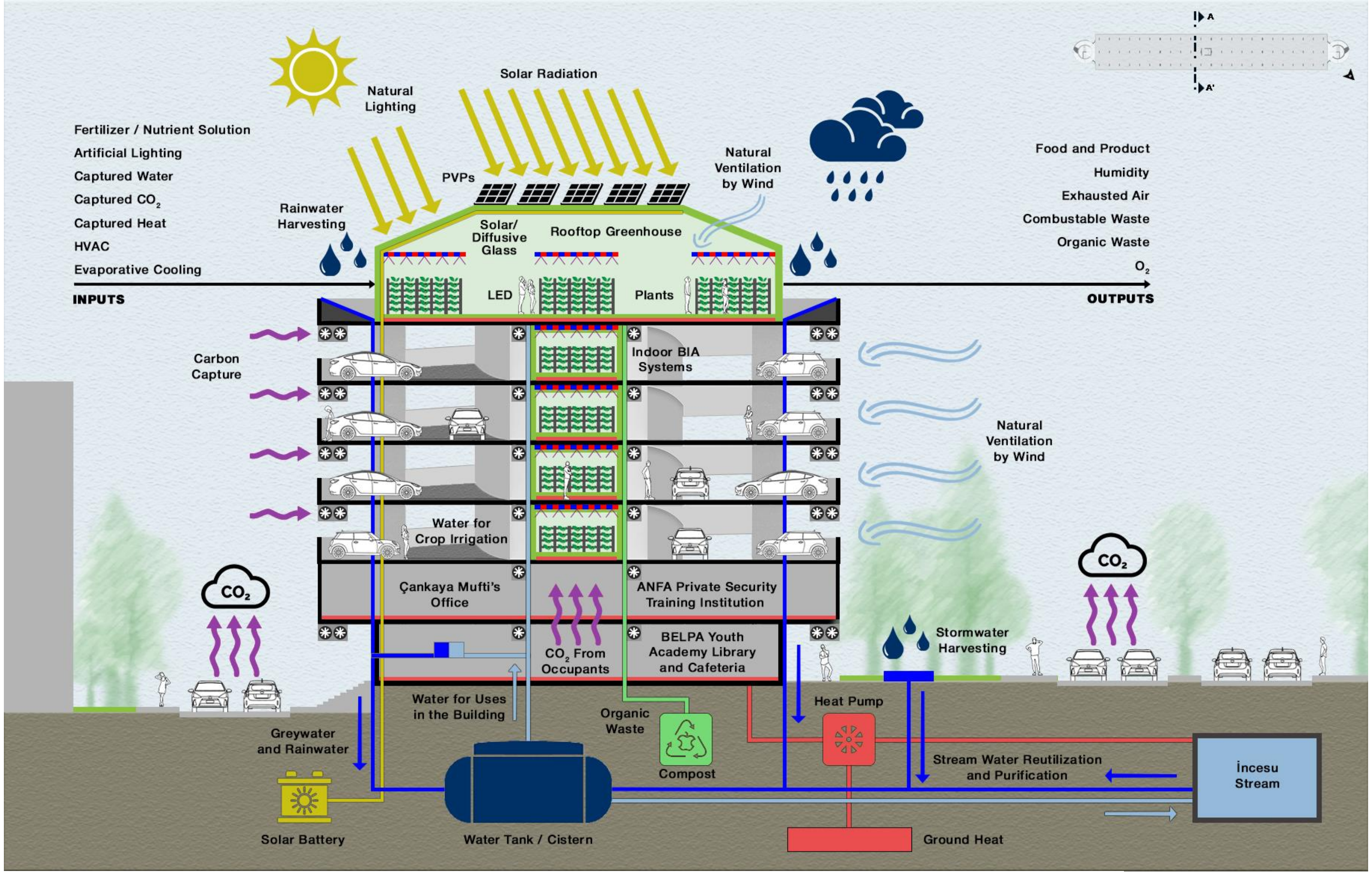


Figure 4.43 Section drawing of the proposed transformation project for BIA, using CEA system.

CHAPTER 5

CONCLUSION AND FUTURE REMARKS

Based on the research, urban agriculture (UA) and building-integrated agriculture (BIA) methods show significant potential but also have notable limitations. Compared to conventional agriculture, UA and BIA offer higher crop yields with reduced water, resource, and land use. They also prevent the clearing of green areas for new lands of agriculture and mitigate the absence of greenery in urban environments. Although most of the BIA methods have less total CO_2 emissions with reduced food miles, in some cases total CO_2 emissions of food production process with BIA can be higher compared to conventional agriculture examples due to reliance on energy for artificial lighting, automation, and climate control systems. To address this, advancements are needed in system efficiency, urban symbiosis options, and integration through architectural design strategies to reduce BIA's energy dependence and carbon footprint. Furthermore, there is still considerable room for BIA improvements regarding investment costs, operational costs, renewable energy integration, waste reuse, wastewater reuse, the efficiency of lighting, material choices of controlled environment agriculture equipment, suitable crop types, delivery systems, climate control systems, and CO_2 capture.

Current regulations for BIA systems and plant factories are primarily based on agricultural requirements; there is generally no consideration for human interaction with agricultural systems because most of them are commercial facilities. However, there is a need for specific standards for buildings incorporating BIA to foster a mutual relationship between agriculture and the built environment. Therefore, architects and designers should develop schemes for various building types, such as hotels, schools, and shopping malls, using appropriate active and passive design strategies to create a coherent urban agriculture architecture (UAA). Furthermore, BIA systems must be designed with potential symbiotic relationships in mind to mitigate the stress on the whole system by defining local self-sufficiency and closing the loops of production and consumption processes through circularity concepts.

For both enhancing BIA systems and creating UAA language, different BIA methods should be compared and investigated to understand their potential and limitations under the same conditions. Doing a meta-analysis can only show the main differences between them, and the numerical data about case studies from the literature and real-life examples differs considerably. More simulations should be done to understand the effects of BIA systems on daylight use efficiency, energy use efficiency, resource efficiency, building performance, occupants' health, and indoor air quality. Moreover, architectural active-passive design strategies, their effects on environmental loads of BIA, and their potentials and limitations should be simulated via related building performance simulation (BPS), building information modeling (BIM), and building integrated agriculture information modeling (BIAIM) tools with climatic data, the geometry of farm, lighting calculations, prevailing wind directions for ventilation, crop conditions and types, material choices of cover, data of energy sources, and water use calculations. Taking advantage of daylight, natural ventilation, and climate control via architectural design strategies (especially passive strategies to decrease the BIA system's demand for energy) can enhance the potential of BIA systems in the built environment. In addition to the simulations, there should be a comprehensive life cycle assessment (LCA) for the whole urban food production process and for different BIA methods.

The transformation project of Sıhhiye Multistorey Car Parking Building demonstrates that urban symbiosis options such as utilizing İncesu Stream, Yenişehir Bazaar, and local CO2 sources can be beneficial for creating a mutual relationship between BIA methods, buildings, and the built environment. In the case of CO_2 capture from the local traffic, vehicles that enter the structure, and the occupants to use it for cultivation and purify the local air, the multistorey carpark's feature as having openings on both sides of the car parking floors causes natural ventilation and the flow of wind through the structure which can clear the accumulated CO_2 in the structure. Thus, for similar future transformation of multistorey carparks can be done with a closed structural design and simulation of the design to understand the effects of vehicle entry-exit values on the usable CO_2 for carbon capture technologies. The interior heat can also be utilized for BIA systems with this closed design. Moreover, harvested rainwater, stormwater, greywater from the building, directed water from İncesu Stream, and organic wastes from Yenişehir Bazaar can also be used in the food production processes. Closing open loops of food production processes can be possible via those symbiotic options and circular design of those systems with BIA systems and their resource use efficiency potential.

According to the transformation scenario of Sıhhiye Multistorey Car Parking Building, there can be an annual lettuce production of 4,860,000 kg in total with BIA system use both on the rooftop and on the car parking floors. Thus, according to the calculations in the scenario, there is a need for 324 diesel trucks annually to deliver 4,860,000 kg.lettuce/year to Ankara which must travel 259,200 km, consume 77,760 liters of fuel, and emit 206,064 kg of CO_2.

For the most energy intensive part of BIA systems as artificial lighting, the daily energy need for the 13,500 m^2 BIA food production area is 843.2539 kWh for the lighting need period of 16 hours for hydroponic lettuce. Thus, the annual total energy requirement for the artificial lighting was calculated as 307,787.7009 kWh which corresponds to 64.2475% of the annual electricity production capacity of the building via PVs as 479,065 kWh. If 10 hours of daylight (10 hours of the required 16 hours lighting period between 08.00-18.00) is used for the rooftop greenhouse with the measured minimum of 1,000 lux, the energy demand can be decreased by 56,812.4798 kWh and 52.3885% of the PVs annual production becomes adequate to fulfill the demand, whereas the use of daylight with an average 8,000 lux for the rooftop greenhouse can further mitigate the requirement by 16,158.8543 kWh to meet the demand from 49.0155% of the annual PVs production. The building becomes self-sufficient with the proposed PVs and their electricity production in terms of artificial lighting demands of the BIA systems.

For the transformation project, the total rainwater harvesting capacity was calculated between 386,317.8 liters and 1,931,589 liters. With the need for irrigation water per kg lettuce as approximately 15 liters (Proksch, 2016) and the potential food production capacity as 4,860,000 kg.lettuce/year in the scenario, the irrigation water need can be calculated as 72,900,000 liters/year. The facility hosts considerable amounts of lettuce crops and cultivation beds for them. Thus, although the irrigation water need of the BIA is much less than conventional agriculture equivalent for annual lettuce production, rainwater harvesting capacity cannot be adequate by only itself to fulfill the demand of calculated irrigation water need. The amount of water from stormwater harvesting, utilizing greywater from the building, and utilizing İncesu Stream should be calculated properly to understand whether the transformation project is self-sufficient regarding water needs or not. Lastly, according to the calculations of carbon capture potential, BIA methods in Sıhhiye Multistorey Car Parking Building can absorb 3,113.17 kg of CO_2 per day which equals to 1,136,306.41 kg per year from surrounding ambient air, exhausted air from the vehicles in the building, and occupants of Youth Academy Cafeteria.

According to the transformation scenario, it can be observed that there are considerable benefits of BIA systems in an urban structure; on the other hand, the energy intensive food production process of BIA requires excessive amount of energy. At this point, architectural passive design strategies such as using blinds, kinetic facades, natural lighting, and natural ventilation can mitigate the demand for energy, while electricity production via PV panels can increase self-sufficiency of the transformation project. Moreover, there can be issues to compromise for making those BIA systems and food production processes more “natural” and efficient in terms of energy use such as the decrease of crop yields, less focus on the health of the food, no airtightness of the system, no total control on lighting, and no filtration of air and water. Static stability and load-bearing capacity of the host structure is also important to consider while designing BIA systems with PV panel load, equipment load, structural load of the rooftop greenhouse and indoor farming units, and plant load. In the transformation scenario, the structure is capable of bearing the loads of BIA systems.

For further research about the transformation of Sıhhiye Multistorey Car Parking Building, an urban scale simulation can be done with Rhino 8 integration, UMI (Urban Modelling Interface) plugin, which was developed by MIT Sustainable Design Lab, can be used to demonstrate urban scale potentials and limitations in terms of food production, CO_2 emission, water consumption, and electricity consumption values of the transformed Sıhhiye Multistorey Car Parking Building as a food production facility with other functions of it.

For future studies, concealed urban waterways can be detected to revitalize them and their surroundings via BIA methods such as streams of Ankara. Moreover, other urban vacant structures like car parking buildings, bazaar structures like Küçükesat District Market-Bazaar Building that is under renovation, factories like the demolished Maltepe Gas Factory, warehouses, etc. can be detected to be transformed into food production facilities as adaptive reuse of them instead of new construction for food production facilities or demolition of the vacant ones. With comprehensive urban planning and proper policies, there can be a holistic system of rooftop greenhouses, rooftop gardens, or other types of BIA from the transformed vacant urban areas. Meaningful outcomes and valuable changes such as decreasing heat island effects, reduction of air pollution, habitat creation for wildlife, and an adequate amount of food production to meet the demand of the increasing local population can be provided not by a single garden or greenhouse but with a complex urban system of green roofs as “roofscape” or other green urban surfaces.

Nowadays, BIA techniques and technologies can be considered strong candidates for being remedies for significant global problems of both agriculture and construction sectors; however, it should not be forgotten that BIA or any other concept cannot be a “panacea” on its own, as Kalantari et al. (2017) claim. Although UA and BIA methods cannot replace conventional agricultural methods and solve all food security problems as Kozai et al. (2019) also state, they can aim to mitigate the load and stress on agricultural fields to rehabilitate them and can provide time to nature for self-recovery.

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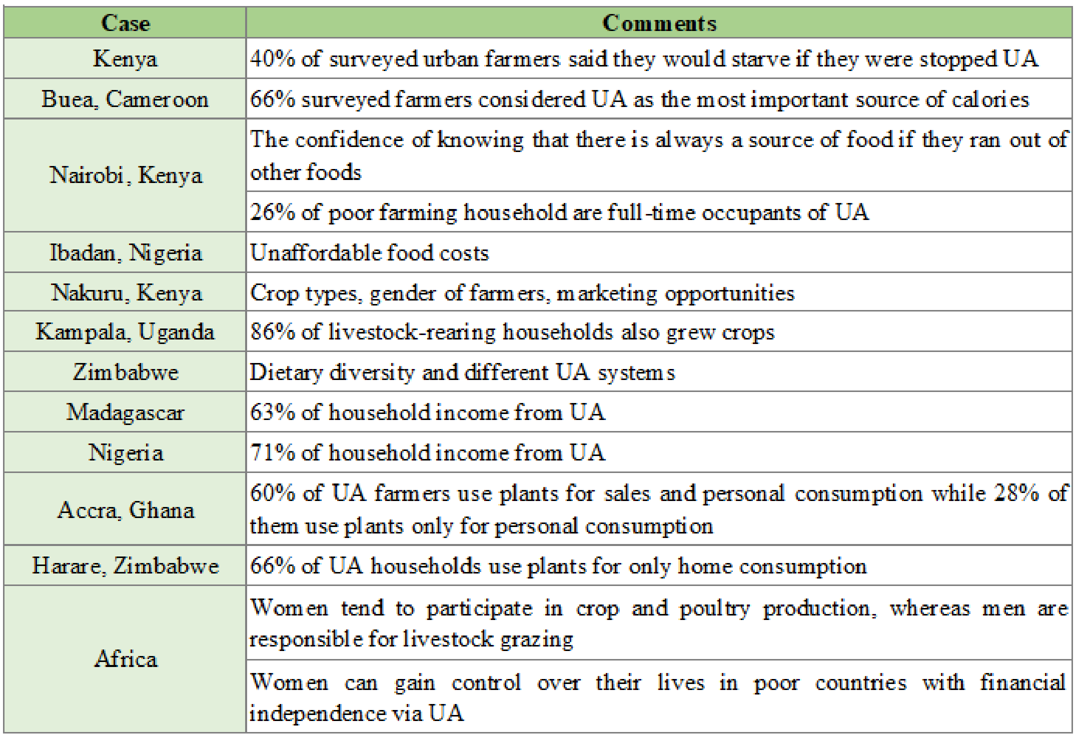
APPENDICES

A. Urban Agriculture Survey for Different African Countries

Table A.1 Survey and analysis results about urban agriculture (UA) in different African countries. (adapted from Poulsen et al., 2015)



Case	Comments
Kenya	40% of surveyed urban farmers said they would starve if they were stopped UA
Buea, Cameroon	66% surveyed farmers considered UA as the most important source of calories
Nairobi, Kenya	The confidence of knowing that there is always a source of food if they ran out of other foods
	26% of poor farming household are full-time occupants of UA
Ibadan, Nigeria	Unaffordable food costs
Nakuru, Kenya	Crop types, gender of farmers, marketing opportunities
Kampala, Uganda	86% of livestock-rearing households also grew crops
Zimbabwe	Dietary diversity and different UA systems
Madagascar	63% of household income from UA
Nigeria	71% of household income from UA
Accra, Ghana	60% of UA farmers use plants for sales and personal consumption while 28% of them use plants only for personal consumption
Harare, Zimbabwe	66% of UA households use plants for only home consumption
Africa	Women tend to participate in crop and poultry production, whereas men are responsible for livestock grazing
	Women can gain control over their lives in poor countries with financial independence via UA

B. Ankara Metropolitan University Archive Documents and Photographs of Sıhhiye Multistorey Car Parking Building

Figure B.1 Sıhhiye Multistorey Car Parking Building from Ankara Metropolitan Municipality archives.

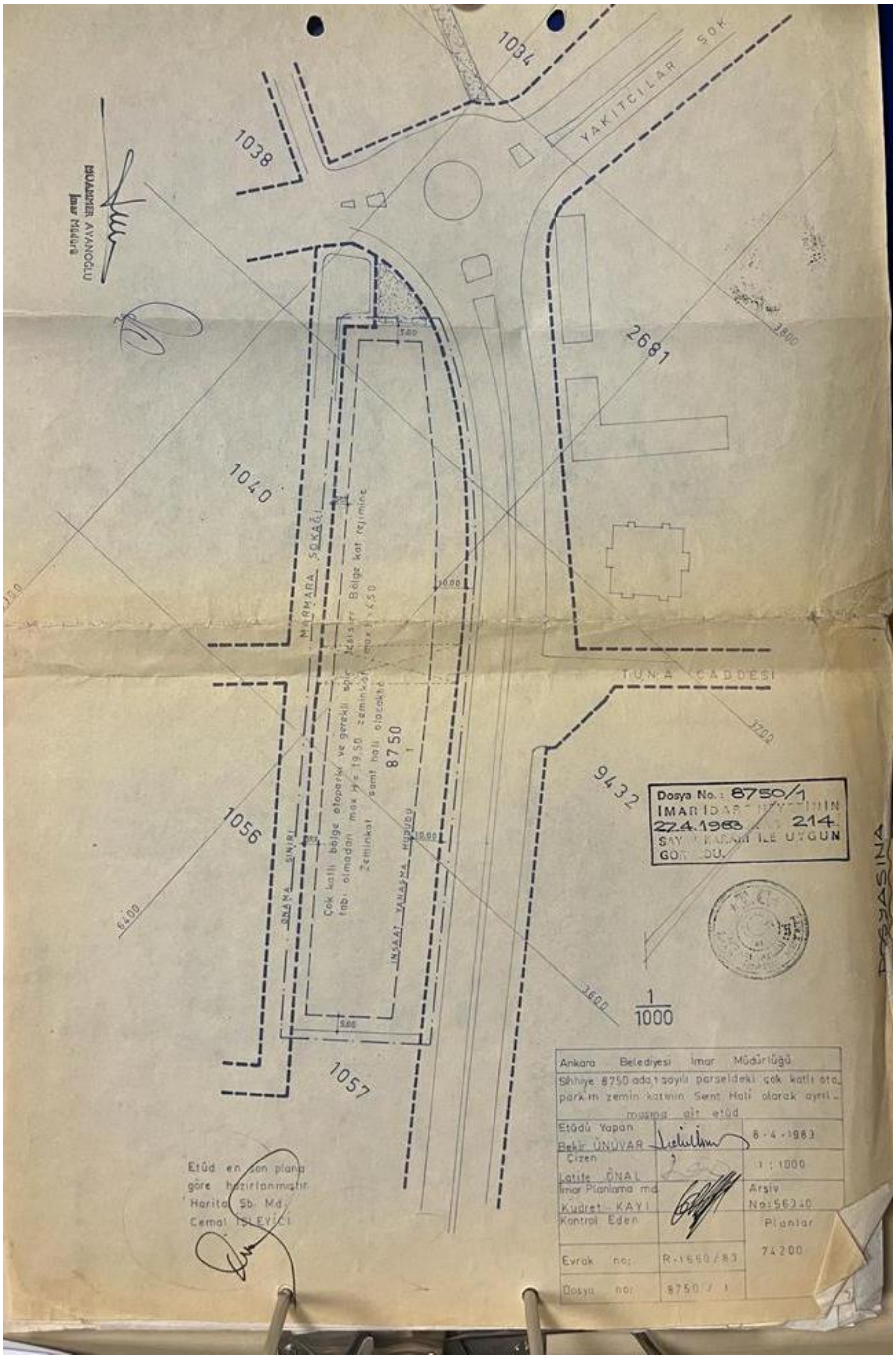


Figure B.2 Lot of Sıhhiye Multistorey Car Parking Building in 1983 from Ankara Metropolitan Municipality archives.

C. Open-air Car Parking Area Near TED University

Figure C.1 Car parking area near TED University.

D. Bibliometric Analysis Tables and VOSviewer Diagrams

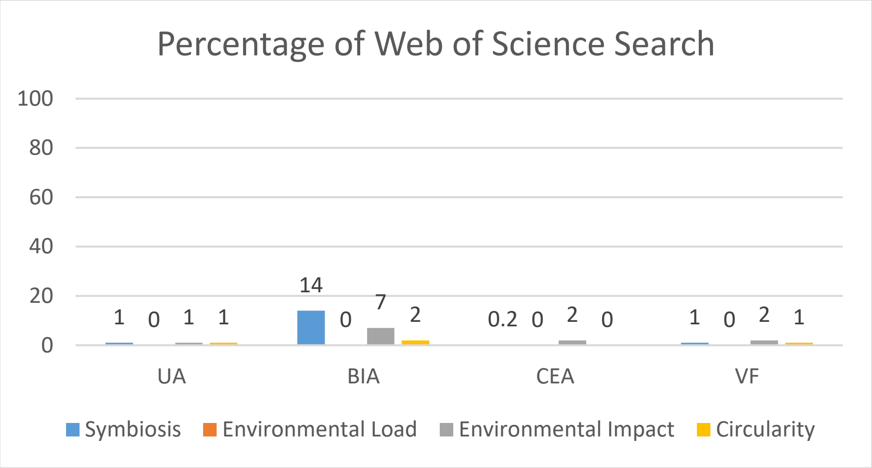


Figure D.1 Percentage of Web of Science search intersections for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF) with symbiosis, environmental load, environmental impact, and circularity.

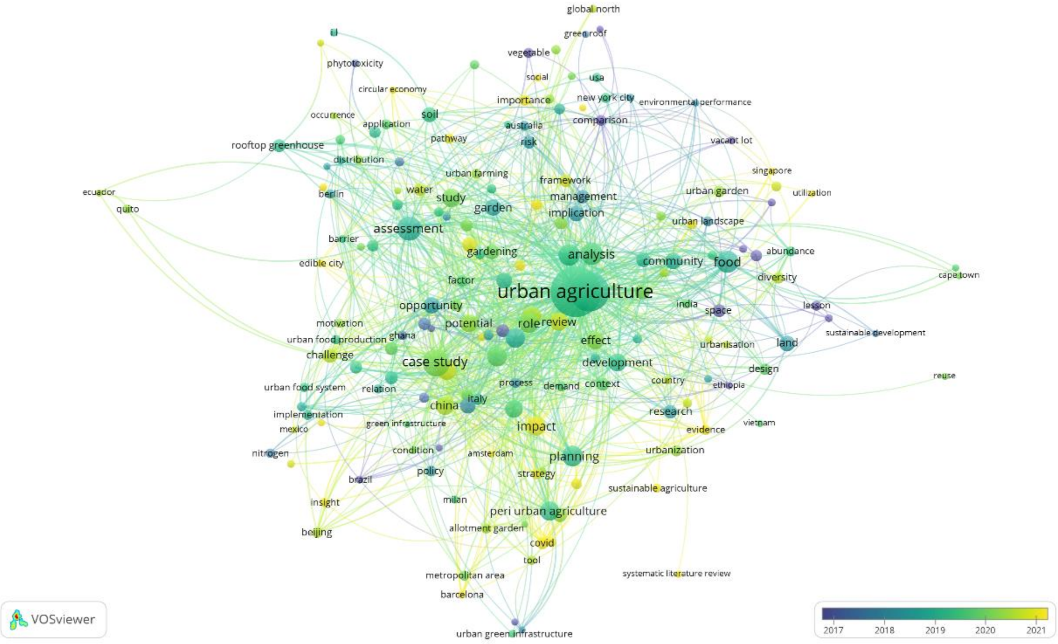


Figure D.2 VOSviewer relation and cooccurrence diagram of keyword search for urban agriculture (UA) in Web of Science.

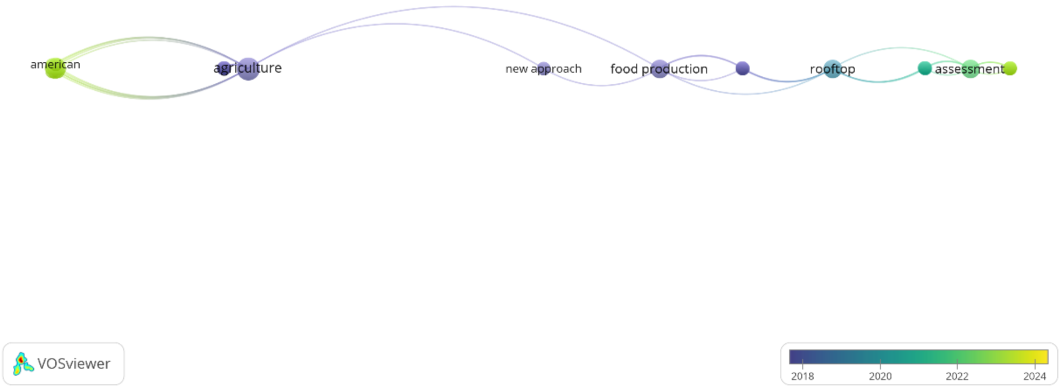


Figure D.3 VOSviewer relation and cooccurrence diagram of keyword search for building-integrated agriculture (BIA) in Web of Science.

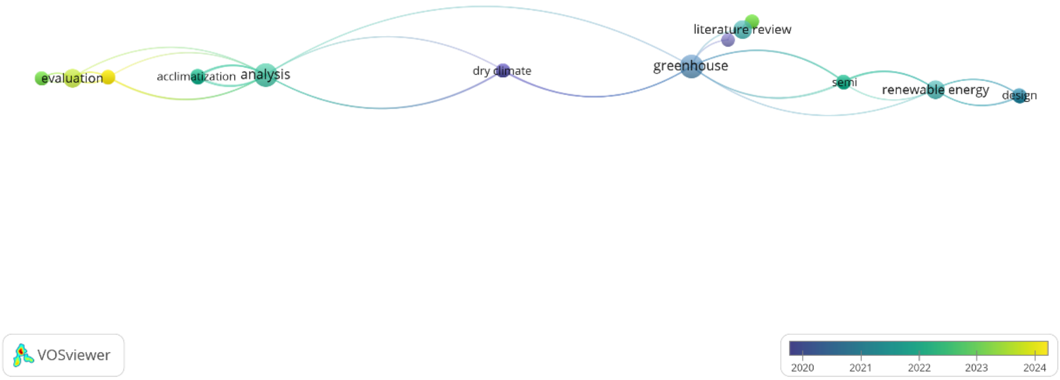


Figure D.4 VOSviewer relation and cooccurrence diagram of keyword search for controlled environment agriculture (CEA) in Web of Science.

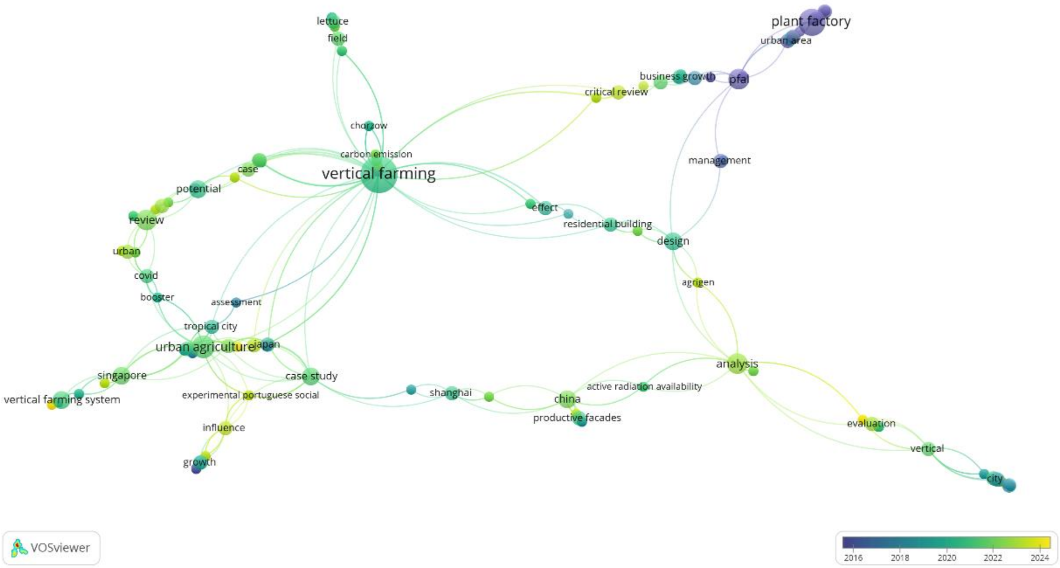


Figure D.5 VOSviewer relation and cooccurrence diagram of keyword search for vertical farming (VF) in Web of Science.

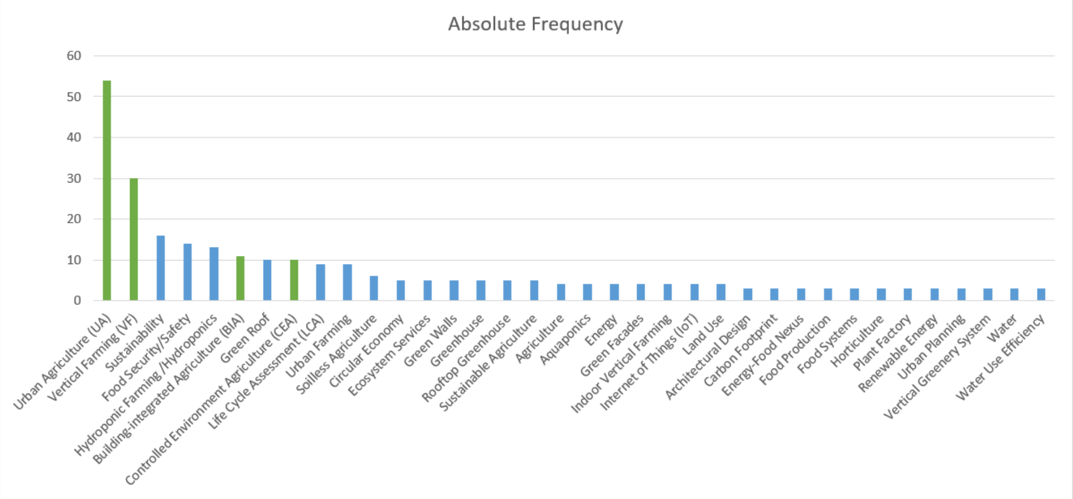


Figure D.6 Absolute frequency of key words in the selected papers. (by the Author, 2024)

Table D.1 Scopus search for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF). (by the Author, 2023)

SCOPUS	**UA**	**BIA**	**CEA**	**VF**
First Search	4749	48	605	770
Date (2000-2024)	4636	48	570	769
Data Paper, Conference Paper, Conference Review, Article, Review, Book Chapter	4515	48	558	742
English and Turkish	4238	47	557	734
Relevant Subject Areas	2650	38	224	392
Relevant Key Words	1807	**36**	178	239

Table D.2 Scopus search for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF) with symbiosis, environmental load, environmental impact, and circularity. (by the Author, 2023)

SCOPUS	**UA**	**BIA**	**CEA**	**VF**
Symbiosis	36	**4**	**4**	**5**
Environmental Load	**2**	**0**	**0**	**0**
Environmental Impact	188	11	31	36
Circularity	26	**1**	**2**	**8**

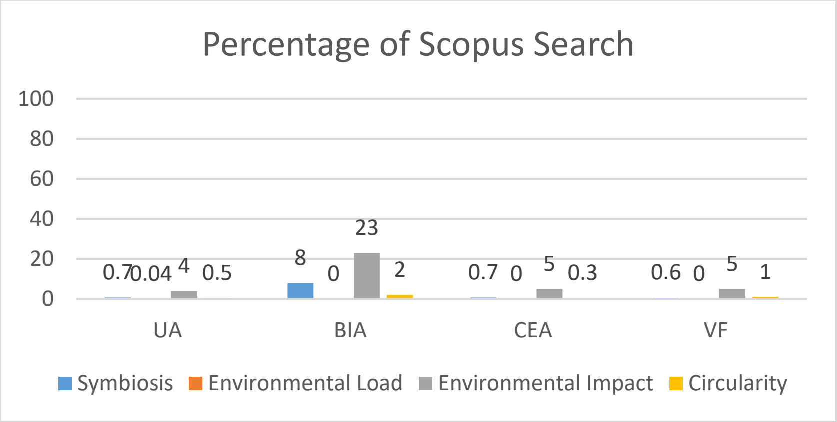


Figure D.7 Percentage of scopus search intersections for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF) with symbiosis, environmental load, environmental impact, and circularity. (by the Author, 2023)

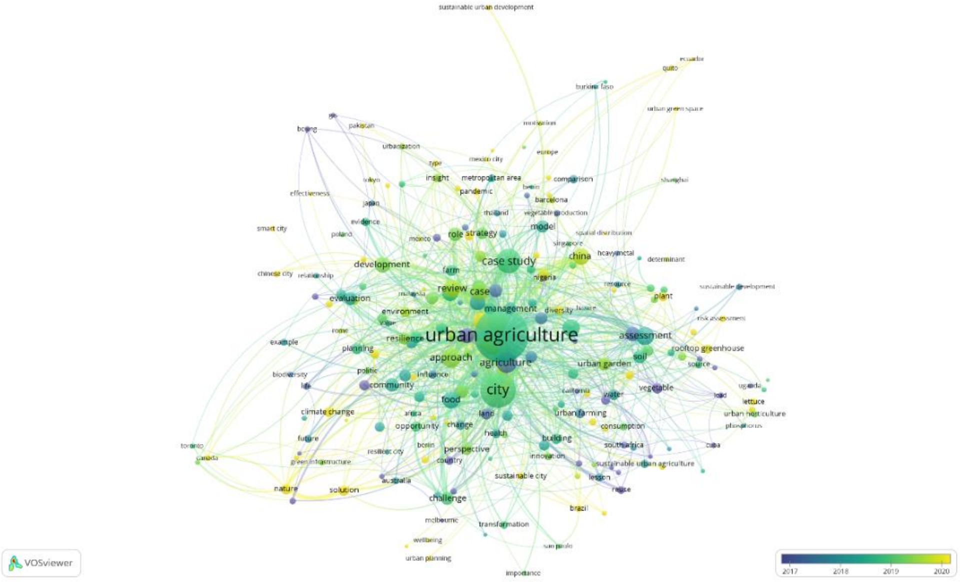


Figure D.8 VOSviewer relation and cooccurence diagram of keyword search for urban agriculture (UA) in Scopus. (by the Author, 2023)

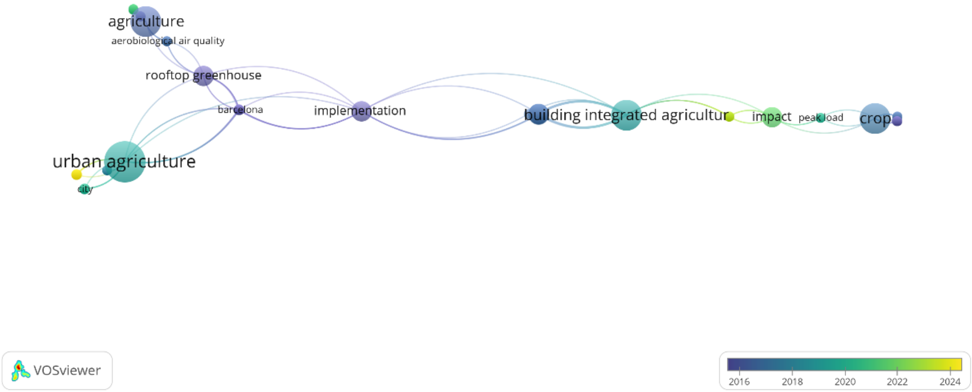


Figure D.93 VOSviewer relation and cooccurence diagram of keyword search for building-integrated agriculture (BIA) in Scopus. (by the Author, 2023)

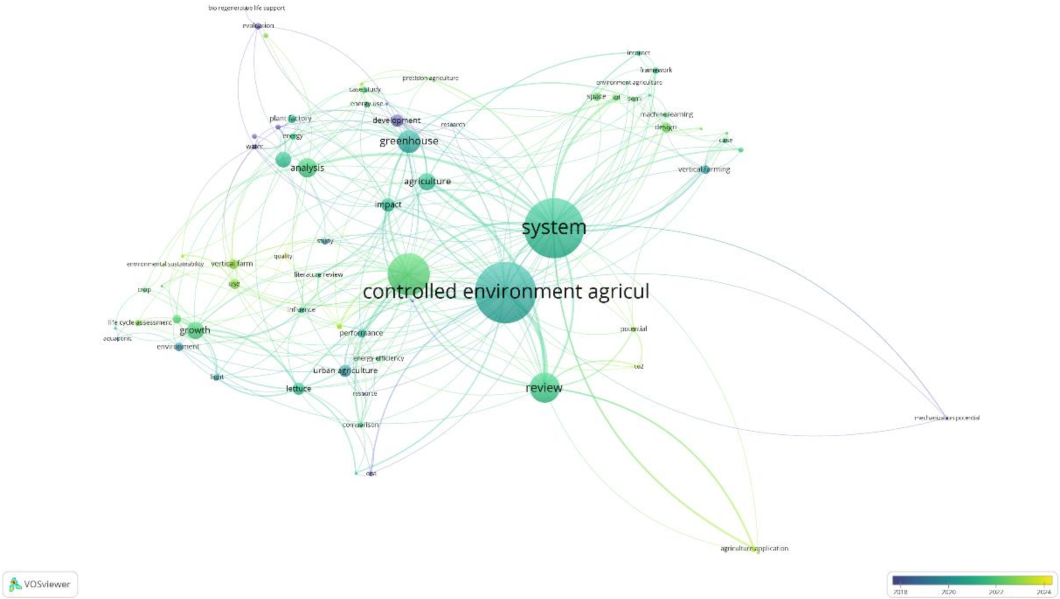


Figure D.10 VOSviewer relation and cooccurence diagram of keyword search for controlled environment agriculture (CEA) in Scopus. (by the Author, 2023)

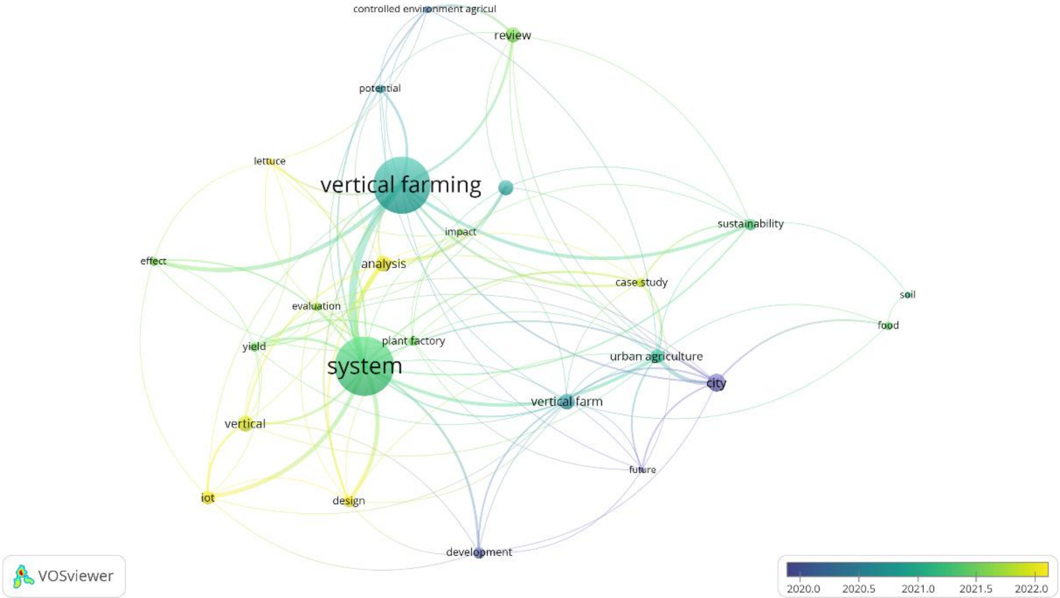


Figure D.11 VOSviewer relation and cooccurence diagram of keyword search for vertical farming (VF) in Scopus. (by the Author, 2023)

Table D.3 Google Scholar search for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF). (by the Author, 2023)

Google Scholar	**UA**	**BIA**	**CEA**	**VF**
First Search	156000	**1040**	7960	15200
Date (2000-2024)	68900	1020	7290	14300
Examine According to Articles	5530	154	716	1340

Table D.4 Google Scholar search for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF) with symbiosis, environmental load, environmental impact, and circularity. (by the Author, 2023)

Google Scholar	**UA**	**BIA**	**CEA**	**VF**
Symbiosis	3120	**150**	320	705
Environmental Load	273	**10**	**36**	**45**
Environmental Impact	15800	363	1360	3120
Circularity	1770	**78**	205	566

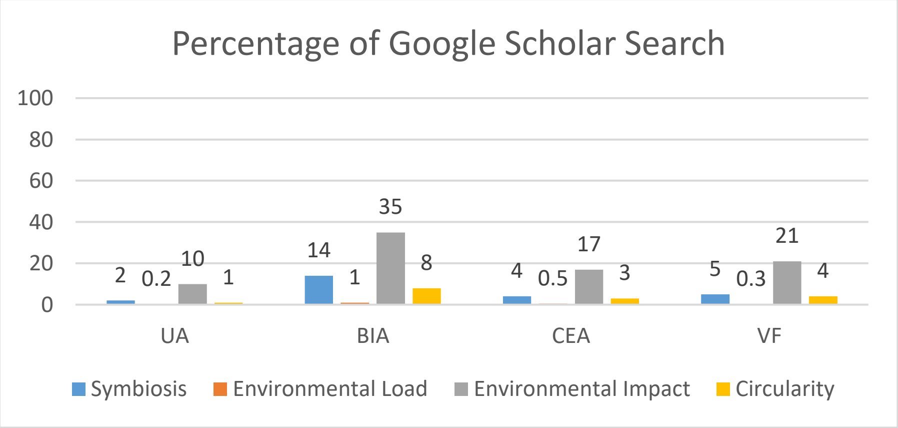


Figure D.12 Percentage of Google Scholar search intersections for urban agriculture (UA), building-integrated agriculture (BIA), controlled environment agriculture (CEA), and vertical farming (VF) with symbiosis, environmental load, environmental impact, and circularity. (by the Author, 2023)

E. Climate Consultant 6.0 Software Visuals for Climatic Conditions of the Transformation Project Area

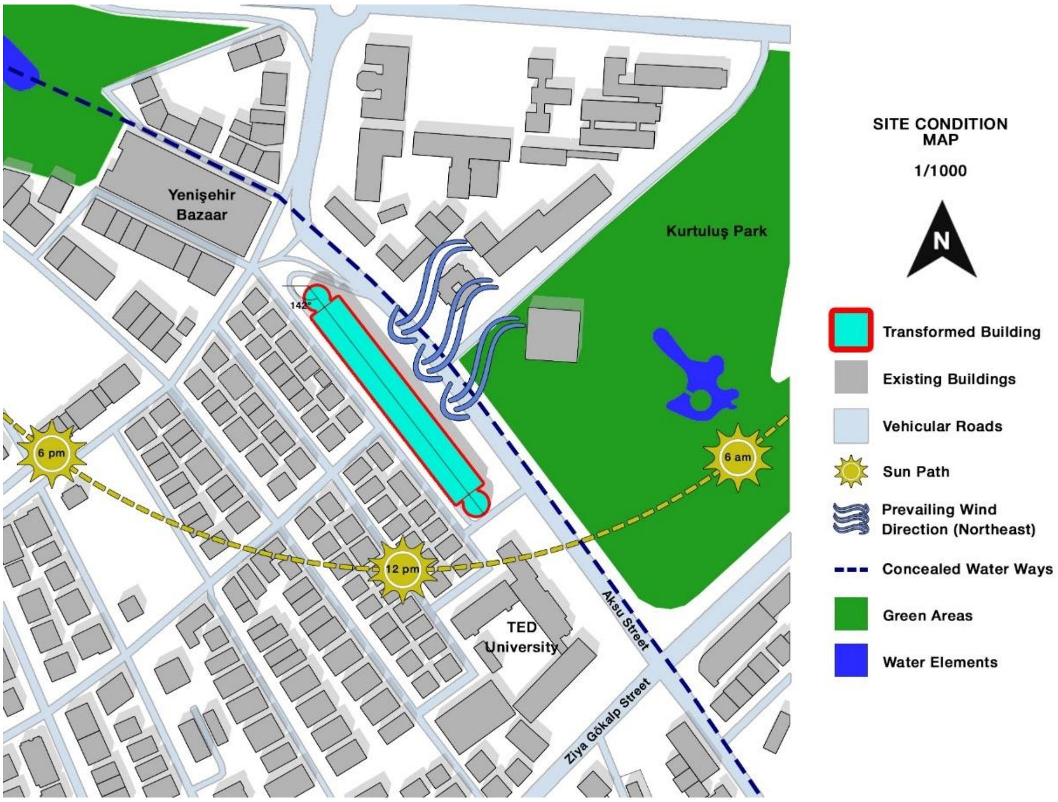
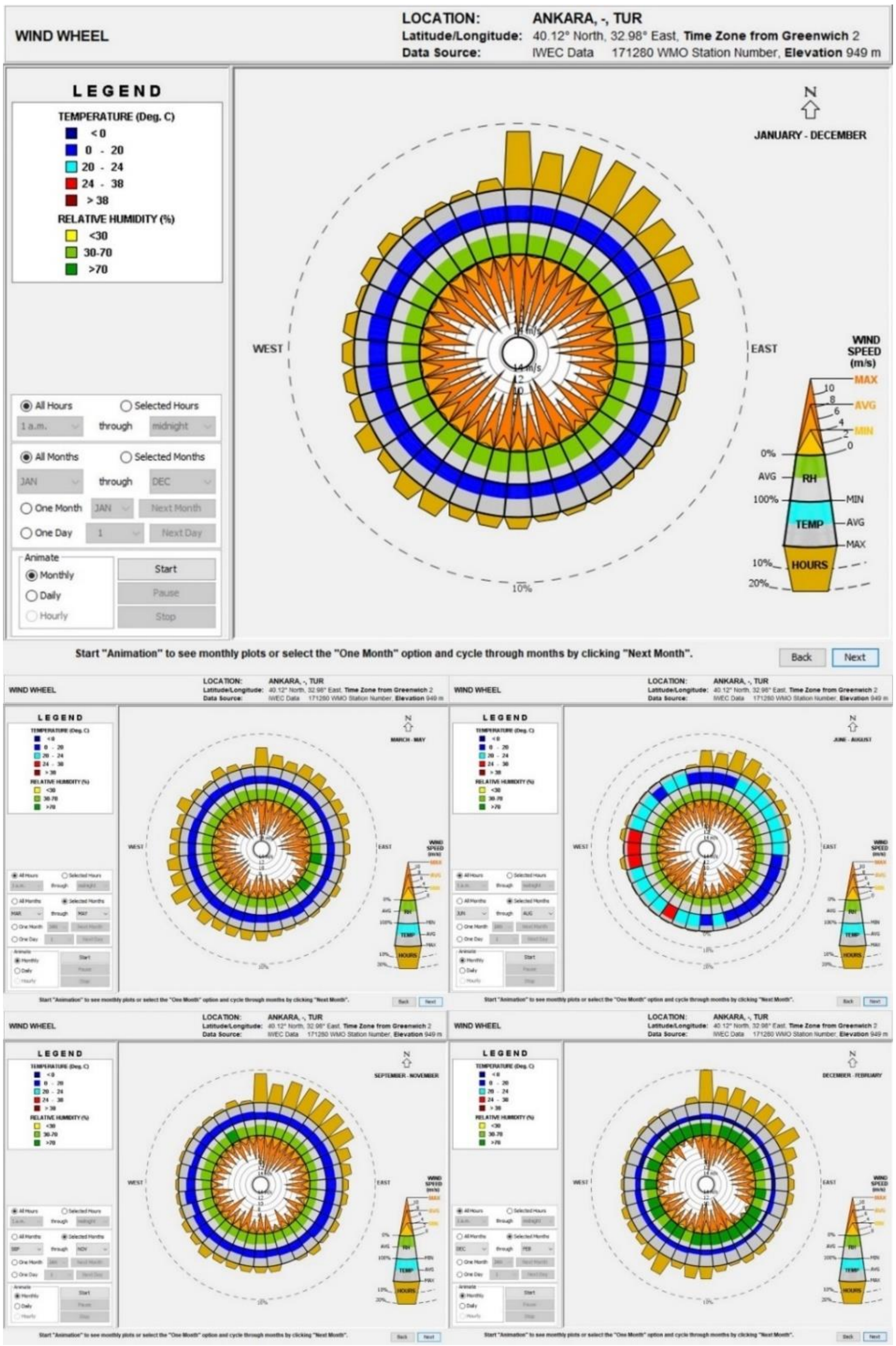


Figure E.1 Site conditions of the transformation project.



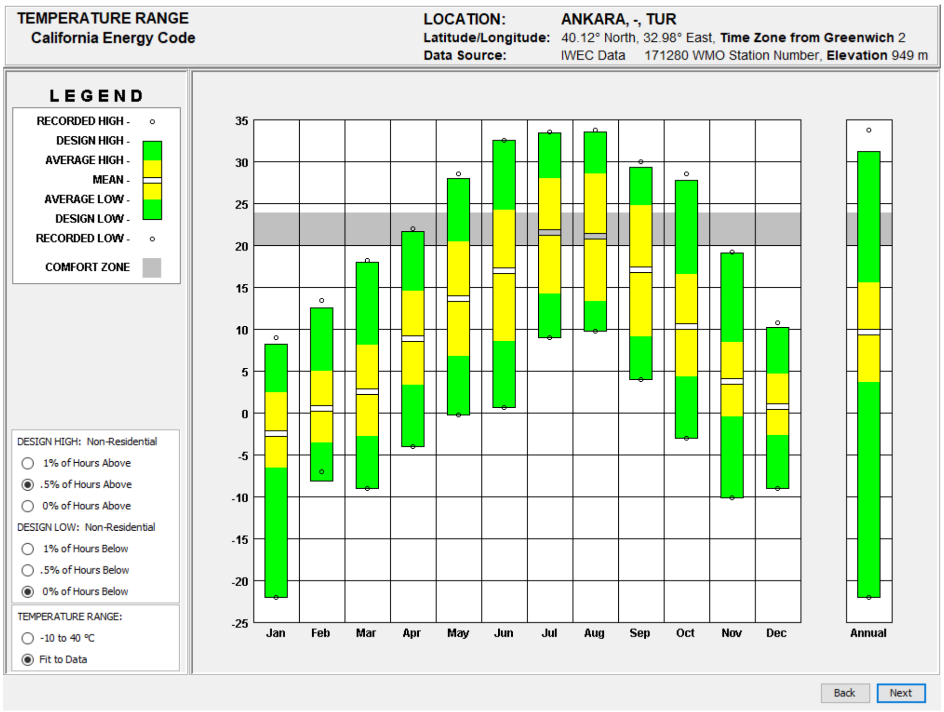
WIND WHEEL

LOCATION: ANKARA, -, TUR
Latitude/Longitude: 40.12° North, 32.98° East, Time Zone from Greenwich 2
Data Source: IWEC Data 171280 WMO Station Number, Elevation 949 m

● All Hours ○ Selected Hours 1 a.m. through midnight
● All Months ○ Selected Months JAN through DEC
○ One Month JAN
○ One Day 1
Animate: ● Monthly ○ Daily ○ Hourly

Start "Animation" to see monthly plots or select the "One Month" option and cycle through months by clicking "Next Month".

Figure E.2 Annual and seasonal wind wheels for Ankara from Climate Consultant 6.0 software.



TEMPERATURE RANGE
California Energy Code

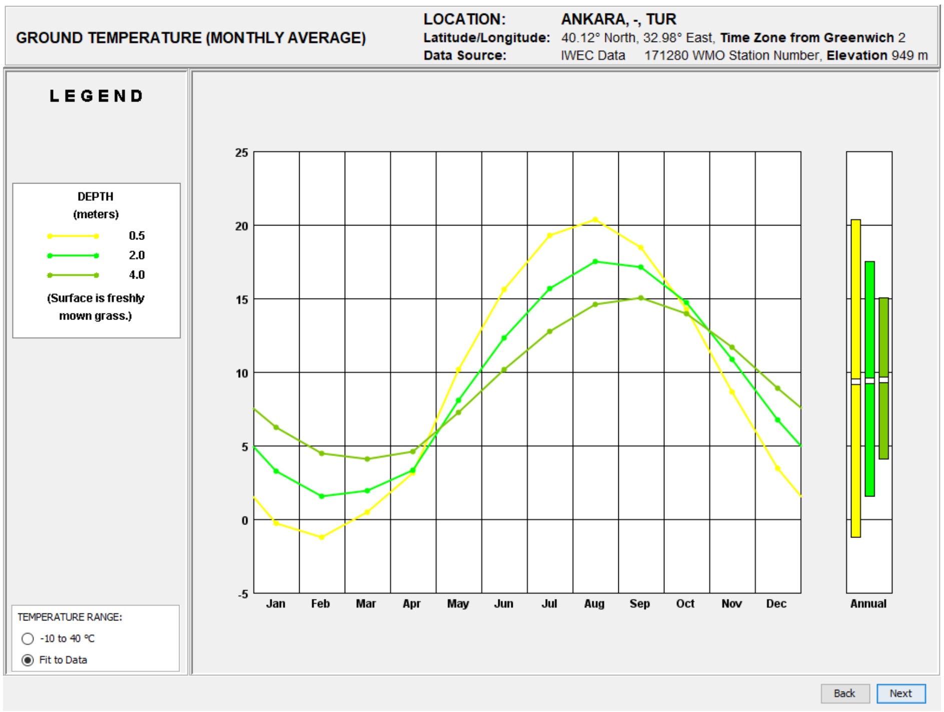
LOCATION: ANKARA, -, TUR
Latitude/Longitude: 40.12° North, 32.98° East, **Time Zone from Greenwich** 2
Data Source: IWEC Data 171280 WMO Station Number, **Elevation** 949 m

DESIGN HIGH: Non-Residential
○ 1% of Hours Above
● .5% of Hours Above
○ 0% of Hours Above

DESIGN LOW: Non-Residential
○ 1% of Hours Below
○ .5% of Hours Below
● 0% of Hours Below

TEMPERATURE RANGE:
○ -10 to 40 °C
● Fit to Data

Figure E.3 Annual temperature range for Ankara from Climate Consultant 6.0 software.



GROUND TEMPERATURE (MONTHLY AVERAGE)

LOCATION: ANKARA, -, TUR
Latitude/Longitude: 40.12° North, 32.98° East, **Time Zone from Greenwich** 2
Data Source: IWEC Data 171280 WMO Station Number, **Elevation** 949 m

TEMPERATURE RANGE:
○ -10 to 40 °C
● Fit to Data

Figure E.4 Annual ground temperature for Ankara from Climate Consultant 6.0 software.

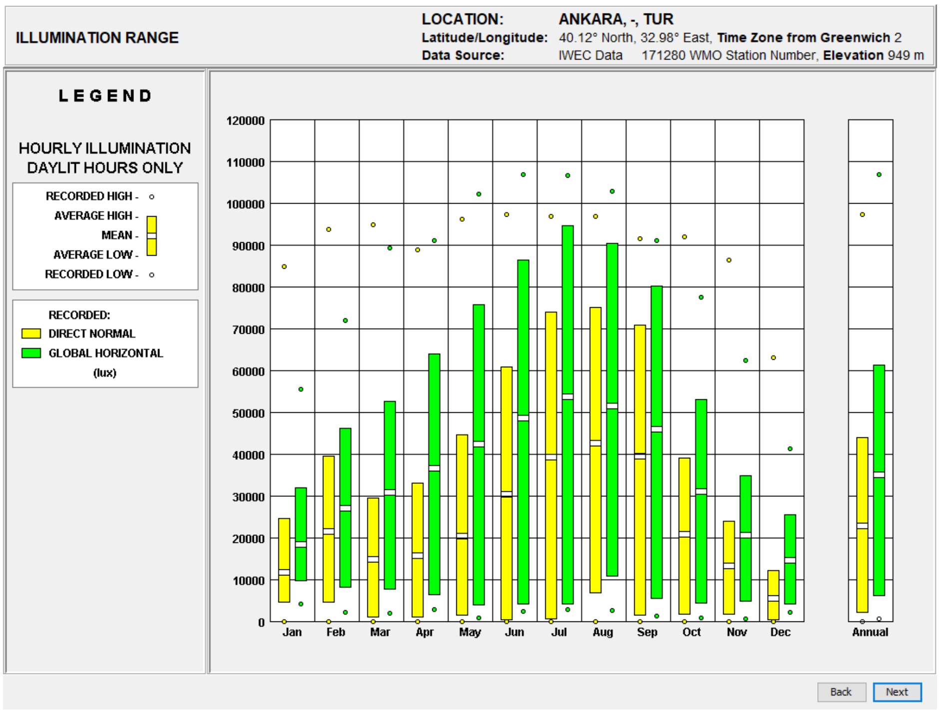


Figure E.5 Annual illumination range for Ankara from Climate Consultant 6.0 software.

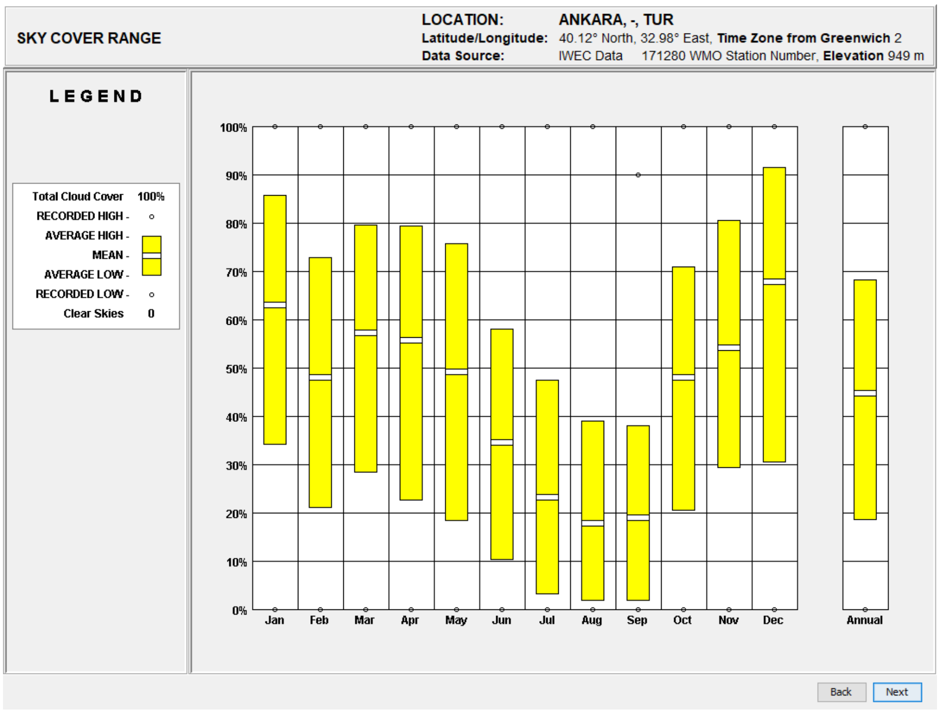
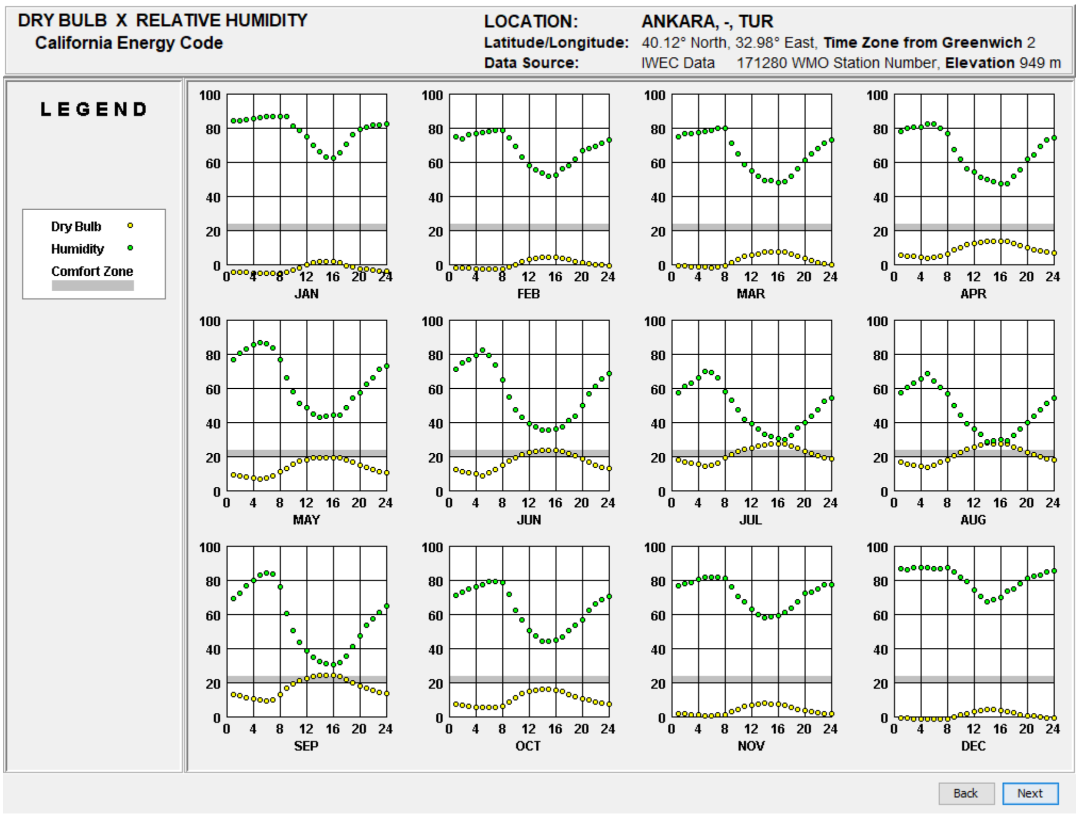


Figure E.6 Annual sky cover range for Ankara from Climate Consultant 6.0 software.


DRY BULB X RELATIVE HUMIDITY
California Energy Code

LOCATION: ANKARA, -, TUR
Latitude/Longitude: 40.12° North, 32.98° East, **Time Zone from Greenwich** 2
Data Source: IWEC Data 171280 WMO Station Number, **Elevation** 949 m

Figure E.7 Annual dry bulb temperature vs relative humidity for Ankara from Climate Consultant 6.0 software.

F. Relationships Between CO₂, RH, Temperature, and Vehicle Entry-Exit in Sıhhiye Multistorey Car Parking Building

Third Deployment of Data Loggers

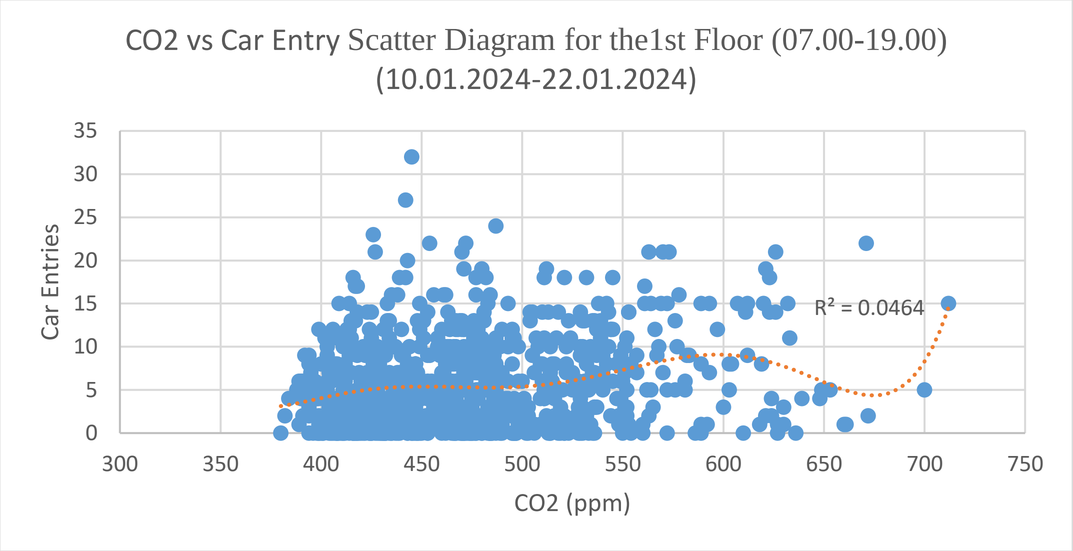


Figure F.1 CO2 vs Car Entry scatter diagram for the 1st floor (07.00-19.00) (10.01.2024-22.01.2024)

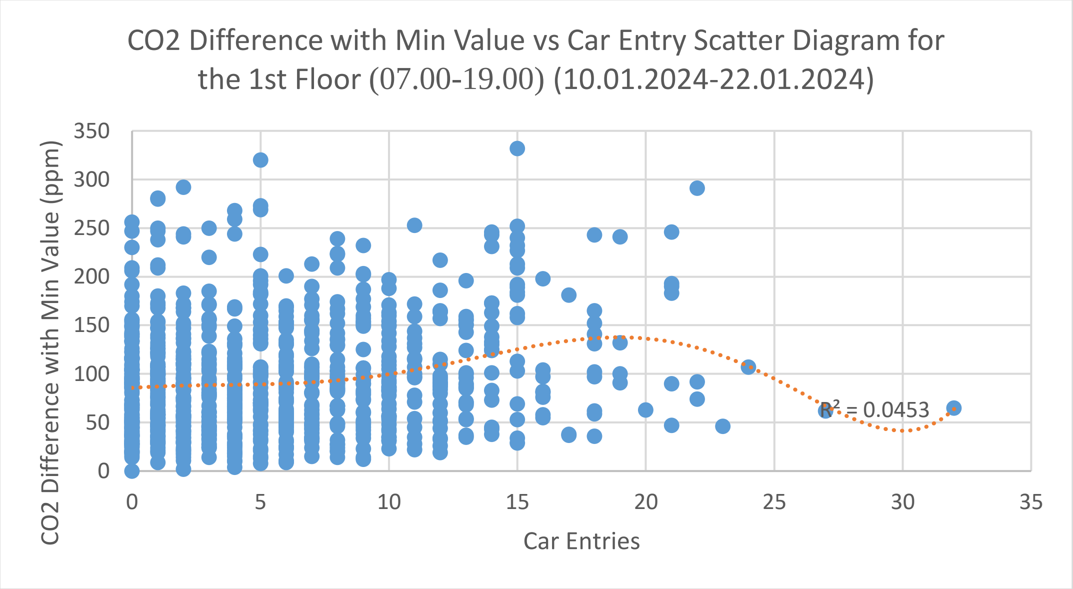


Figure F.2 CO2 Difference with Min Value vs Car Entry scatter diagram for the 1st floor (07.00-19.00) (10.01.2024-22.01.2024)

Fifth Deployment of Data Loggers

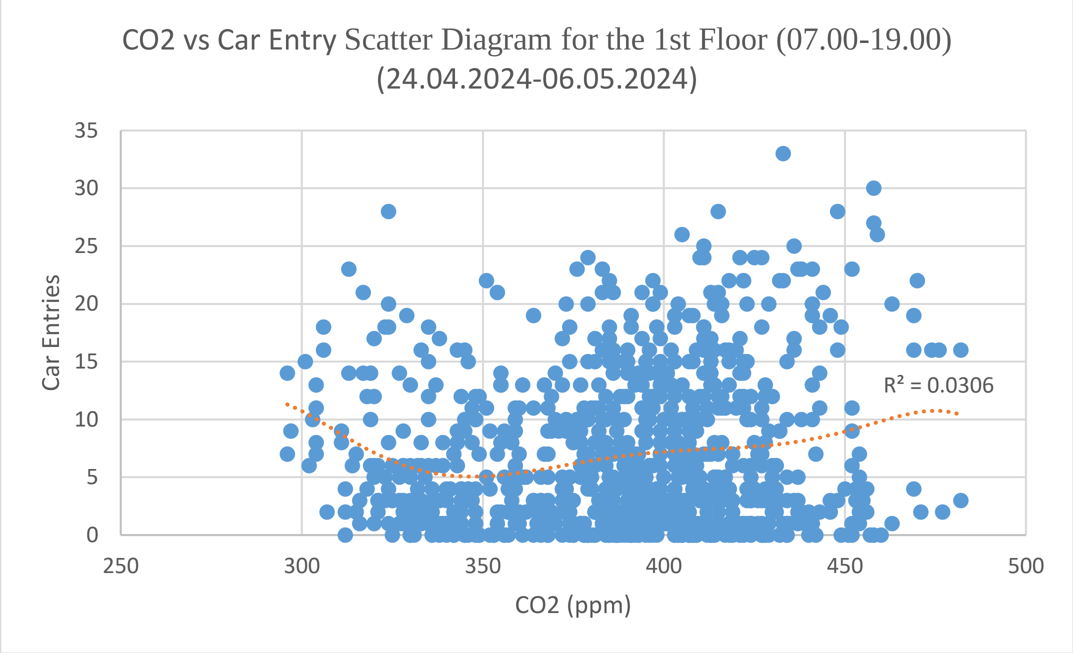


Figure F.3 CO2 vs Car Entry scatter diagram for the 1st floor (07.00-19.00) (24.04.2024-06.05.2024)

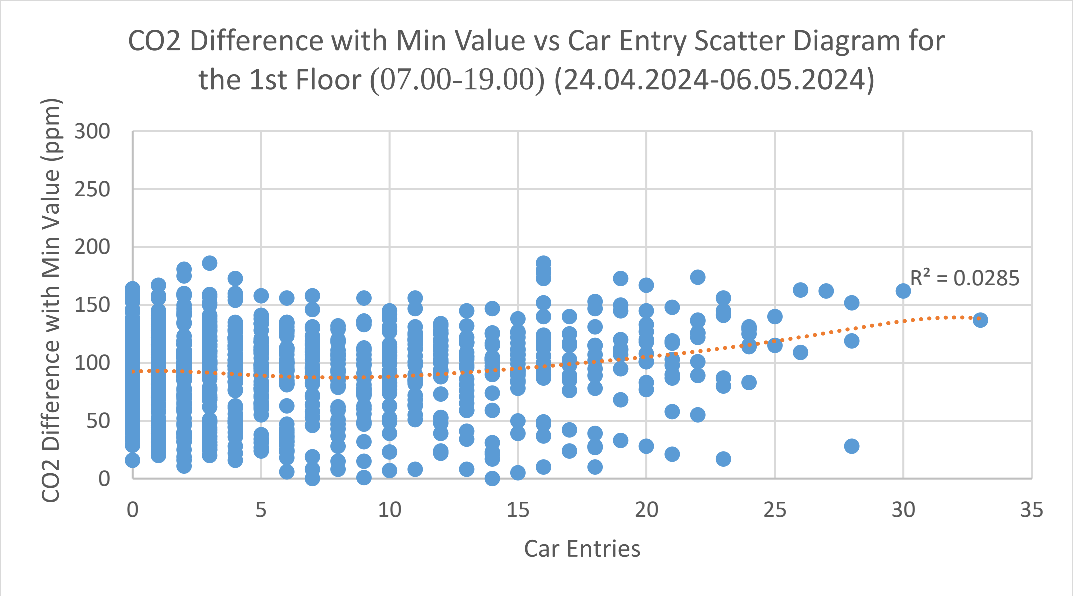


Figure F.4 CO2 Difference with Min Value vs Car Entry scatter diagram for the 1st floor (07.00-19.00) (24.04.2024-06.05.2024)