A Sustainable Solution to Urban Food Consumption by Rooftop Vegetation

By

Sara Kamal

Ijaz Fiaz

Saad Siddique

Faisal Mehmood

Supervisor

Dr. Hira Amjad

Institute of Environmental Sciences and Engineering (IESE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST), Islamabad

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By

Sara Kamal (00000260933)

Ijaz Fiaz (00000244846)

Saad Siddique (00000260978)

Faisal Mehmood (00000258130)

Supervisor

Dr. Hira Amjad

Institute of Environmental Sciences and Engineering (IESE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST), Islamabad

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APPROVAL SHEET

It is certified that contents and form of thesis entitled "A Sustainable Solution to Urban Food Consumption by Rooftop Vegetation" submitted by Sara Kamal, Ijaz Fiaz, Faisal Mehmood and Saad Siddique have been approved for the requirement of the degree.

____

Dr. Hira Amjad
Assistant Professor (Project Supervisor) IESE, SCEE, NUST

____

Dr. Zeeshan Ali Khan
Assistant Professor (Head of Department) IESE, SCEE, NUST

____

Dr. Imran Hashmi
Professor (Associated Dean) IESE, SCEE, NUST

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Abstract

The recent increase in population and consequently the food demand has led to food insecurity majorly in urban areas. The solution for the imbalances in production and consumption of goods and resources has always been a sustainable solution that benefits the population as well as caters for the environment. Hence, we opted for a green building concept in the form of urban agriculture and focused on rooftop vegetation. The project revolves around studying rooftop vegetation gardens in urban areas and in our case, particularly at NUST H-12. We have incorporated the construction of a pilot scale model to study the growth of tomatoes in a soil medium with natural added fertilizer. The pilot scale model has served as a basis for estimating the production of tomatoes and comparing it to the consumption of tomatoes already present, acquired from the data obtained from NUST Admin.

The study on rooftop vegetation also discusses the related impacts it has on urban society and how it makes cities more sustainable and self-resilient.

Chapter 1

Introduction

The rising trend towards reliance on external sources for necessities has been increasing in Pakistan recently. This creates an unhealthy dependence on other countries and highly affects the economy of the country. While it leads people to develop lethargic lifestyles, it also majorly impacts their monetary conditions and brings about related issues from the provision of food from external sources. The travelling cost and emissions also add up to create a significant impact on the environment by degrading the air quality due to the PM and NOx emissions. As observed, the declining climate and change in its patterns urges humans to always opt for better and sustainable lifestyle choices to elongate the lifespan of Earth and the availability of future needs.

As a solution to the increasing population and linearly increasing food demand, we have proposed the idea of Rooftop Vegetation, which aims at providing fresh organic produce at urban level while utilizing the vacant roof spaces in cities. Urbanization in the recent years has created increased buildings expanding urban areas as well as vacant rooftops. The concept of Rooftop Vegetation can promote several healthy activities while guiding the localities towards sustainable living. It can help in meeting the present food needs and also save up for the next generation to come.

The study focuses on creating hypothesis for rooftop vegetation by constructing a pilot scale model which would aid in further calculating the production vs. consumption statistics.

According to the sustainable development goals, the opted project accounts for the sustainable goals 2, 11 and 12; “Zero Hunger”, “Sustainable Cities and Communities”, “Responsible Consumption and Production” respectively.

The problem statement can be that over the past 3 years, Pakistan's double digit food price inflation in tandem with declining incomes has made increased Pakistanis food insecure.

Hence, it is important to focus on sustainable production to match the current and expected consumption of the society.

Urban Rooftop Agriculture is sustainable, environment friendly and space efficient production of fresh organic vegetables at urban level to meet the needs of increasing population which involves the following factors: it is man-made green space, it uses rooftops of residential and commercial structures, it eliminates environmental problems, it promotes food production at domestic level, and it improves a building’s aesthetics

A total of 1.7 million population has been estimated in Islamabad in 2021, where 43 % citizens are food insecure and 18% are facing severe food shortage.

The vegetable consumption per person is 3.6 kg per capita in Pakistan according to Federal Bureau of Statistics, while in Islamabad it is estimated to be 6.46 million kg per capita per month. The food wastage is approximately 40% (36 million tons) in Pakistan.

The Objective of our project are stated as (1) Integrating urban food security and urban agriculture into climate change adaptation, (2) Maintaining and managing agriculture projects as part of the urban and peri-urban green infrastructure, (3) Pilot study and design of urban vegetation at NUST H-12 and (4)Cost benefit analysis of the proposed model.

The scope of project is that it promotes a healthy lifestyle creating awareness regarding optimal options, it is a major shift towards more ecologically sustainable farming compared to conventional system at large scale, it serves as an efficient approach, making use of vacant rooftop spaces for food production at domestic levels, it conservation of energy and resources while providing localities with basic necessities from their own physical footprint.

Chapter 2

Literature Review

2.1 Assessment of Urban Agriculture in Pakistan

Rapid urbanization is taking place in the metropolis of Pakistan, which is having an impact on urban agriculture. This study follows the evolution of agriculture conditions in the urban areas. Land demand for housing and other non-farm purposes such as industries, commerce, and transportation are expanding as the population and economic activities grow. The built-up area is spreading in all directions around the cities, which is the best agricultural land. As a result, any increase in the urbanized environment has led in and continues to result in the loss of agriculture. In the process of urban expansion, farmland has been consumed by nonfarm uses.

Furthermore, an examination of the land capability classes reveals that the majority of the growth in farmland has occurred in the low-productivity class IV category, whilst built-up territory has encroached on the most fertile and productive class I category. While examining the encroachment process, we also consider policy solutions for preserving remaining farmland by increasing the profitability of urban agriculture and including the activity into city plans for implementation.

Cities and their residents benefit from urban agriculture in a variety of ways. In terms of economics, it helps enhance household income, allowing for financial savings. It fosters a sense of community and promotes women's and youth's nutrition by providing substantial food. In terms of the environment, it promotes the reuse of wastewater and organic solid waste, decreases the usage of fertilizers and pesticides, and makes cities more climate resilient.

Despite its growing relevance, urban agriculture is under severe threat from urban sprawl, which is compromising its long-term viability. We've been warned about the devastating effects of urban expansion on global farmland. According to a study, the continents of Asia and Africa will face the greatest absolute loss of cropland in the near future, with much of this loss being prime agricultural land (producing twice as much as that, which comes from the average national land).

2.2 Rooftop Vegetation awareness and implementation in Pakistan

Urban Rooftop farming is a sustainable solution for addressing the urban environmental difficulties. In many locations, this is a well-established technology, yet in underdeveloped countries, rooftop gardening is generally seen as a novelty. The potential benefits of rooftop gardening have garnered a lot of attention, but the social and aesthetic perceptions of people have gotten less attention. This is the first report on a survey of the public impression and visual attractiveness (aesthetic reactions) of rooftop gardening in the Faisalabad (Pakistan) community. A rooftop garden was created on the roof of a single-story structure, and a visitor survey was conducted on the premises to determine the visitors' general attitudes and visual aesthetic inclinations in this area.

A survey was designed and given to the 387 visitors in order to elicit their comments, and the acquired data was statistically analyzed. The results demonstrated the visitors' positive reaction to the evaluation procedure. Furthermore, 45 percent of visitors said that green roof gardening has a high value of up to 50%. Finally, the majority of respondents supported the use of the rooftop gardening technique. The findings of this paper may be valuable in future town planning, with a focus on increasing rooftop gardening to reduce the negative environmental effects of cities. The most common negative impact indicated by respondents (40%) was worried about the rooftop garden's heavy weight, while 30% were concerned about the potential of garden water spilling into the roof. 20% indicated they had no information of the potential harmful effects of rooftop gardens, while 10% said there were no negative effects. (*Younis et al., 2011*)

People feel rooftop gardens benefit the urban environment and have an overall good attitude to them for both aesthetic and personal benefits.

Green roofs would also boost ecological diversity in the city, improve urban inhabitant health and comfort, and maybe reduce urban environmental consequences. Producing medicinal and culinary crops would be a wonderful way to raise awareness and ensure the long-term viability of such roof gardens. To boost widespread approval, the economic costs must be clearly stated and compared to possible reductions on food and energy purchases. Green roofs must also be well-designed to avoid causing structural concerns with the building due to higher load or water problems.

2.3 Production Potential of Rooftop Vegetation in Urban Areas

Many cities throughout the world continue to source a big percentage of their food from within city limits, however this number is decreasing as the global food chain increases. Urban agriculture is more prevalent in underdeveloped countries, yet even in the Netherlands, urban fields account for 33% of total agricultural production.

It also is worth noting that grown food in cities is probably more organic than food that is produced by the standard industrial food system from an environmental standpoint. It is due to a variety of variables, including the relatively modest scale of urban agriculture, a huge labor pool, and cost savings from decreased transportation expenses. Furthermore, due to their intensive labor, urban farms can generate up to 15 times more per acre than their rural counterparts (*Ableman 2000*). Localized farming benefits the community both economically and socially by providing healthier, more fresh food. Finally, interacting with living things calms and cures the mind and body while reminding city inhabitants of the fundamental source of human assistance, as well as the limits of that assistance.

It was found that growing conditions on the rooftop are not dissimilar to those on the ground. According to the study, there was no difference in produce yield between an intensive green roof, a green roof platform, or growing conditions on the ground. Urban agriculture's annual food yields are estimated to be 10 tons per acre, or 2.2 Kg per square meter. The City Slickers farm in West Oakland produced nearly 4350 Kg of food on 2003 square meter, yielding 2.19 Kg per square meter. *(Kortright, 2011; Whittinghill et al., 2013)*

Chapter 3

Data Collection and Analysis

3.1 Food Consumption Analysis for NUST H-12 Hostels Mess

The data for the vegetable's consumption was obtained from NUST Admin block from hostel branch which was then used to compare the calculated production from the rooftop garden models

Table 1. Vegetable Consumption Data in NUST H-12

Details	JUNE 2021	JULY 2021	AUG 2021	SEP 2021	OCT 2021	NOV 2021	TOTAL
No of Students	79837	34052	37102	61077	102259	118242	432569
Tomatoes (kg)	4645	2094	2340	3603	5440	5590	23712
Potatoes (kg)	5350	2033	2320	3555	5665	6680	25603
Onions (kg)	5160	2310	2440	3660	5505	5855	24930
Cucumber (kg)	457	180	329	424	545	619	2554
Carrot (kg)	07	91	145	194	171	202	810
Cauliflower (kg)	-	-	-	-	1310	1355	2665

3.2 Specific Analysis for Consumption of Tomatoes

Our study was mainly subjected to the production and consumption of tomatoes at NUST H-12. Hence, we obtained the data for individual consumption of tomatoes as follows:

Table 2. Tomato Consumption Data in NUST H-12

Details	JUNE 2021	JULY 2021	AUG 2021	SEP 2021	OCT 2021	NOV 2021	TOTAL
No of Students	79837	34052	37102	61077	102259	118242	432569
Tomatoes (kg)	4645	2094	2340	3603	5440	5590	23712

Average Daily Consumption per Student = 57/30 = **1.9g/day**

(Data of vegetables consumption obtained from **Assistant Director, Messing** and **Hostels** in Admin Block.)

3.3 Rooftop areas data collection:

Table 3. Rooftop Area Data in NUST H-12

Sr. No.	Building	Rooftop area(m^2)	Selected area(m^2)
1	**IESE**	**2320**	**1624**
2	**ASAB**	**2600**	**1820**
3	**SMME**	**2730**	**1911**
4	**SCME**	**1690**	**1183**
5	**S3H**	**1590**	**1113**
6	**RIMMS**	**500**	**350**
7	**SADA**	**2538**	**1777**
8	**NBS**	**6200**	**4340**

9	**IGIS**	**1000**	**700**
Sr. No	**Building**	**Rooftop area(m2)**	**Selected area(m2)**
10	**SNS BLOCK2**	**585**	**410**
11	**SMME Workshop**	**1330**	**931**
12	**Rumi hostels**	**2223**	**1556**
13	**Fatima hostels**	**1482**	**1037**
14	**NSTP 1**	**2550**	**1785**
15	**NSTP 2**	**1720**	**1204**
16	**CIPS**	**2275**	**1593**
17	**Design Center**	**1330**	**931**

(Zain Sajid et al., 2021)

The given tables represent the data of the area of NUST's rooftops. One column shows the total area of the rooftops and the columns next to it show the selected area. The selected area is the area which can be utilized for rooftop garden model. The whole rooftop cannot be utilized due to different constraints like usage of rooftop for other purposes and leaving some free space to tread.

3.4 Soil Specifications and Testing:

Agricultural crops that require more intensive roofing and deeper soils are required (*Kortright et al, 2011*). Furthermore, one square foot of moist soil can weigh up to 50 pounds. Buildings are planned and constructed to support a specified living load on the roof, usually in accordance with the current building code. Some rooftops have the structural as well as loading capacities to enable extensive food production rooftops. Before constructing an intensive rooftop agricultural system on rooftops in the rest of the world, costly retrofits will almost certainly be required. Straight compost is a better growing medium than soil since it is lighter and contains more nutrients.

3.4.4. Soil composition:

Soil Type	Organic Fertilizer
Loamy Soil + **Cow Dung**	**Cow dung which is rich in organic materials nutrients.** **Contains about 3 percent nitrogen, 2 percent phosphorus, and 1 percent potassium (3-2-1 NPK).**

3.4.5. Soil testing

pH Measurement

The pH of soil that we have used was measured by using a pH meter from laboratory. We obtained the soil sample to be used and diluted it in some water to form a slurry and then checked the pH by inserting the pH probe in the slurry. This was repeated 3 times and an average value was obtained. pH was found to be approximately 7 which is suitable for growth of tomatoes according to literature.

Soil density measurement:

To find the density of the soil we used the standard Proctor apparatus from NICE Geotech Laboratory. The density is going to help on calculating the mass of soil that can be used on the rooftops. Standard Proctor Test gave a density value of 1236 kg/m^3.

Chapter 4

Model Rooftop Farm Construction

A Pilot scale is proof of concept at a scaled-up size for treating up to few % of a total actual flow for the application. Usually these are on-site at the eventual place where full scale will be built and operated.

We have established a Pilot scale model to get the actual results practically. We didn't get the Permission to develop this model on IESE Roof top due to some issues, that's why we were advised to progress the model at IESE Backyard.

4.1 Site selection, analysis, and conditions:

We aim to construct our Pilot Scale model on IESE rooftop but that was not suitable for our model, that's why we started to develop our Pilot scale model in the backyard of IESE where there were already built some concrete compartments. Water availability was provided there, and every compartment has a seepage pipe through which the excess water can easily get out and it has helps from getting waterlogged conditions.

Figure 1. Model At Backyard of IESE

4.2 Site selection and Dimensions

We have selected 2 compartments initially. One for tomatoes and other one was for Spinach and Turnips. The Dimensions for both compartments are given below:

Dimensions of compartments1: L=W=4.5 ft

Dimensions of Compartment 2: L=4.7ft, W=4.4ft

And the depths of the compartments were same about 18 inches. So, the vegetables that we were selected can easily grow in such depth of soil.

4.3 Setting up the model

1. **Cleaning up the Compartments:**

Initially we have cleaned the model and we contacted to a Gardner inside NUST working at Nursery. He managed to deliver us the Loamy soil as well as cow dung.

2. **Plastic Sheet:**

We have used Plastic sheet before pouring the soil in the compartments to avoid the seepage. And then Almost 150 kg soil was used in the compartments along with 30 kg cow dung.

3. **Sapling deployment:**

We have purchased 15 saplings of Tomatoes as well as some seeds of Spinach and Turnips. We deployed the Seeds and saplings in December.

4. **Using stems for support**

Extra tree stems were used to provide support to the growing sapling to avoid mixing and fungus.

5. **Covering of Plastic sheet:**

Due to low temperature over the pilot scale model, we have used plastic sheet and cover the whole model so that it may not get affected by the frost and low temperature.

Figure 2. Step by step RTG model construction

4.4 Vegetables Planted for study:

We have collected data of different vegetables from the messing and Hostels Directorate. So, we selected following vegetables for our pilot scale model:

1) Tomatoes
2) Spinach
3) Turnips

Table 4. conditions and time requirements for these vegetables

Vegetables	**Plantation**	**Root depth**	**Season**	**Maturing Time**	**Spacing**
Tomatoes (Roma variety)	Tomato Saplings	12 inches - 2 feet	End of Fall, Spring	100 days	24-36 inches
Turnip	Seeds	12-14 inches	Spring & Fall	30-60 days	4-6 inches b/w plants, Rows 12 inches apart
Spinach	seeds	1 foot	Fall & spring	37-45 days	8-12 inches b/w plants in rows 22-30 inches apart

4.5 Enhancing the Growth of Vegetables:

We have taken following steps to enhance the Growth of Plants, these are summarized below:

- Sunlight 6-8 hours per day
- Remove suckers for faster growth
- Tickle the flowers to promote pollination
- Remove unwanted plants and weeds that suck out essential nutrients from plants and spread diseases

- Use wooden sticks to provide support to the plant as it grows taller
- DIY homemade organic pesticide spray: ginger, garlic, neem oil and water boiled together and strained to extract the liquid pesticide
- Addition of cow dung after 12-15 days for essential nitrogen requirement
- Keep removing bottom leaves as the plant grows taller to avoid fungal disease and promote air supply

4.6 Water Requirements for Growth:

Water requirements differed at various growth stages and seasonal changes.

An average quantity of water consumed by the tomato plants is estimated as **1-2 inches of water/week.**

1. **At Plantation (Dec-Jan):**
   In early Spring season, watering the plants once in 2 days was sufficient.
2. **Plant Development (Feb-March):**
   Due to increasing heat and lack of moisture (soil level decreasing 1 inch below), we watered the plants once every day.
3. **Fruit Development (April):**
   Water requirements reached a peak at this stage during summertime, and we had to water sometimes twice a day.
4. **Ripening (May):**
   Water requirements decreased, however due to increasing temperature and Eid holidays, mild water stresses occurred which resulted in smaller fruit.

4.7 Growth of Tomato Plant:

Initially we deployed saplings of Tomatoes and watered them properly so they grow up as you can see in the images from Day 1 to Day 120:

Day 1

Day 70

Figure 3a. Growth of Tomatoes

Day 120

Figure 3b. Growth of Tomatoes

4.8 Nutrients required for growth of plants

Soil is a major source of nutrients needed by plants for growth. The three main nutrients are

1) Nitrogen (N)
2) Phosphorus (P)
3) Potassium (K).

Together they make up the trio known as NPK. Other important nutrients are calcium, magnesium, and Sulphur.

- Molybdenum (Mo); Molybdenum helps bacteria.
- Copper (Cu); Copper is an essential constituent.
- Boron (B); Boron helps with the formation of cell.
- Zinc (Zn); Zinc helps in the production of a plant.

4.9 Problems faced during growth of plants and their optimal solution:

We have faced some problems during the and after the growth of plants these are listed below with optimal Solutions:

Blossom End Rot:

The tomato plants appear healthy, but as the tomatoes ripen, an ugly black patch appears on the bottoms. The black spots on tomatoes look leathery. When you try to cut off the patch to eat the tomato, the fruit inside looks mealy.

Optimal Solution:

Before planting tomatoes in the spring, have your local garden center or Cooperative Extension conduct a soil test. Lime and gypsum may be added for calcium, but they must be added in the proper amounts depending on your soil's condition. That's why a soil test is necessary. Adding crushed eggshells to your compost pile can also boost calcium naturally when you add compost to the soil

Fruit Cracking:

Cracks appear on ripe tomatoes, usually in concentric circles. Sometimes insects use the cracks as an opportunity to eat the fruit, or birds attack cracked fruit.

Optimal Solution:

Although you can't control the rain, you can water tomatoes evenly during the growing season. This prevents them from being so thirsty that they take up too much rainwater during a heavy downpour.

Cat-facing:

Cat facing makes tomatoes appear deformed. The blossom end is rippled, bumpy and lumpy.

Optimal Solution:

If possible, plant tomatoes a little later in the season. Make sure the weather has truly warmed up enough to support proper tomato development.

Black plastic can be used as a temporary measure until the temperatures warm up enough that it's no longer needed. Cat faced tomatoes are safe to eat; simply cut away the scarred areas.

Early Ripening:

In this most of the tomatoes will ripe early and their size will be too small, so they look small ripe tomatoes.

Optimal Solution:

It is due to the irregular watering to tomatoes plants, sometimes excess of water and sometimes lack of water, this type of situation will cause early ripening of tomatoes.

So, through regular and proper watering of plants we can avoid these problems.

4.10 Climate's Impact on our RTG Model

<u>Rainfall Patterns over the Past Months:</u>

In the early growing period, there was a course of heavy rainfall observed in Islamabad.
These rain patterns were good to suffice the water requirements of the plant, but sometimes exceeded the optimum water content which affected the turnip and spinach plant adversely.
However, as the tomato plant had a plastic sheet over it, it remained safe from over saturation.

Table 5. Average Rainfall that affected the initial plant development stages:

Avg Rainfall in January	67 mm
Avg Rainfall in February	96 mm
Avg Rainfall in March	109 mm

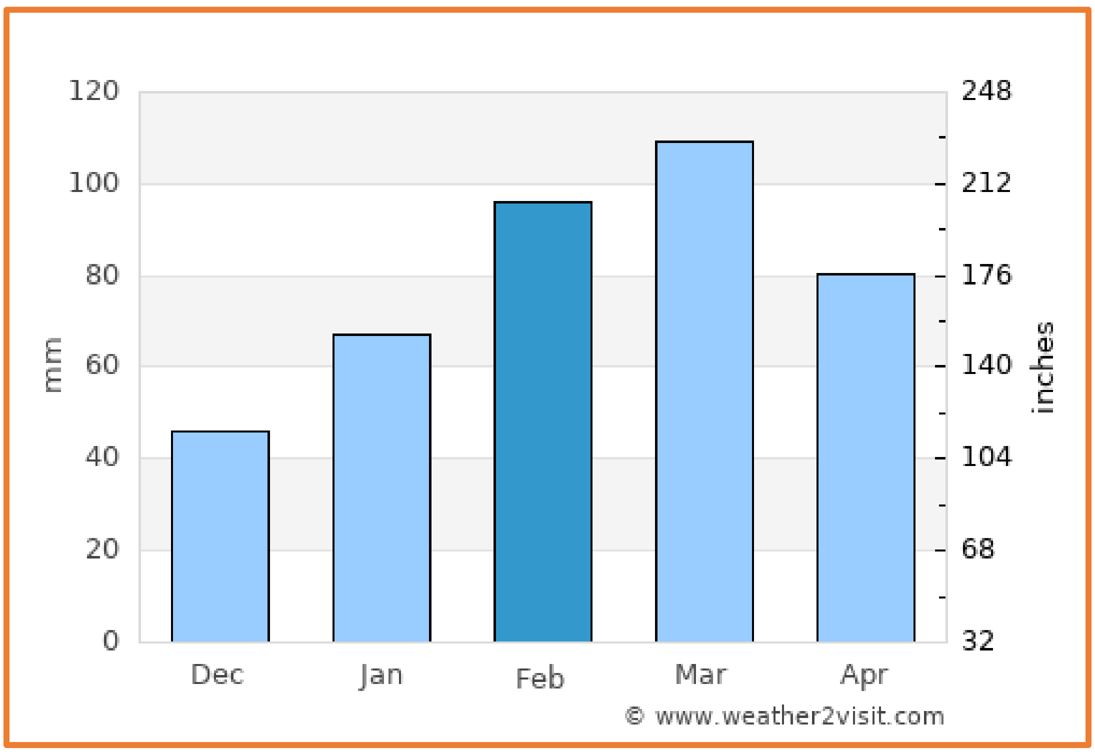


Figure 4. Rainfall Data from January to March (Weather2visit, 2022)

Temperature Variations (March-May)

The optimum temperature for tomatoes is **70-75^{0}F**. The mean temperature below 60^{0}F and above 80^{0}F are not desirable.

The temperature rose significantly in Islamabad during mid of March up till mid of May which hampered the growth of tomatoes and also caused yellowing of leaves and damaged stems

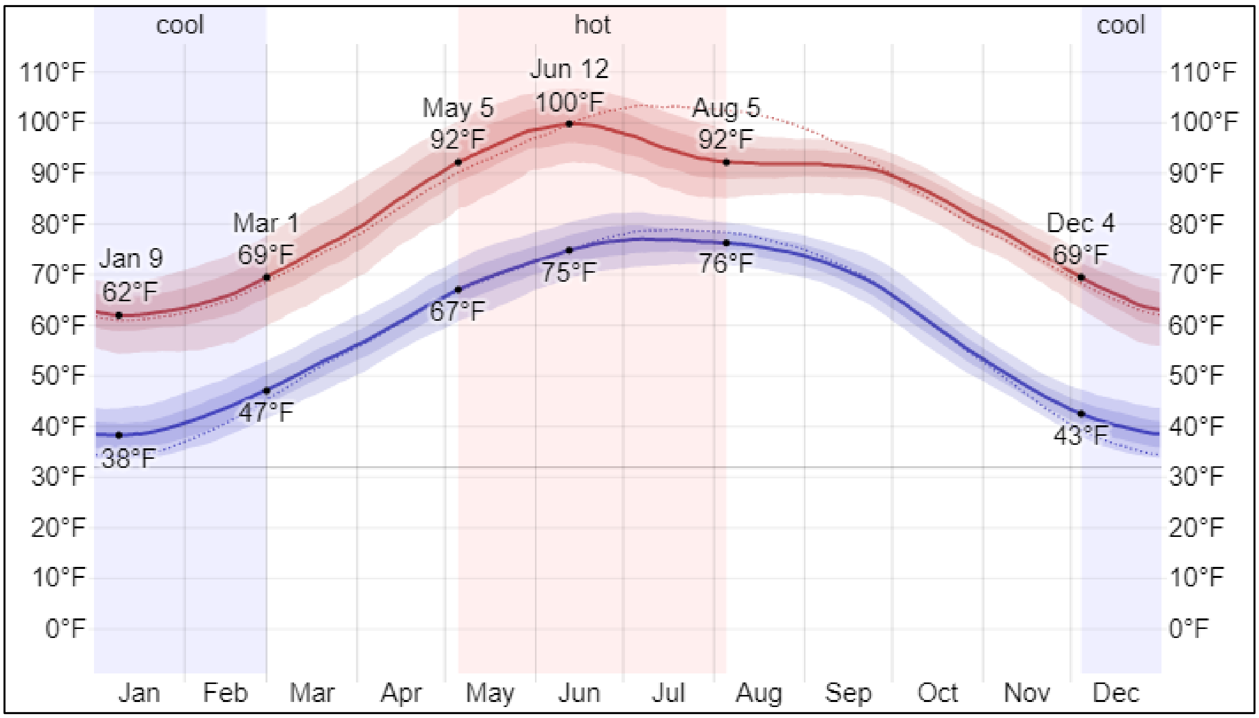


Figure 5. Temperature Variations that affected our RTG model from March to May (Weather Spark, 2021)

Chapter 5

Environmental Impacts of Rooftop Vegetation

5.1. Indirect Impacts of Rooftop Vegetation:

Green Roofs have a direct effect on indoor comfort throughout the entire building, whereas the effect of green roofs is apparently primarily confined to the upper floor. Moreover, the indirect effect of a green wall is greater, mainly due to the drop in infrared emissions resulting from a lower surface temperature. It has also been observed that the indirect effects of green walls and surrounding lawns can help reduce the loads acting on a non-insulated building.

The Major Indirect Effect of Green Roofs is the Heat Island effect.

5.1.1 Heat Island Effect

- Heat islands are urbanized areas that experience higher temperatures than outlying areas. Structures such as buildings, roads, and other infrastructure absorb and re-emit the sun's heat more than natural landscapes such as forests and water bodies.
- Due to this there will be increase in energy demand as well as Greenhouse gases and Discomforts for Humans.
- Green roofs provide shade, remove heat from the air, and reduce temperatures of the roof surface and surrounding air.

5.1.2 Measurement and Estimation of Reduction in Heat Island Effect

We obtained the ambient temp over the week from weather application and calculated the avg temperature at peak times. Then we used a simple thermometer around the RTG model and held it slightly below the surface for some time, once every day in the week. We then compared the results of the temperature values obtained to those of the peal temperature values.

From the data we found,

Average Temperature at peak times over the week **= 40.3 ℃**

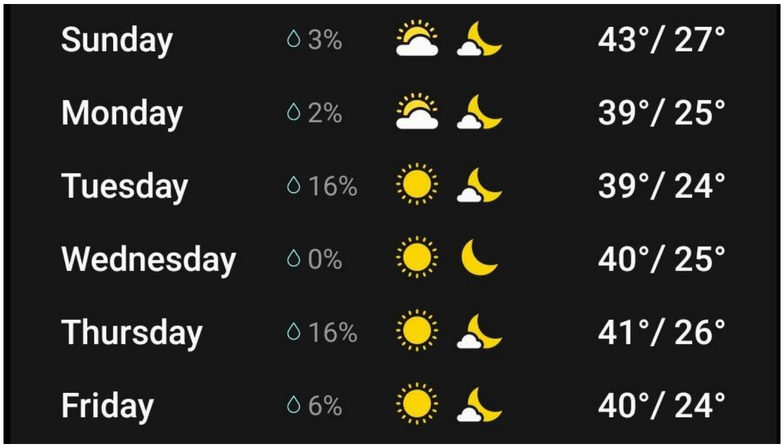


Figure 6. Ambient Temperature over the week

Table 6.RTG Model Temperature over the week

Weekday	**Temp.**
Sunday	41℃
Monday	38℃
Tuesday	37.5℃
Wednesday	39.5℃
Thursday	39.5℃
Friday	39℃

Average RTG Temperature **= 39.1 ℃**

The difference in temperature results to be = 40.3-39.1 = **1.2 ℃**

We have also measured the temperature under the soil at different depths over the week so the difference that we observed is that the Average Temperature at peak times over the week is **40.3 ℃,** However the Average temperature the under the soil was **39.4℃**

Heat difference was insignificant due to unavailability for indoor testing and model constraints as well as outdoor heat interference.

Data from Literature,

The indirect effect of green roofs over different countries has been observed and it results in a significant Energy saving percentage due to indoor cooling effect.

Table 7. Energy Saving Data

Location	Season	Scale	Cooling or Energy saving
Hong Kong, China	Summer	Community	0.1–1.6 °C 0.2–2.1 °C
La Rochelle, France	Summer	Building	6%
Toronto, Canada	Summer	City	1–2 °C
New York, US	Entire year	City, Building	40–110%
Incheon, Korea	Summer, Winter	Building	3.7%
Mexico	Entire year	City	45%

(Hongqing Liu, et al., 2021)

5.2 Direct Impacts of Rooftop Vegetation

Green roofs (roofs with a vegetated surface and substrate) provide ecosystem services in urban areas, including improved storm-water management, better regulation of building temperatures, reduced urban heat-island effects, and increased urban wildlife habitat. They can reduce the energy required for the maintenance of interior climate, because vegetation and growing plant media intercept and dissipate solar radiation.

5.2.1 Air Quality Management:

A green roof has many benefits at economic, ecological, and societal levels. A green roof provides following benefits to Environment:

1) Rainwater buffer
2) Purifies the air
3) Reduces the ambient temperature

4) Regulates the indoor temperature
5) Saves energy and encourages biodiversity in the city. Green roofs are part of climate-proof construction.

5.2.2 Carbon Sequestration:

Photosynthetic carbon sequestration at a specific moment was obtained using instantaneous photosynthetic speed and respiratory rates. The experimental results from different studies showed that the green stonecrop roof can absorb **1.79 kg** of CO_2 and release 1.3 kg of O_2 per square meter per year.

Data from Literature,

1) **Currie and Bass (2008) [Toronto, Canada]:**
   Estimated that the 109 ha of green roofs with herbaceous plants would reduce 7.87 metric tons of air pollutants every year.
2) **Yang et al. (2008) [Chicago, Illinois]:**
   Green Roofs in an area of 19.8 ha, 1675 kg of air pollutants could be removed in one year(approx.). If all the rooftops in were covered with GRs, a reduction of 2046.89 metric tons of air pollutants estimated.
3) **Luo et al. (2015) [Chengdu, China]:**
   To evaluate carbon-capturing performance, the field study results showed that the average carbon storage capacity of the green roof was 8.58 kg/cm^2 and 13.15 kg/cm^2 respectively.

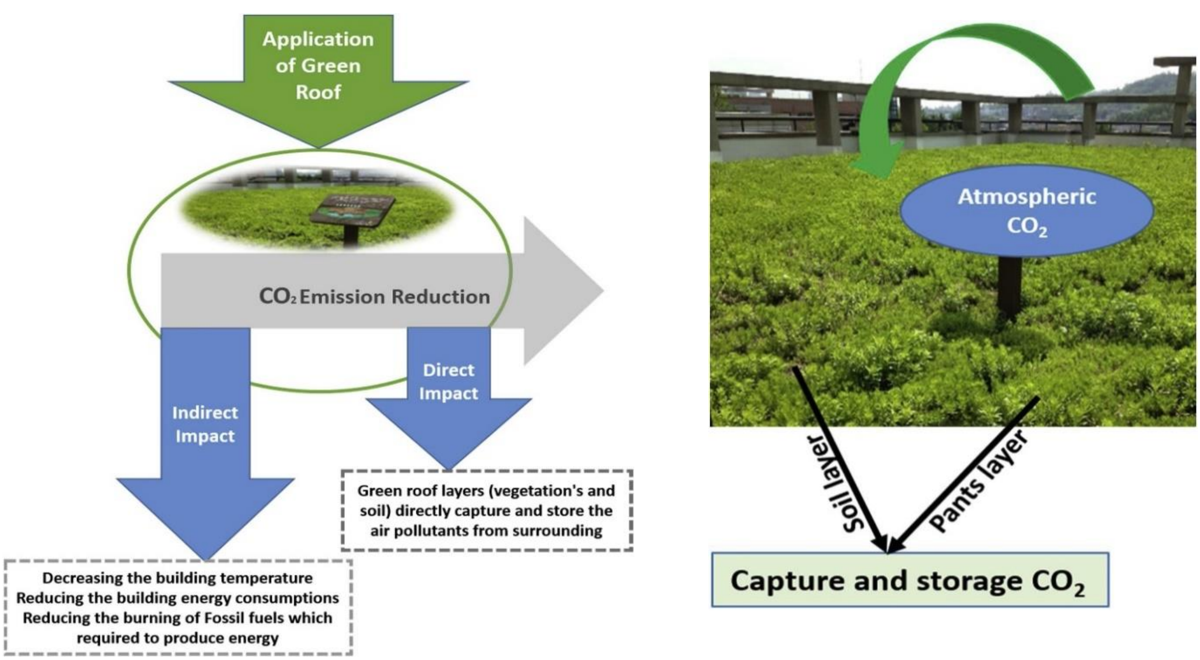


Figure 7. Impacts of Rooftop Vegetatin (Shafique, 2020)

Chapter 6

Production Potential Analysis

This chapter focuses on technical and production analysis of the project. Various required calculations are being performed to check for the sustainability of NUST for vegetation consumption. In first part, the calculations for rooftop areas are performed using secondary data and are validated by using the software ArcGIS 10.8.4 and specific area is used based 'area selection criteria".

In the later part, the production of pilot scale model is represented. The production of model is shown in different intervals as the planted vegetation was tomato and it is being harvested on equal intervals of days. The production from pilot model is used to calculate the possible production on area of unit meter square (1 m^2).

In the last part, the production from model is used to calculate the overall potential of NUST to produce vegetation. The available area is used in such a way that NUST can be made sustainable for vegetation consumption by studying the consumption pattern of various vegetables. All the parameters were being kept in observation to achieve the maximum efficiency.

6.1 Measurement of Rooftop Area

NUST is located in sector H-12 of Islamabad with the location coordinates of 33.6429° N and 72.9927° E.

NUST comprises of various buildings which includes schools, hostels (male and female), apartments and others like CSD, NSTP. As per observations, there is a large amount of rooftop which is vacant and available to use. The structure of buildings is of good standard and can bear the optimal weight if applied.

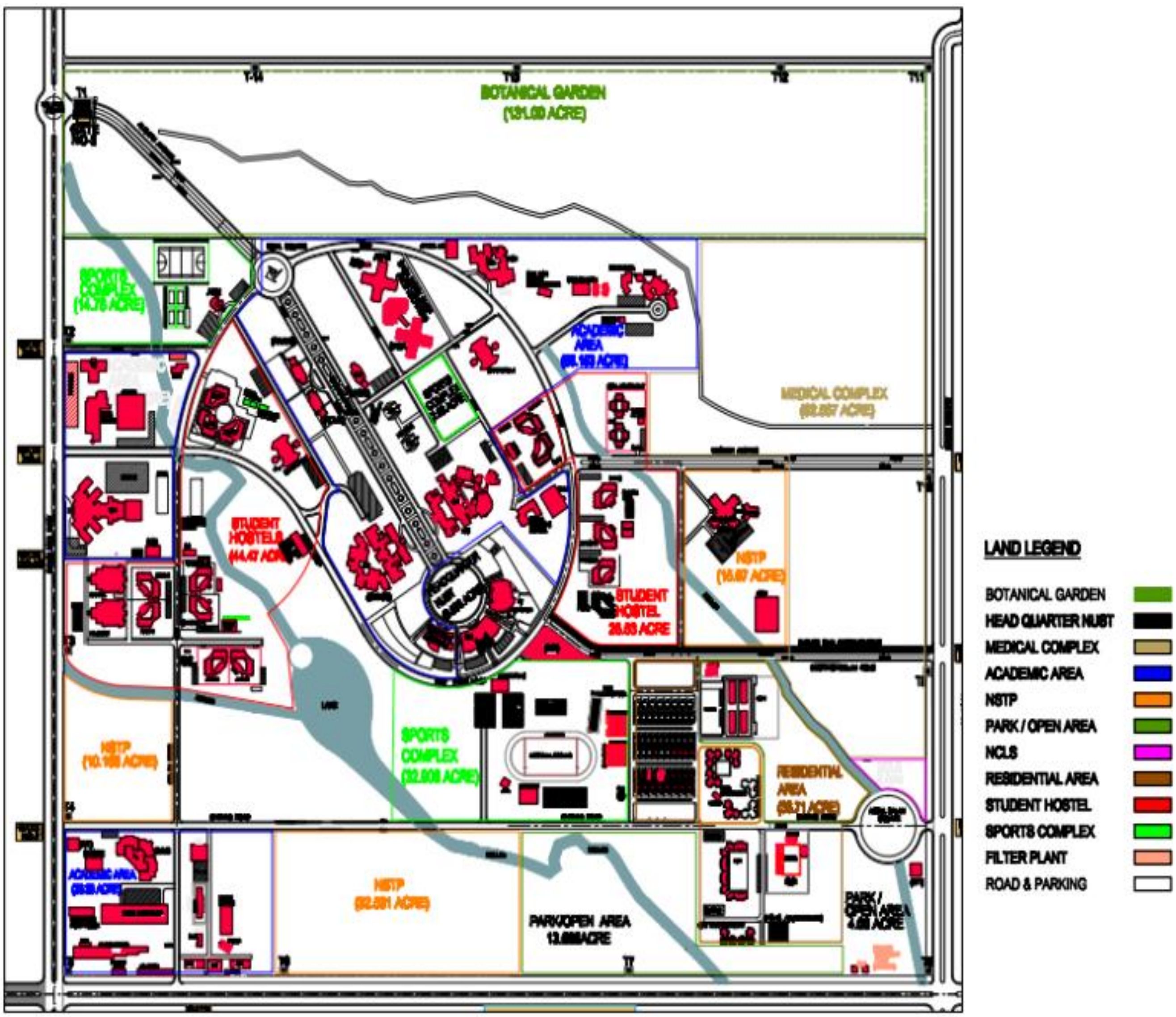


Figure 8. Recent map of NUST (Zain Sajid et al.,2021)

The rooftop areas selected for the vegetation in NUST are identified by physical survey and Google map images. This helps in identifying the amount of useful area which can be used for vegetation purpose. The rooftop areas for all buildings were already calculated by students of previous batch for their research purpose. The overview of total available rooftop areas and selected areas is represented in the table below.

Table 8. Data of Rooftop Areas

Sr. No.	**Building**	**Rooftop area (m^2)**	**Selected area (m^2)**
1	IESE	2320	1624
2	ASAB	2600	1820
3	SMME	2730	1911
4	SCME	1690	1183
5	S3H	1590	1113
6	RIMMS	500	350
7	SADA	2538	1777
8	NBS	6200	4340
9	IGIS	1000	700
10	SNS BLOCK2	585	410
11	SMME Workshop	1330	931
12	Rumi hostels	2223	1556
13	Fatima hostels	1482	1037
14	NSTP 1	2550	1785

15	NSTP 2	1720	1204
16	CIPS	2275	1593
17	Design Center	1330	931

(Zain Sajid et al.,2021)

Most of the rooftops in NUST are vacant and not used for any specific purpose. They were assessed on physical visits and their characteristics do not differ from one another. They can be used for any optimal use for which rooftop vegetation is good option.

6.2 Selection Criteria

Suitability of each rooftop area was assessed by keeping the certain criteria in mind to meet the optimal use and design. The following points were considered when selecting the rooftop area available for vegetation.

Only 70% of total rooftop area is selected for vegetation which is labeled as 'selected area' in the table given above. 5% of total available area is left vacant in between vegetation for movement, watering the plants, fertilization and other purposes. Other 35% of total area is left empty for other purposes like research setups, water tanks, pipes and so on.

We selected only specific area of rooftop for vegetation by keeping the building safety and bearing capacity of rooftop in mind. Thus, this will help to avoid any issue related to building.

The rooftop in most of most buildings are kept vacant and it proves them easy target to be used for vegetation and can be helpful in making NUST sustainable for vegetable consumption.

The flat part of the rooftop is considered to avoid any disturbance and thick plastic sheet can be used to prevent from seepage of water and moisture through the rooftop. The recycled sheets of plastic can be used for this purpose.

The wall around rooftop for safety purpose can be used for covering the vegetation by green sheet in extreme weather which includes extreme winter, extreme summer and heavy rainfall. Each of the rooftop is with wall around it so it can be effectively used.

Not all the buildings in NUST are considered for RTG instead only specific buildings are used with larger area available. By implementing RTG on rooftop of specific buildings we can meet the vegetable consumption of NUST. It fulfils the basic purpose which is making NUST sustainable. So, buildings with less rooftop area and busy rooftops are not chosen for the study and analysis.

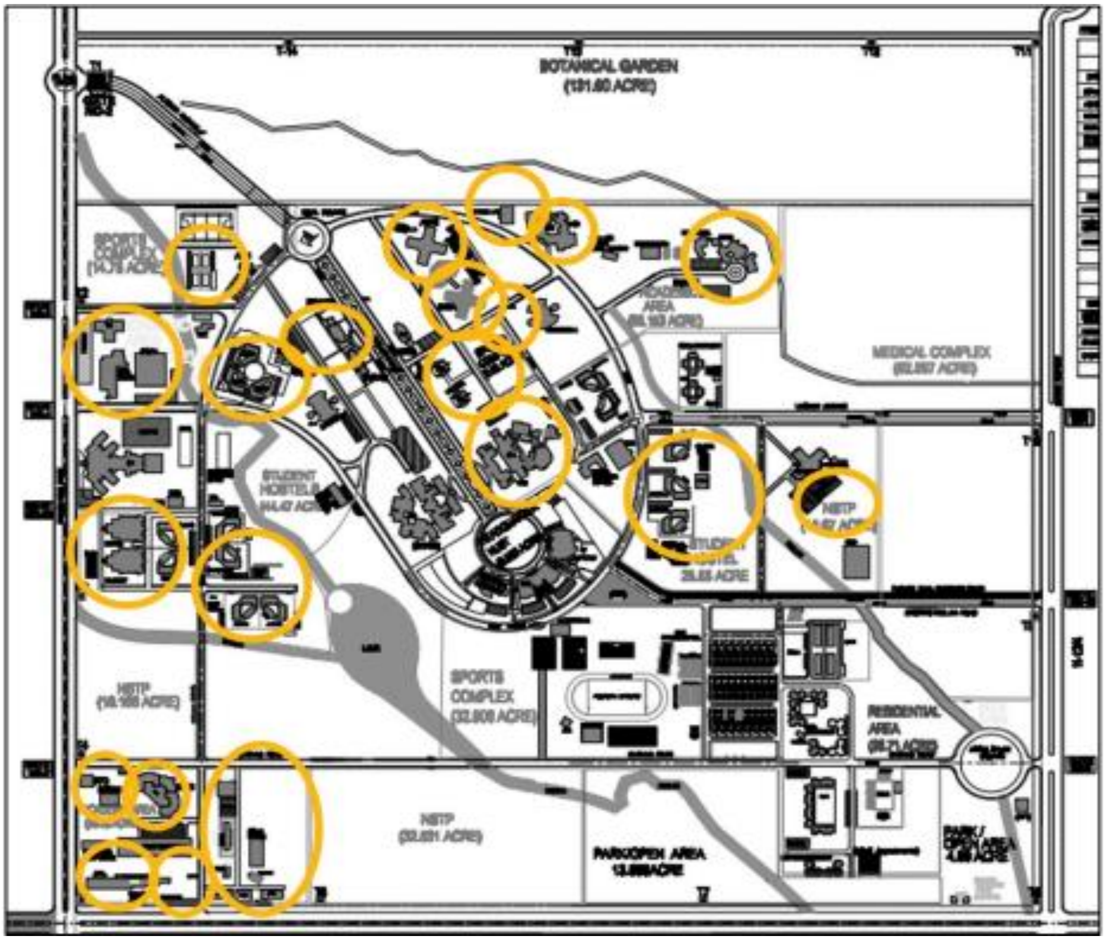


Figure 9. Selected buildings of NUST

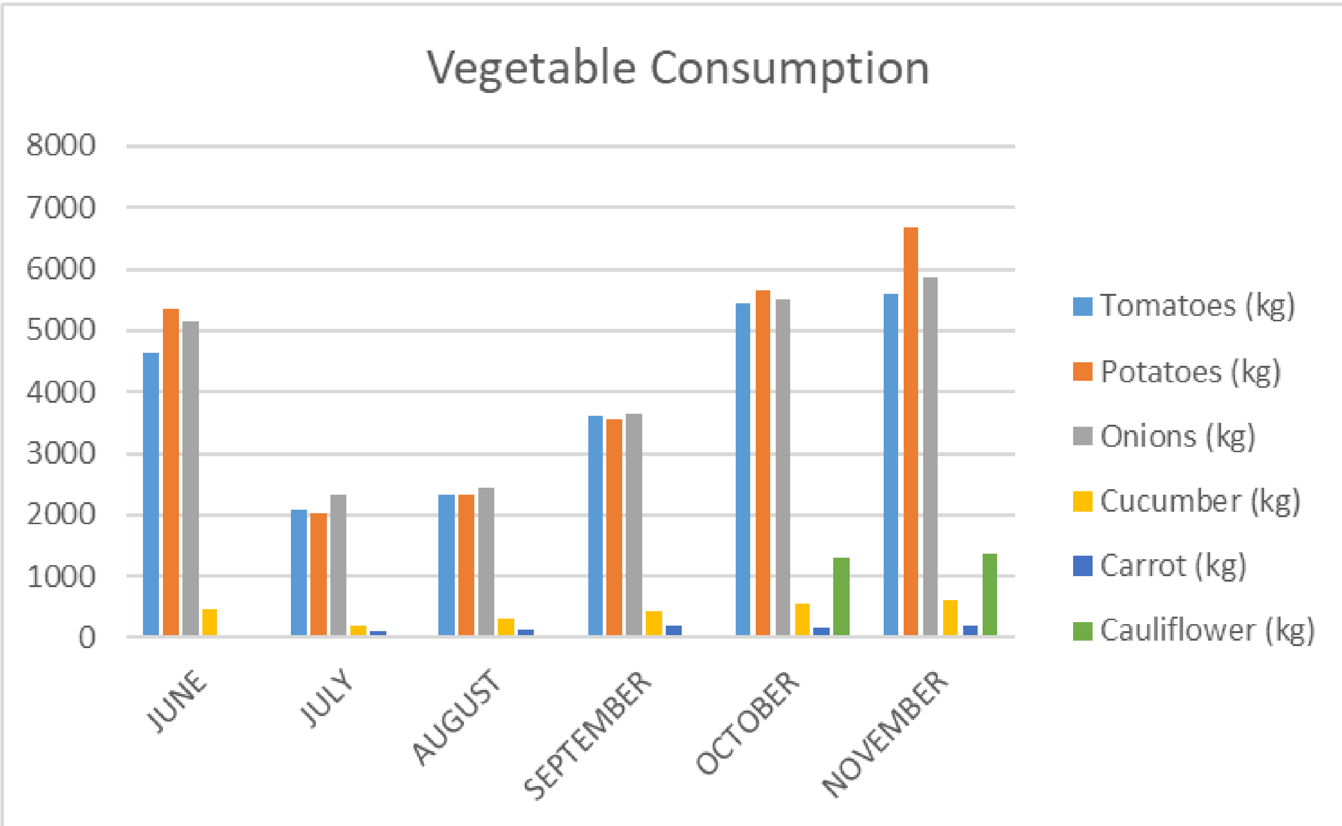
6.3 Calculations of Production from Pilot Scale Model

To study the effect of weather conditions and other parameters on production of vegetables in NUST was important. The geography of the area plays an important role on vegetable growth. Every vegetable needs specific climatic conditions to grow until harvested. We identified the vegetables those can be grown in climatic conditions of NUST by making analysis of weather using internet and location of NUST.

Since the pattern of vegetables consumption in NUST is almost same over the time intervals as the menu and number of students in hostels remains same. This helps to use the selected rooftop area effectively to meet the required quantity. For the vegetable consumption analysis, we obtained the data from NUST administration to check the consumption in different months over the year. Some of the vegetables were identified as major contributor which were used in large quantity almost in whole of the year. We developed the graph for vegetable consumption with w.r.t to months and quantity being used. The table given below shows the consumption of various vegetables in NUST.

Table 9. Vegetable Consumption Data

Details	**JUNE 2021**	**JULY 2021**	**AUGUST 2021**	**SEPTEMBER 2021**	**OCTOBER 2021**	**NOVEMBER 2021**	**TOTAL**
No of Students	79837	34052	37102	61077	102259	118242	432569
Tomatoes (kg)	4645	2094	2340	3603	5440	5590	23712
Potatoes (kg)	5350	2033	2320	3555	5665	6680	25603
Onions (kg)	5160	2310	2440	3660	5505	5855	24930
Cucumber (kg)	457	180	329	424	545	619	2554
Carrot (kg)	07	91	145	194	171	202	810
Cauliflower (kg)	-	-	-	-	1310	1355	2665



Graph 1. Vegetables Consumption in NUST

By looking at the table of vegetable consumption provided by NUST administration and the histogram of all vegetables, one can clearly predict that potato and tomato are the major vegetables consumed in NUST hostels. So, we picked tomato to study its production and then we can calculate production potential of NUST. The setup of model and all necessary information about it explained and shared in the chapters above. Also, all the critical requirements are being written as well.

We started the model in January 2022 and the plats matured in the end of April 2022 as the maturation period for tomato plants is 60-90 days. Then we built a record of production from the model in the form of table which is shown below. The given quantity is being harvested in time intervals of 4-5 days as the tomatoes are not usually harvested on daily basis.

Table 10. Production data of pilot scale model

Sr. No.	Quantity (kg)
1	**1.122**
2	**1.309**
3	**1.907**
4	**2.244**
5	**1.926**

Using the results obtained as shown in table, we can calculate the average production by formula which is represented below.

$$\text{Average production(kg)} = \frac{1.122+1.309+1.907+2.244+1.926}{5}$$

$$= 1.702 \text{ kg}$$

- The area of our model in the study was 1.87 m^2

So,

Avg. production on 1.87 m^2 = 1.702 kg

Avg. production on 1 m^2 = 0.91 kg

6.4 Calculating Production Potential for NUST

After getting the results for production of tomatoes on unit area in meter square, now the area of rooftops selected can be used effectively to produce the same quantity as consumption or more than consumption. By keeping in mind, the consumption pattern of vegetables we can develop the models as explained below.

6.3.1 Production Potential for Tomatoes

The maturation time for tomatoes is 60-90 days and its production can be harvested for 4-6 weeks. After that you need to sow new saplings and they will again get matured in 60-90 days. By keeping this factor in mind, we need at least four set ups for tomatoes to complete the cycle so that if the harvesting period of one model is near to end, the next model should be ready to meet the consumption of next month and so on.

Table 11. Maturation period for tomatoes

Starting month	Harvesting month
March	June
April	July
May	August
June	September

There are some months (Nov, Dec, Jan) are not suitable for tomato growth as temperature falls down to low and tomato cannot grow until fully covered. The addition of plastic sheet around the rooftop will increase the capital cost but it is justified as cost of tomatoes also gets hike in winters.

Set up 01:

From table, the consumption of tomatoes in June is 4645 kg. So, our model starting in March must meet this consumption. The set up can be made on following three schools.

Sr. No.	Building	Area (m^2)
1	NBS	4340
2	IGIS	700
3	RIMMS	350

Total area of three schools= 5390 m^2

Using the above area, we can calculate the production potential of the model.

Total expected production in June= 0.91*5390= 4904 kg

Total consumption in June = 4645 kg

Set up 02:

Similarly, the consumption in July is 2094 kg which is way less and we can use second model on small area which will start in April and its maturation time will be completed in July to meet the requirement. For this we can use area of two buildings as shown in table.

Sr. No.	Building	Area (m^2)
1	SMME Workshop	931
2	CIPS	1593

Total area of two buildings= 2524 m^2

Total expected production in July = 0.91*2524= 2296 kg

Total expected consumption in July= 2094 kg

Set up 03:

The third set up should start in May and expected to be harvested in August. The tomato consumption in August is expected to be 2340 kg. To meet this consumption, we can use area of Rumi and Fatima hostels.

Sr. No.	Building	Area
1	Rumi hostels	1556
2	Fatima hostels	1037

Total area of set up = 2593 m^2

Total expected production in August= 2360 kg

Total expected consumption in August= 2340 kg

Set up 04:

The last and fourth set up should start in June and will be harvested in September. This should meet the consumption in September. The consumption in September is expected to be 3555 kg. So, we can use the rooftop of NSTP 1, NSTP 2 and Design Center.

Sr. No.	Building	Area(m^2)
1	NSTP 1	1785
2	NSTP 2	1204
3	Design Center	931

Total area used = 3920 m^2

Total expected production in September= 3566 kg

Total expected consumption in September= 3555 kg

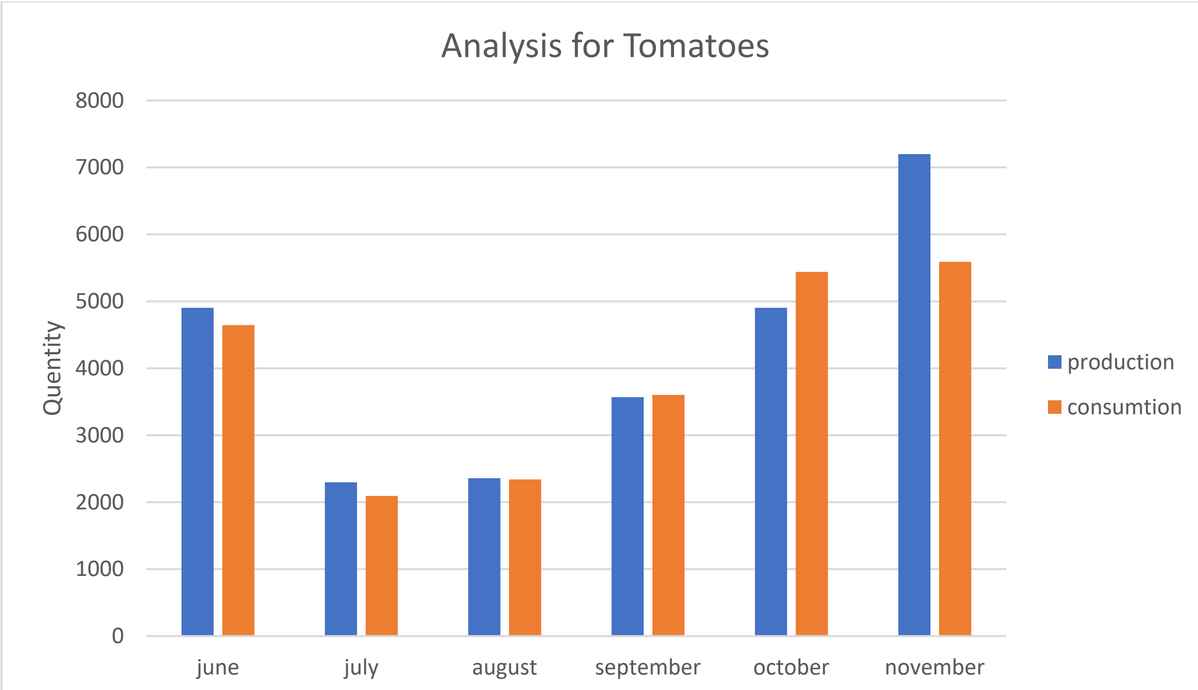
Note:

We recommended for set ups for production of Tomatoes by studying the pattern of consumption and maturation period of plants. Each set up should be started after the time interval of 1 month after the previous one. This will create a cycle and when one set up in on end of harvesting, the other will be ready to be harvested. The set-up areas are adjusted that they meet the consumption pattern, and they can fulfil the requirement automatically. The production pattern is aligned in a way that consumption can be fulfilled.

Now we can generate a table between the consumption quantity and production quantity of all set ups for the tomato vegetable. Similarly, the histogram between these both can be developed to check for the pattern of consumption and production.

Table 12. Consumption vs Production table

Month	Production (kg)	Consumption (kg)
June	4904	4645
July	2296	2094
August	2360	2340
September	3570	3603
October	4904	5440
November	7200	5590



Graph 2. Consumption vs Production Analysis of Tomatoes

Similar calculations can be made for other vegetables after making analysis of NUST climatic conditions and requirements for their growth. The consumption pattern can be studied from the table of consumption data and set ups for other vegetables can be developed to meet the consumption and to make the NUST sustainable.

Chapter 07

Analyses and Conclusion

This chapter basically focuses on analytical part of the system. The analysis is made to check if the system is practically feasible and can be implemented. This is the most important part of system which helps to decide and locate pros and cons of the system and model. It covers all type of costs and revenue generated. It also highlights the recovery of capital cost along with environmental benefits that can be observed on long period of time. All the parameters are studied thoroughly to perform these analyses.

The feasibility analysis is further divided into different types based on their impacts and advantages. The system is observed by comparison of different factors to make it successful and beneficial. Every type covers specific part of analysis and if it seems beneficial on over all scale then the implementation of system is recommended. Otherwise, the recommendations are made to make the system feasible in all aspects.

7.1 Environmental feasibility

This part of analysis covers all aspect of environment to make the system feasible. It includes weather patterns, wind pattern, temperature and precipitation and so on. Since the environment plays a vital role in growth of vegetables and their production, it is necessary to consider all the environmental parameters. All these parameters and their impact is already discussed in above chapters in explanatory way. While setting the pilot scale model, all these factors were kept under study and observation.

7.2 Financial Feasibility

This part of analysis includes all the costs involved in the system and the revenue can be generated possibility. The initial cost is way higher but then the cost reduces as the it will only then require maintenance. The main material used in vegetation is the soil which can be locally available. Indeed, most of the material is locally available or we can use homemade products.

Using the market rates of vegetable under study, which is tomato, we developed a table of money (PKR) NUST spent on buying vegetables and then the revenue we can generate by adopting rooftop vegetation model in NUST. Sustainability was the basic purpose and we achieved it by using only rooftop of specific buildings in NUST. We can generate more revenue by adopting and implementing the urban vegetation system on all rooftops of NUST. The more the area we use the more revenue we can generate. Table given below shows comparison of money spent on consumption and money we can generate from rooftop vegetation.

Table 13. Market rates of tomato

Month	Price per kg (PKR)
June	50
July	48
August	60
September	80
October	120
November	150

Table 14.Consumption price vs Production price

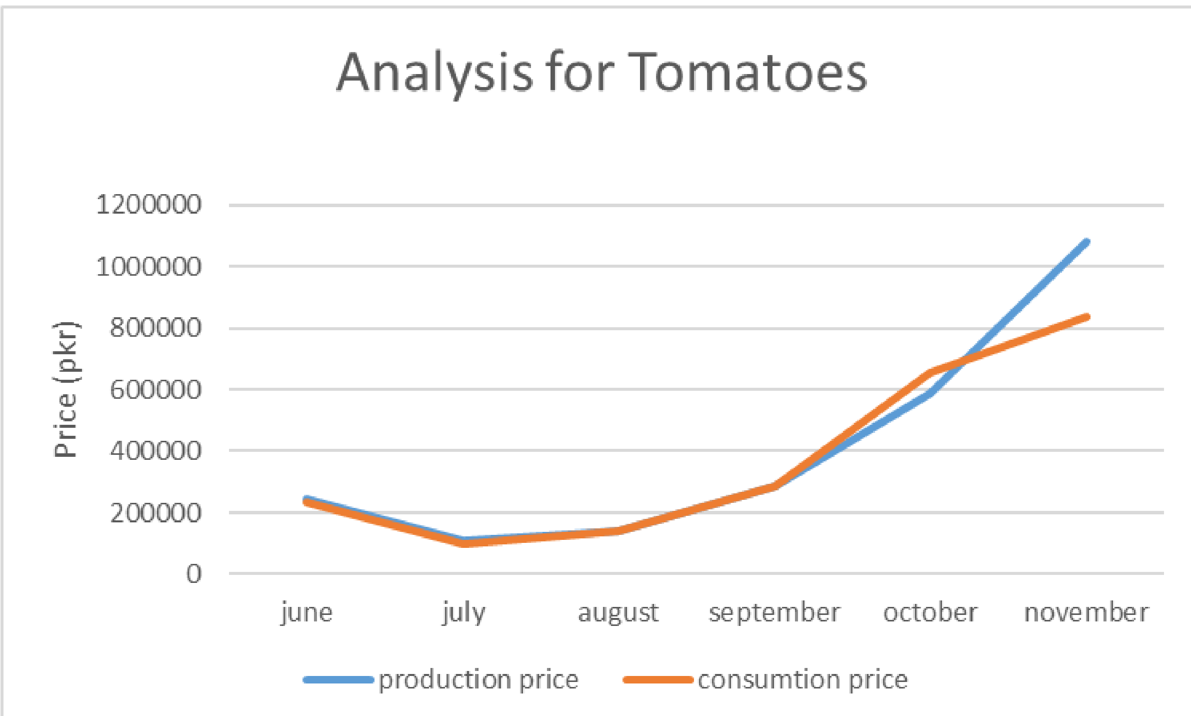
Month	production price (PKR)	consumption price (PKR)	Net profit
June	245200	232100	13100
July	110208	100512	9696
august	141600	140760	840
September	285600	288240	-2640
October	588480	652800	-34320
November	1080000	838500	241500
Total Profit			228176

The two tables shown above represent market value of tomatoes per kg in PKR on the basis of different month in a year. The price varies in each season depending upon the production of tomatoes. Usually, the cost of tomatoes is high in winter or cooler months as low temperature causes huge impacts on growth of tomatoes.

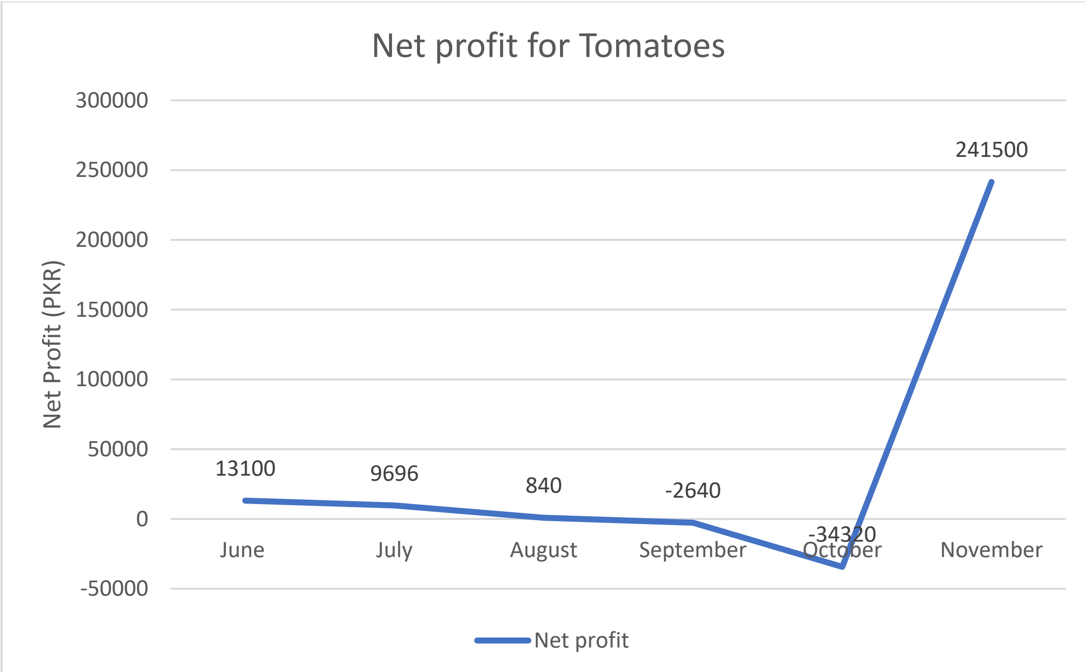
The second table represents the money spent on tomatoes in NUST and the revenue we can expect from production of tomatoes on rooftops. Then net profit is calculated by taking difference between both quantities. In some months the net profit id negative because of the consumption is more while the production is less. This can be overcome by using more area of rooftops in buildings of NUST. Thus, this will boost the production and can covers the net loss, and we can make profit in those months as well.

7.3 Cost Benefit Analysis

The graph between consumption price and production price is shown below for the purpose of comparison between both quantities.



Graph 3. Graph of production price vs consumption price



Graph 4. Net profit curve for tomatoes

7.4 Conclusions

Rooftop vegetation is one of the steps we can take towards green buildings. This system put many useful effects on building like reduction in energy spent on cooling. This system can be applied to make the urban society by using vacant rooftop space and making best use of it. It does not need any extra space and hence no financial burden is applied. The goal of food sustainability can be achieved.

During the pilot scale study, we observed decrease in temperature of 1.2 degrees centigrade. This can prove itself much more significant in energy consumption. We can calculate the cost of energy savings by calculating how much less units will be spent on running our inverters 1.2 degrees centigrade less than already running temperature of inverters. The cost be calculated by multiplying units saved with cost of one unit of electricity.

Green roof vegetation can prove itself a great initiative towards green technology practices and significant decrease in carbon dioxide emissions. A lot of fuel is consumed while transportation of vegetable items from villages to urban cities. This burning of fuel adds thousands of tons of carbon emissions into the environment. A big portion of vegetables also gets spoiled during its transportation to urban areas. By adopting green vegetation, we can make environment healthy and sustainable.

The problem of urban heat island is global issue, and it is increasing over time. More heat means more cost of building cooling. This has also increased energy demands in major part of the year. Green roofs are natural and sustainable way of controlling building heat inside and outside. This can be a great step towards heat reduction in the perimeter of building.

Overall study and analysis show that 1st world countries are moving towards natural solutions and green building technologies due to environmental crisis increase cause by industrialization and tremendous population around the world. Environmentally friendly solutions towards health and food problems are welcomed on international platforms. NUST can adopt this model to sustain its vegetable consumption and generate revenue by using rooftops of all buildings effectively. This will also help to manage energy consumption during working hours and decreases load on grid stations. This will ultimately lead to less fuel consumption overall.

7.5 Recommendations

General recommendations on the basis of project analysis are made below to cover the problem faced and to show awareness about its advantages. These recommendations can help to understand the purpose and needs of the system for implementation.

We can integrate green roofs in urban planning, to support food security, to conserve energy and reduce the money spent on air conditioning systems. Green infrastructure aims to make cities more resilient and less dependent on outside resource inputs through more efficient use.

Hydroponics is the latest technological innovation used in the urban area for agriculture where the quality of the soil is not as good for cultivation. It helps plants to grow in mineral nutrient solutions without using enough soil like perlite and gravel to solve the problem of soil quality, which ultimately increases the production of urban agriculture

The water requirement of outdoor grown tomatoes varies between 4000 - 6000 m^3/ha. In greenhouses up to 10,000 m3/ha of water are required. 70% or more of the root system are in the upper 20 cm of the soil. Therefore, a drip system is advisable if we are to construct a rooftop garden at our rooftops at a considerably large area.

According to **“Building Code of Pakistan”**, greenhouse roof bars shall be designed to carry a 450 Newton (100 pounds) minimum concentrated load, in addition to the uniform live load. However, it is best to consult a civil engineer and check for building standards.

The revenue generated from production of vegetation can be used to meet the vegetation requirement when the climatic conditions are way too harsh for growth of vegetables. This revenue can also be used to store the vegetables which can only grow in specific months so they can be used throughout the year.

Since it includes a big capital cost to set the system on rooftops and building safety is concerned as high priority of owners, so we need strong convincing power to make this possible. Adding up all the environmental benefits of the system and revenue generation can help in convincing the authorities. Moreover, awareness related to environmental crisis can play an important role in this case.

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