ROLE OF URBAN GREEN INFRASTRUCTURE (UGI) IN REDUCTION OF URBAN HEAT ISLAND (UHI) EFFECT IN CITIES

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OF

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IN

HYDRAULICS AND WATER RESOURCES ENGINEERING

SUBMITTED BY

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I, KRINSHU SHARMA, Roll No. 2K20/HFE/04, student of M.Tech (Hydraulics and Water Resources Engineering), hereby declare that the project Dissertation titled "ROLE OF URBAN GREEN INFRASTRUCTURE (UGI) IN REDUCTION OF URBAN HEAT ISLAND(UHI) EFFECT IN CITIES", is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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I hereby certify that the Project Dissertation titled "ROLE OF URBAN GREEN INFRASTRUCTURE (UGI) IN REDUCTION OF URBAN HEAT ISLAND(UHI) EFFECT IN CITIES" which is submitted by Krinshu Sharma, Roll No. 2K20/HFE/04, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge and based on declaration of student, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

The urbanization of major cities gets further accelerated in the near future and due to this the environmental parameters like atmosphere, biosphere, hydrosphere, and lithosphere also gets drastically affected which in turn affect the Global Climate Change (GCC). It refers to the long-term shift in temperature and weather pattern. It is a prime major of concern in the present scenario and many countries in the world are adopting the sustainable ways to deal with it. From many studies, it has been found that the carbon-di-oxide concentration drives global climate change and is indirectly responsible for risks related to other climate indicators such as rise in temperature, change in rainfall pattern, to list a few.

The rise in temperature in the cities due to urbanization causes the heat island effect. In this, the cities tend to experience higher temperatures than its proximate neighboring rural or non-urban area. As we know, the capital city of India i.e., New Delhi is known for its inordinate heat conditions during summer months during which the highest day-time temperature on an average rise to 46 degrees Celsius and the night-time temperature falls to 37 degrees Celsius as per the IMD (Indian Meteorological Department) data maintaining a temperature difference of 15 degrees Celsius with the nearby rural areas causing the effect of urban heat island in the city.

For this study, three-dimensional urban microclimate simulations were carried out to reduce the effect of UHI. The study area chosen is the Academic Block of Delhi Technological University. The parameters used were the percentage of green cover surrounding the site, atmospheric temperature, speed of wind, orientation of the building and other factors such as impervious surface and anthropogenic conditions. From the study, it was found that by the increment of vegetation in the vicinity by means of green roofs and more roadside cover the value of maximum temperature decreased by 0.19 degrees Celsius and the value for minimum temperature decreased by 0.47 degrees Celsius.

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LIST OF ABBREVIATIONS

AQI = Air Quality Index
AHI = Atmospheric Heat Island
CFD = Computational Fluid Dynamics
DEM = Digital Elevation Model
GHG = Green House Gases
GI = Green Infrastructure
GCC = Global Climate Change
H/W ratio = height- width ratio
HVAC = Heating, Ventilation and Air-Conditioning
LAD = Leaf Area Density
MRT = Mean Radiant Temperature
NDVI = Normalized Difference Vegetation Index
Pa = Pascal
PAT = Potential Air Temperature
PET = Physiological Equivalent Temperature
PM = Particulate Matter
PMV = Predicted Mean Vote
RAD = Root Area Density
RH = Relative Humidity
UGS = Urban Green Space
RSB = Residential Solar Block
SHI = Surface Heat Island
UAS = Unmanned Aerial System
UGI = Urban Green Infrastructure
UHI = Urban Heat Island
WC = Water Content

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND RESEARCH

The city always experiences increase in population and subsequential expansion which leads to the upsurge in urban built-up density. Building materials having higher albedo values emits back most of the atmospheric radiations which causes rise in temperature. Natural surfaces like open ground soil add vegetation absorbs most of the solar radiation and releases water vapour through the process of evapotranspiration keeping the surroundings cooler than the build-up area. Due to more build up area in most of the urban areas and less presence of vegetation area results in higher temperatures than the surrounding suburban or rural area causes the phenomenon known as urban heat island (UHI) effect. The artificial way of generation of heat by vehicular emissions and air conditioning equipment are mainly done by the man-made causes which is known as the anthropogenic heat which increases this effect in the cities. The temperature difference between the city and nearby area causing the urban heat island effect can be as high as 12 ^{o}C. The adverse effects of you hi include increase in thermal discomfort of people which results in higher energy consumption by means of using airconditioned buildings. This problem is more prominent in developing cities, and it has been estimated that by the year 2030, more than 3 billion people will leave in the urban areas in the world grieving more to this problem.

Urbanization always demands for the development in infrastructure and but this the basic amenities comes in hand. The rapid growth in infrastructure has results in the increase of hard surface in the form of pavements and roadways with high albedo values. This has resulted in the increase in more reflective surfaces causing the temperature to rise and making discomfort at human comfort level.

The national the national capital of India New Delhi has a very high population density and vehicle air condition. Delhi's population has risen in from 9.1 million in 1991 to more than 32 million in 2022. The farmlands and grasslands nearby New Delhi are getting replaced by urban build-ups making it as one of the fastest urban expansions in the world. Delhi has a semi-arid climate. Its climate is an overlap between semiarid and monsoon influenced humid subtropical with high variation in temperatures and precipitation for summer and winter.

Summer in Delhi starts in early April and peaks in late May or early June within average temperatures near 38 ^{o}C. On some days, the apparent temperature of the city is close to 45 ^{o}C. Half the peripheral of New Delhi is surrounded by other major cities such as Gurugram, Faridabad, Noida and Ghaziabad. The rest of the periphery is surrounded by rural areas from states of Haryana and Uttar Pradesh. These major cities are spreading out over a large area with impermeable build-ups resulting in higher atmospheric temperature for the city. During daytime, the temperature of the city rises to 49 ^{oC} while the nearby rural areas have temperature increase of 45 ^{o}C. Temperature of the city during night-time is 35 ^{o}C and rises as close to as 39 ^{o}C while the temperature in the nearby rural areas is around 15 ^{o}C (Source Indian Meteorological Department) . This vast difference between the temperatures of the city and the nearby rural area during night-time creates the phenomenon of urban heat island effect. The following map showing the location of Delhi and its nearby cities.

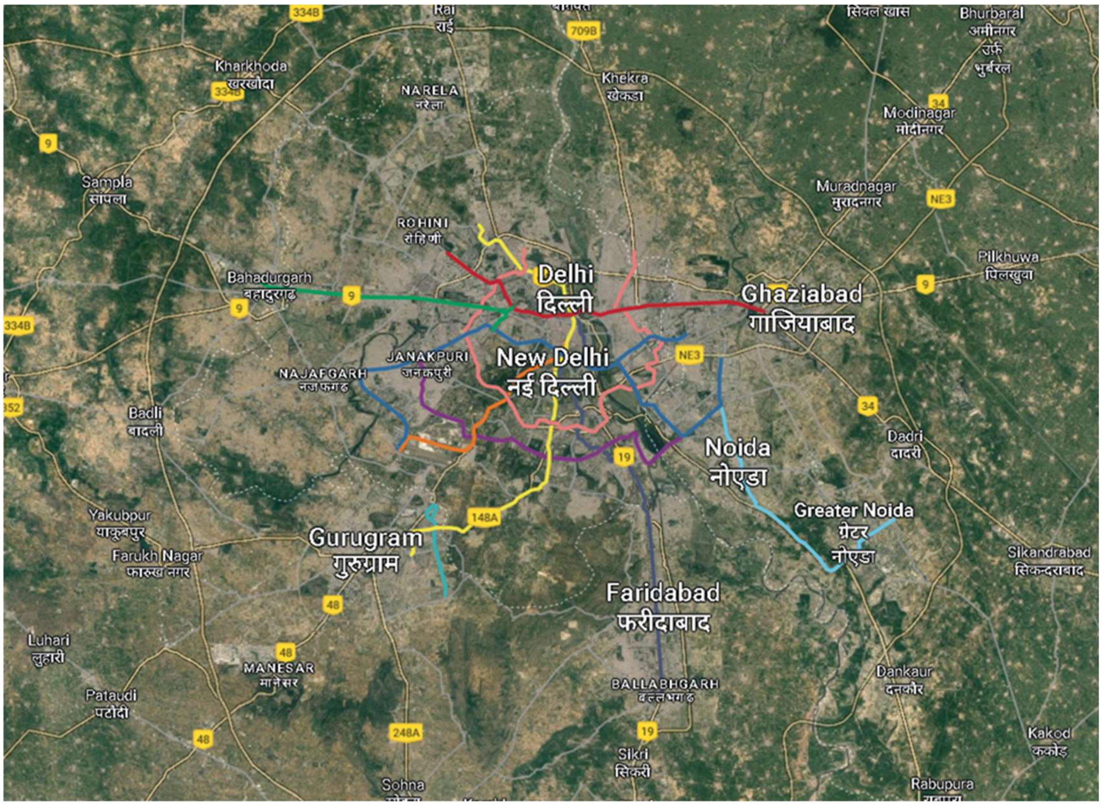


Figure 1.1.1 Satellite Image showing Delhi city and nearby cities

(Source: Google Maps)

The total area of the city is1484 Km^2 of which forest area covers 195 Km^2 which is 13.14% of the total area. But for the past decade, the city has lost its 0.44 Km^2 of forest cover dropping by 0.23% of the existing forest cover which is less than the national average forest cover which is 24.62% of the geographical area of the country. On the other hand, urbanisation area in and around the city has increased by 17% in the last 5 decades. this is the reason that has increased the high emissivity surfaces and the unshaded areas causing increase of temperature by 1.5 ^{o}C compared to the pre-industrial which is considered as the critical cut-off point for survival of mankind. Warmer weather increases the risk of weather contributing to heat waves, which results in high influx of direct and diffused solar radiation. This also has an impact on the air quality of the city. The AQI was measured more than 360 for the month of April 2022. The city showed an AQI of more than 300 for 29 days for the month of April. Recent studies by International Energy Agency shows each country share towards the greenhouse (GHG) emissions in which India is ranked 3rd for contributing 7% of the total worldwide emissions out of that 7%, New Delhi share is around 2.3% alone. Air quality, the surface urban heat island can also affect water quality by raising the temperature of surface runoff water after flowing over the heated pavements and concrete surfaces. This storm water flowing into the water bodies tends to Disturb the balance of aquatic ecosystems.

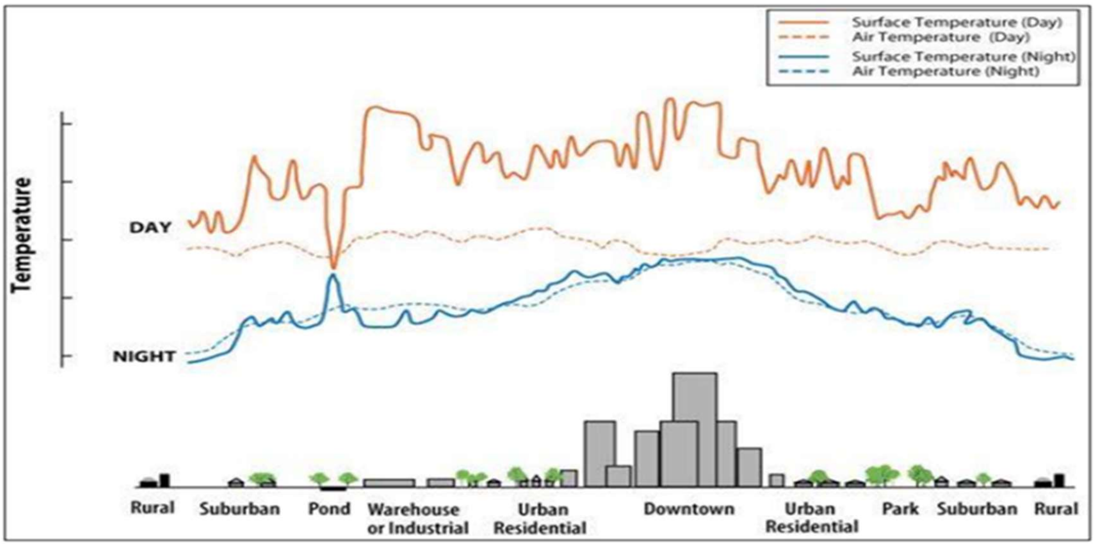


Figure 1.1.2: The diurnal difference between surface heat islands (SHI) and atmospheric heal islands (AHI). Both types are present during the day and night, but the influx of solar radiation makes the SHI stronger. (Source EPA, 2008)

It has been estimated that for every 0.6 °C rise in temperatures, there would be rise in electricity consumption of about 2%. This thermal discomfort leads to the increase in use of air conditioning appliances, resulting in increase of emission of harmful greenhouse gases which leads to global climate change.

The only way to mitigate the problems caused by raising temperature is by adopting sustainable methods. It is a principle for meeting human development goals while also sustaining the ability of natural systems to provide the natural resources and ecosystem services on which the economy and society depends.

1.1.1 URBAN HEAT ISLAND AND CLIMATE CHANGE

The effect of Urban Heat Island and climate change is a two-fold phenomenon. Firstly, the heat build-up can worsen the effect of global warming in affected areas resulting in severe heat waves with high daytime summer temperature.

Secondly, the heat trapped by the buildings leads to the increase in electricity demand for cooling. As developing countries are predominantly dependent on conventional methods of energy generation, increased electricity demand can cause searching the rate at which greenhouse gases are released into the atmosphere. For developing countries with limited natural resources, increase in demand of electricity can lead to economic stress.

Hence employing strategies to mitigate UHI can be beneficial for tropical countries.

1.1.2 TYPES OF UHI

Based on its impact, the urban heat island effect can be of two types: Surface UHI and Atmospheric UHI.

a. Surface-Urban Heat Islands

   These are caused when the heat from solar radiation is absorbed by dry and exposed surfaces of the urban set-up. Its magnitude is thus dependent on the intensity of solar radiation, which changes seasonally and diurnally. Therefore, Surface Urban Heat Islands are highest during summers, especially during the daytime. Another reason why summers characterize high Surface UHI is that: in summers, due to prevalent clear-sky conditions, the solar radiation remains undispersed. Also, the days are calm, with low wind speeds, because of which the mixing of air is minimized.

b. Atmospheric Urban Heat Islands

These are formed where there is a difference between the air temperatures of urban and rural areas. These are further sub-dived into two types: Canopy Layer UHI and Boundary Layer UHI.

Canopy Layer UHI occurs close to the ground surface, where people and built environment exists, that is from the ground surface to the topmost level of trees and roofs.

Boundary Layer UHI occurs at a level starting from the rooftops and treetops, until the point where urban landscapes no longer affect the atmosphere.

1.1.3 URBAN HEAT ISLAND AND URBANIZATION

The increase in the build-up environment has led to the rampant eforestations which has resulted in the reduction in urban green cover causing urban heat island. Thus, UHI mitigation strategies should aim to restrict the excessive heat build-up by:

a. reduction of hard and impervious surfaces
b. providing sufficient shading from solid radiation
c. reducing anthropogenic GHG emission

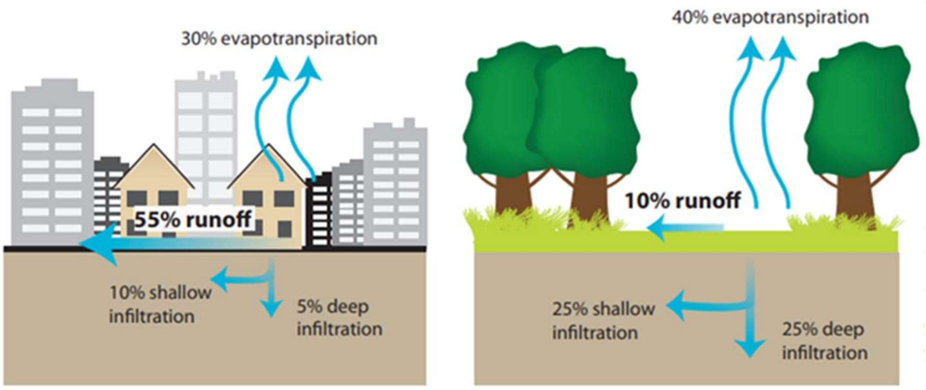


Figure 1.1.3.1: Image showing the water retention into the ground in urban and rural areas

Highly developed urban areas (right), which has 75%-100% impervious surfaces, have less surface moisture available for evapotranspiration than natural vegetative cover area, which has less than 10% impervious cover (left). This characteristic contributes to higher surface and air temperatures in urban areas.

Urban materials have properties louch as solar reflectance, thermal emissivity and heat capacity which influences the urban heat island development as the show the reflection, emission and absorption of the heat energy. Solar reflectance of a material a property known as the albedo which is a tendency to reflect the solar energy play surface. Energy is related with wavelength hence it is correlated with a materials colour. Darker surfaces tend to have higher values of albedo than the lighter surfaces.

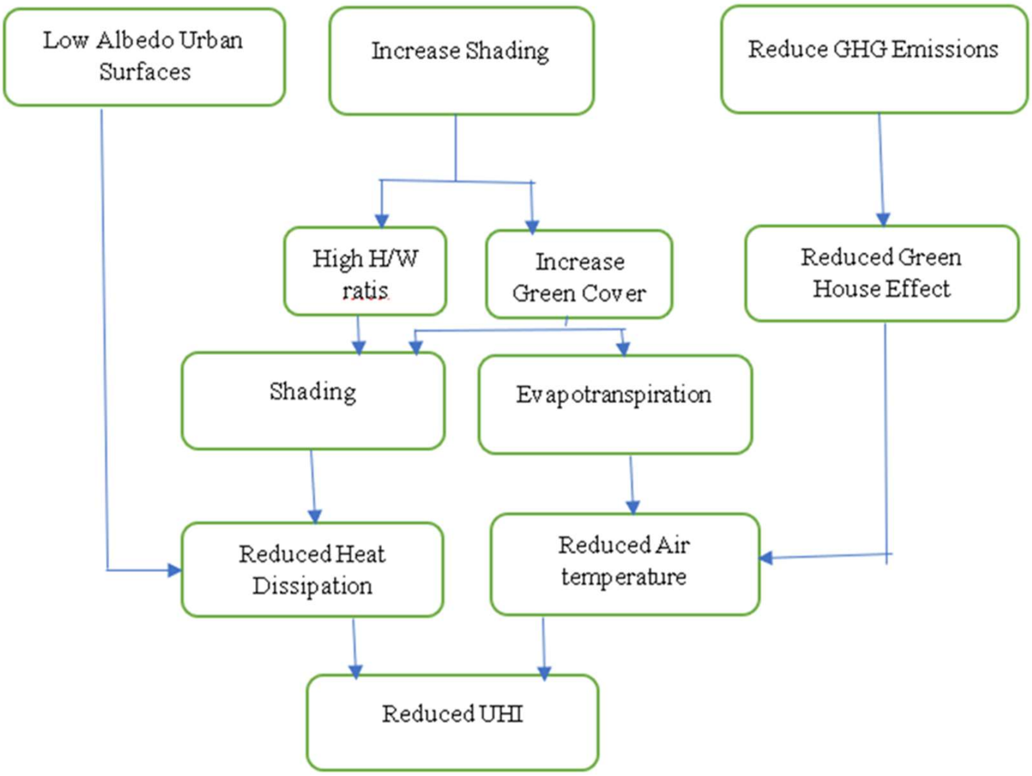


Figure 1.1.3.2: UHI Mitigation measures

1.1.4 SURFACE ENERGY BALANCE OF URBAN AND RURAL AREAS

The built-up surface of the urban area interacts with the urban climate in various ways. The fluxes of heat, moisture and momentum are significantly altered by the urban surface. The anthropogenic input of pollutants in the urban atmosphere changes the wave radiation budget by reducing the incident flux of short-wave solar radiation, by re-emitting long-wave radiation to the urban surfaces, and by absorbing long-wave radiation which then warms up the air. The impervious surfaces in the built-up environment does not absorb rainwater and remains dry. This leads to the evaporation deficiency in the city. However, in the rural areas, the grasslands and farmlands retain water and remains moist. These moist surfaces enhance latent heat flux by evaporative cooling..

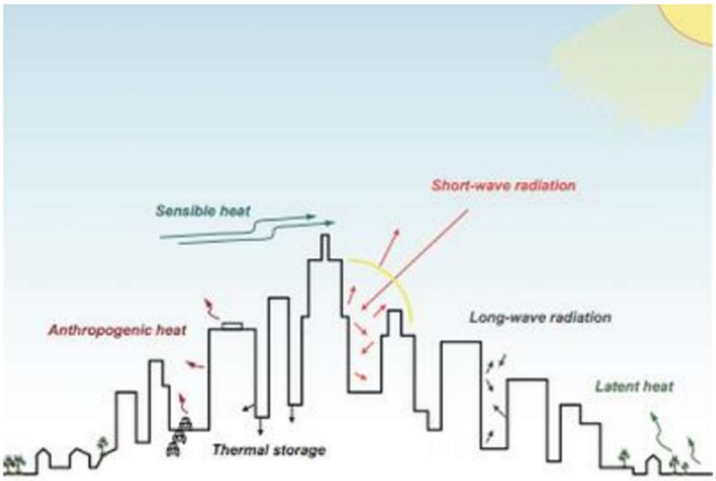


Figure 1.1.4.1: Radiation fluxes and effect of urban canyons

The enclosures formed by tall buildings and streets, known as urban canyons, can behave as radiation traps. During the day, the canyon surfaces continuously absorb short-wave radiation from the sun and release it slowly to the sky as long wave radiation during the night. Where the canyons are tall and the sky-view factor is less, most of the long-wave radiation remains trapped in the canyon below the canopy level, causing an increase in the urban heat island effect.

1.1.5 ESSENTIAL UHI PARAMETERS

1.1.5.1 Potential Air Temperature (PAT)

The temperature that an unsaturated parcel of dry air would have if brought adiabatically and reversely from its initial state to a standard pressure, p_o, typically 100 kPa.

Its mathematical expression is,

$$\Theta = T\,(p_o / p)^{K}$$

Where, Θ is the potential temperature
T is temperature
and K is the Poisson’s constant

1.1.5.2 Relative Humidity (RH)

It is a measure of how much water vapor is in a water-air mixture compared to the maximum amount possible. RH is a ratio of the humidity ratio of a particular water-air mixture compared to the saturation humidity ratio at a given temperature

1.1.5.3 Diffuse Shortwave Radiation

Diffuse SW Radiation is solar radiation reaching the Earth's surface after having been scattered from the direct solar beam by molecules or particulates in the atmosphere.

1.1.5.4 Predicted Mean Vote (PMV)

PMV is an index that aims to predict the mean value of votes of a group of occupants on a seven-point thermal sensation scale. Thermal equilibrium is obtained when an occupant’s internal heat production is the same as its heat loss. The heat balance of an individual can be influenced by levels of physical activity, clothing insulation, as well as the parameters of the thermal environment. For example, thermal sensation is generally perceived as better when occupants of a space have control over indoor temperature (i.e., natural ventilation through opening or closing windows), as it helps to alleviate high occupant thermal expectations on a mechanical ventilation system. Within the PMV index, +3 translates as too hot, while -3 translates as too cold, as depicted below.

1.1.5.5 Mean Radiant Temperature (MRT)

MRT is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure. MRT is a useful concept as the net exchange of radiant energy between two objects is approximately proportional to the product of their temperature difference multiplied by their emissivity (ability to emit and absorb heat). The MRT is simply the area weighted mean temperature of all the objects surrounding the body. This is meaningful as long as the temperature differences of the objects are small compared to their absolute temperatures, allowing linearization of the Stefan-Boltzmann Law in the relevant temperature range. There are different ways to estimate the mean radiant temperature, either applying its definition and using equations to calculate it or measuring it with thermometers or sensors.

Since the amount of radiant heat lost or received by human body is the algebraic sum of all radiant fluxes exchanged by its exposed parts with the surrounding sources, MRT can be calculated from the measured temperature of surrounding walls and surfaces and their positions with respect to the person. Therefore, it is necessary to measure those temperatures and the angle factors between the person and the surrounding surfaces. Most building materials have a high emittance ε, so all surfaces in the room can be assumed to be black. Because the sum of the angle factors is unity, the fourth power of MRT equals the mean value of the surrounding surface temperatures to the fourth power, weighted by the respective angle factors.

1.2 MITIGATION STRATEGIES

Urban green infrastructure is an important part of sustainable Urban Development. Green spaces as a network can have a major positive impact on the environment, societies and economies. Green spaces added as a building statement in cities are said to be an effective way to minimise the urban heat island effects and it also provides relief to residents. The built-up green space has cooling effect surrounding environment cooling the actual space. Rapid crease in global temperature patterns in the environment have resulted from the increased concentration of greenhouse gases in the Earth's atmosphere. Measurements have already proved the efficacy of green infrastructure introducing urban thermal islands. Green infrastructure has increased levels of thermal comfort than other urban spaces. This is particularly true for urban forest and big parks, which can have daytime temperature as low as 0.94 ºC. Another recent review study found that the size and shape of a UGS affects its thermal comfort and UHI reduction effect. The cooling effect of UGS is directly associated with its vegetation cover and tree shaded area.

Presence of green fields, trees another vegetation can help introduction of ambient temperatures. Shaded and evapo-transpiration helps to cool air and ground. shading provided by trees and plants reduces the amount of direct solar radiation received by urban surfaces. Building shading by vegetation reduces the need for electricity used for air conditioning resulting in lower energy demand, less pollution and greenhouse gas emissions.

1.2.1 ROLE OF ALBEDO

On a scale of 0-1, albedo is measured. A 0 indicates that the material's surface absorbs all the sunlight that strikes it. A 1 indicates that a substance represents all light energy that it encounters. To put it another way, a 1 on the albedo scale equals 100% reflection. A 0 indicates that there is no reflection. For e.g., fresh asphalt has an albedo of about 0.04, meaning that only 4% of the light is reflected. The remaining 96% is absorbed. When a material receives solar rays, some of the light energy is converted to heat energy, which causes the material to heat. On a hot sunny day, therefore walking around an asphalt parking lot feels hot. The influence of albedo in populated areas with many buildings and inhabitants may lead to a phenomenon known as an urban heat island, which is an area with a higher average temperature than neighbouring rural areas. Materials that are cool have high reflectivity that help to preserve lower surface temperatures, making them an efficient way to reduce UHI.

1.2.2 ROLE OF ANTHROPOGENIC HEAT

The built environment is linked to environmental changes such as rising urban temperatures, increased energy use, increased use of raw materials, deforestation, and waste generation, transfer of rural to developed land, habitat degradation, and water scarcity. Buildings that are not built for high climatic efficiency need much more energy for space cooling and lighting. A climatic environmental phenomenon known as the "urban heat island" (UHI) has emerged because of the concentration of anthropogenic activities into urban areas. As a function, this becomes an unhealthy and not a sustainable cause that contributes to unnecessary energy use for cooling, putting the urban population at risk of increased morbidity and mortality. Considering the above, and with the impending rapid and massive population growth, it is becoming increasingly necessary to implement UHI reduction strategies in order to minimize energy demand and increase quality of life while focusing on energy consumption. Anthropogenic carbon dioxide emissions originate in urban environments from the burning of fossil fuels for heating and cooling, manufacturing activities, and people and products transportation. Pollutant sources that are both stationary (industrial) and nonstationary (vehicles) are increasing, resulting in deteriorating ozone conditions. While anthropogenic heat, low wind speeds, and air quality in urban areas can all lead to UHI formation, there are two key reasons for UHI formation.

- Moisture is unavailable to dissipate the sun's heat due to impermeable and watertight

- Dark materials, in combination with urban canyons, absorb and trap much of the sun's energy. During the day, temperatures on dark, dry surfaces under direct sunlight can reach 88°C, whereas temperatures on vegetated surfaces with damp soil can reach till only 20 ^{o}C.

Cooling and ventilation, construction, transportation, and lighting are also examples of anthropogenic heat sources. The metabolisms of humans and animals are also called artificial heat sources. By conduction, convection, and radiation, heat from these sources warms urban atmosphere. Particulate, water vapor and carbon dioxide emissions from manufacturing, residential and vehicle combustion systems contribute to air pollution. These emissions alter the net all-wave radiation in cities.

1.2.3 ROLE OF GREEN SPACES

Green species can be added in the society in various sizes like parks, wildlife corridors, urban forests, national parks, etc. They have different functions in cities and their surroundings. Green infrastructure (GI) force generally towards system of natural and artificial green spaces that provides ecological and social functions in urban areas. GI Includes not just green and blue spaces also other physical features in terrestrial and marine areas, hedges, agriculture fields common green roofs and walls eco-bridges and fish ladders. Has been introduced in the urban environment to direct mostly the stormwater runoff through soil and vegetation-based techniques and other benefits such as air and water purification, energy demand reduction urban heat island mitigation, carbon sequestration commerce thetic enhancement in natural resource benefits.

The green faster check concept has been applied mostly to advance settings in effort to improve city's structure and ensure that benefits of natural capital are granted in urban system dominated by built areas. Urban green spaces support biodiversity and provides a variety of ecosystem services which is crucial for the wellbeing of urban population in terms of their health benefits. Urban green spaces provide habitats for species and novel ecosystems, agricultural connectivity and food security purify air and water, moderates local climate, sequester carbon dioxide, reduce soil erosion, elevate noise pollution, increase real state value improve neighbourhood in landscape aesthetics and enhances humans physical and psychological well-being.

Implementation of GI at different scales may increase urban adaptability to environment changes and the provisioning of ecosystem services by green spaces. Moreover, common GI contributes to the green economy by playing a crucial role in climate change adaptation and mitigation in urban areas into circular economy by providing bio-products.

1.3 MOTIVATION

After learning about UHI and UGI and their co-dependency and various tools used for its measurement, I decided to do a project in this field. There are various tools available by which we can calculate the amount by which green spaces has been useful in the reduction of urban heat island effect.

For this project, I chose Academic Block of Delhi Technological University. The building is covered with green lush all around and inside of it. It is a G+3 storey building.

1.4 OBJECTIVE OF THE RESEARCH

The aim of my project is:

i. to observe the phenomenon of heat island in the surrounding area and human thermal comfort
ii. to observe the impact of urban parameters like vegetation and building materials on urban micro-climate
iii. to carry out parametric analysis for mitigating UHI using various surface finishes

1.5 DEFINITIONS OF IMPORTANT TERMS USED:

1. **Aerodynamic Roughness Length:** The height above the displacement plane at which the mean wind becomes zero when extrapolating the logarithmic wind speed profile downward through the surface layer. It is a theoretical height that must be determined from the wind speed profile and is related to the height to the arrangement, spacing and physical height of individual roughness elements such as trees or houses.

2. **Albedo:** It a non-dimensional, unitless quantity that indicates how well a surface reflects solar energy. Albedo varies between 0 and 1. Albedo commonly refers to the "whiteness" of a surface, with 0 meaning black and 1 meaning white.

3. **Albero:** It is a Latin word used for trees.

4. **CO_2 fixation type:** It is the process by which inorganic carbon (particularly in the form of carbon dioxide) is converted to organic compounds by living organisms. The compounds are then used to store energy and as structure for other biomolecules.

5. **Emissivity:** It is the ability of a material to emit energy and is strongly correlated. with its surface characteristics. Emissivity values can vary between 0 (perfect reflector/mirror) and 1 (perfect emitter/blackbody).

6. **Façade**: A façade is generally the front part or exterior of a building. It is a loan word from the French façade, which means 'frontage' or 'face'. In architecture, the façade of a building is often the most important aspect from a design standpoint, as it sets the tone for the rest of the building.

7. **Heat Capacity**: It is a physical property of matter, defined as the amount of heat to be supplied to an object to produce a unit change in its temperature. The SI unit of heat capacity is joule per kelvin (J/K).

8. **Hydraulic Conductivity:** It is a property of vascular plants, soils and rocks, that describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid.

9. **Leaf Area Density (LAD):** It is a key index for characterizing the vertical and horizontal crown structures and is defined as the total one-sided leaf area per unit volume.

10. **Matrix Potential of Soil**: It represents the relative availability of the amount of water held in the soil profile for plant uptake/use and indicates how much energy plants will have to exert to extract the water molecules from soil particles.

11. **Normalized Difference Vegetation Index (NDVI**): It is used to determine the density of green on a patch of land, researchers must observe the distinct colours (wavelengths) of visible and near-infrared sunlight reflected by the plants.

12. **PM 10:** PM stands for particulate matter (also called particle pollution): the term for a mixture of solid particles and liquid droplets found in the air. It is inhalable particles, with diameters that are generally 10 micrometres and smaller.

13. **PM 2.**5: It is a fine inhalable particle, with diameters that are generally 2.5 micrometres and smaller.

14. **Reflection over a surface:** It is when light bounces off an object. If the surface is smooth and shiny, like glass, water or polished metal, the light will reflect at the same angle as it hit the surface. This is called specular reflection. Diffuse reflection is when light hits an object and reflects in lots of different directions.

15. **Root Zone Depth:** It is the depth within the soil profile that commodity crop (cc) roots can effectively extract water and nutrients for growth.

16. **Roughness Length:** It is a parameter of some vertical wind profile equations that model the horizontal mean wind speed near the ground. In the log wind profile, it is

equivalent to the height at which the wind speed theoretically becomes zero in the absence of wind-slowing obstacles and under neutral conditions.

17. **Specific Heat Capacity:** It is the heat capacity of a sample of the substance divided by the mass of the sample, also sometimes referred to as massic heat capacity. Informally, it is the amount of heat that must be added to one unit of mass of the substance in order to cause an increase of one unit in temperature.

18. **Transmittance of a substance:** Transmittance of the surface of a material is its effectiveness in transmitting radiant energy. It is the fraction of incident electromagnetic power that is transmitted through a sample, in contrast to the transmission coefficient, which is the ratio of the transmitted to incident electric field.

19. **Water Content at field capacity:** The water content of a soil after gravitational drainage over approximately a day and the suction that defines this value varies from soil to soil.

20. **Water Content at saturation:** It is the maximum amount of water a soil can store. It is closely related to the total soil porosity.

21. **Water content at wilting point:** The wilting point, also called the permanent wilting point, may be defined as the amount of water per unit weight or per unit soil bulk volume in the soil, expressed in percent, that is held so tightly by the soil matrix that roots cannot absorb this water and a plant will wilt.

22. **Water turbidity**: Turbidity is the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid include clay, silt, very tiny inorganic and organic matter, algae, dissolved coloured organic compounds, and plankton and other microscopic organisms.

CHAPTER 2

LITERATURE REVIEW

Salvati and Kolokotroni (2019) has used ENVI-met software to find out its accuracy in various conditions such as meteorological forcing conditions, input area size and modelling details. It is assessed by using air temperature measurements of urban canyon. The results show the importance of hourly air temperature and average wind speed values for forcing the simulation. It allows the understanding of tools and scale of analysis for boundary conditions for building energy modelling considering the modifications in the climate made. The simulation also showed negligible horizontal and vertical thermal gradients within the micro-scale. It also confirmed the significance of in the variations in the incoming solar radiation, wind speed and surface temperature occurring at micro-scale.

Chatzinikolaou et al (2018) used ENVI-met software for the investigation of different Bioclimatic Scenarios in the microclimatic simulations using the micro-scale numerical model. Their study compares the bioclimatic scenarios of the roof top and roadside vegetation plan in the current conditions, in order to evaluate how the existence of vegetation can affect the local air temperature and the thermal comfort condition of urban environment. Analysis of thermal comfort index also proved the selection of plant types for more improvement in thermal conditions.

Ambrosini et al (2014) has worked on the possible formation of an UHI and the evaluation of its magnitude, in the context of a small city has been carried out with the ENVI-met software. They studied three different case-studies: Base Case, Cool Case and Green Case. They concluded that the urban microclimate is quite altered even in such a small area, and it is reasonable to think that, for the city area, a fully developed UHI may rise. Their analysis shows differences of up to 8K during hottest hours and greater than 3 K during night-time within the modelled area.

Abdulateef and Al-Alwan (2021) has studied to assess the effectiveness of UGI in reducing SUHI in Baghdad city. They selected two typical models within the city. Surface temperature (Ts) of different points in these two models were measured according to the base case scenario and to three proposed scenarios of UGI. The results show that UGI has an apparent role in declining Ts in both models. It was also found that the cooling effects of injecting UGI scenarios in similar surfaces of the two models are convergent. They confirmed the UGI as the great effectiveness in reducing SUHI in Baghdad City. It was also found that the effectiveness of UGI in cooling the existing surfaces depends on the original condition of the surfaces and the intensity and types of the injected UGI assets.

Maleki and Mahdavi (2016) studied the effects of the variation of physical and geometrical properties of the urban fabric (i.e., cool roofs including green and white roofs and perviousness of paving materials) on the urban micro-climate and outdoor thermal comfort were investigated using 3dimentional urban micro-climate model, ENVI-met. Based on the predicted results, increasing the amount of vegetation and permeable pavements can cool the air temperature down by up to 3 K. The simulation model was performed to predict air temperature, MRT, PET and specific humidity to evaluate the effect of defined mitigation scenarios.

Manteghi et al (2016) suggested that that vegetation and water bodies can be effective ways of reducing urban temperatures by 0.5 to 4.0°C. Based on the findings, they concluded that the increase of evapotranspiration in cities which is derived from vegetation and water body, can effectively mitigate the effect of urban heat islands. The cooling effects of water and greenery were confirmed via simulation. It was also concluded that the cooling effects of water and greenery upon the surrounding areas are strongly correlated to distance between the greenery area and the water body. It was determined that the best cooling effect on the surrounding area was achieved via greenery. This is proven via quantitative analysis, which shows that greenery scenario is 0°C lower compared to the other scenarios. This effect diminishes when greenery is replaced with pavements.

Ahmed et al (2020) studied the indoor CO_2 emissions of green and conventional building. They assessed the embodied carbon of a green building material. And found that the reinforced concrete has the significant negative impact, as it represents 78% of the total embodied carbon emissions. On the other hand, the insulation materials represent (2%) of the total emissions. Heavyweight cast concrete and the autoclaved aerated concrete have been proposed as alternatives and it was found that they achieved 23% & 50% reduction in the total embodied carbon emissions, respectively. They recommended to use autoclaved aerated concrete component as environmental alternative to rein forced concrete.

Okeil A. (2010) stated a holistic approach to energy efficient building forms is needed. It demonstrates a generic energy efficient building form derived by cutting solar profiles in a conventional block. Results show that the proposed building form, the Residential Solar Block (RSB), can maximize solar energy falling on facades and minimize solar energy falling on roofs and on the ground surrounding buildings in an urban area in winter; thus, maximizing the potential of passive utilization of solar energy. The RSB also supports strategies for mitigating the urban heat island through increased airflow between buildings, the promotion of marketable green roofs and the reduction of transportation energy.

Makido et al (2019) used ENVI-met microclimate modelling at the city-block scale specifically to determine what built environment characteristics are most associated with high temperatures, and the extent to which different physical designs reduce ambient temperature. The analysis included six green infrastructure interventions modelled across six different land-use types and indicated the varying degrees to which approaches are effective. Results were inconsistent across landscapes and showed that one mitigation solution alone would not significantly reduce extreme heat. These results can be used to develop targeted, climate- and landscape-specific cooling interventions for different land uses, which can help to inform and refine current guidance to achieve urban climate adaptation goal.

Baloloy et al (2020) analysed both the horizontal and vertical extent of air temperature variations as affected by vegetation leaf area density (LAD) and building area per height threshold. Remotely sensed data were used in creating the primary model inputs including the initial built-up layer from PlanetScope green-based built-up index, and digital elevation models (DEM) and normalized difference vegetation index (NDVI) maps derived from unmanned aerial system (UAS) for tree canopy mapping. The horizontal variations in air temperature were observed by selecting three subsites with different proximity to the adjusted variables, while vertical analysis was done by comparing the temperature values from the near ground up to the 20 m height range.

Ozkeresteci et al (2003) discussed in detail the construction of a simulation modelling procedure to assist the Phoenix metropolitan area planners in advancing their open space and park planning strategies. Using the advanced 3D-4D numerical models called ENVI-met and LEONARDO, which have the capacity to project small to large-scale climatic impacts, the model can evaluate future parkways in areas of optimal outdoor comfort, optimal citizen uses and minimal environmental damage. As a non-hydrostatic model that simulates surface-plant-air interactions inside urban environments on a three-dimensional rectangular grid with variable spacing in x-, y- and z-directions, the model functions over a range of spatial scales.

Hiena et al (2012) studied the UHI impact mitigation strategies are to increase the open spaces to allow urban ventilation and plant green cover. They predicted two methods for their model simulation: STEVE and ENVI-met. Screening Tool for Estate Environment Evaluation (STEVE) is a prediction tool which can calculate the Tmin, Tavg and Tmax of the point of interest for certain urban settings and ENVI-met which is a Computational Fluid Dynamics (CFD) based micro-climate and local air quality model. It calculates temperature within the interval times for 24 to 48 hours. Their objective of this study is to compare both prediction models to understand their benefits and limitations, in order to justify which model is more appropriate for a tropical urban context.

Huttner et al (2008) studied and quantified the urban heat island effect on human health and to propose possible counter measures for urban planners. They used micro-climate simulation ENVI-met to simulate and study the interaction of cities on the human thermal comfort and to predicted how it will be affected by climate change. In their study, the effects of the more extreme summerly weather conditions on an exemplary quarter of a central European city are investigated by comparing two simulations with different boundary conditions, one presenting an average European summer day, the other representing the conditions of an extreme summer heat wave.

Elnabawi et al (2013) presented a micro scale numerical model for two different urban forms within the same alley for hot summers day in Cairo. In both cases, on site measurements are used to validate the improvement results which showed in agreement to measurements representing adequate TMRT and PMV climatic map as an initial step in addressing the urgent need for environment platform accessible to urban designers, architects and decision makers towards sustainable urban forms.

Ebrahimnejad et al (2017) studied the effect of Tehran Nature Bridge green roof as a sustainable structure on its surrounding microclimate is investigated using urban microclimate model, ENVI-met, on a hot summer day in July 2015. For this purpose, two simulation scenarios were generated to assess the impact of extensive and intensive green roofs on some climate variables. Overall, green roof altered climatic parameters such as air temperature, RH, and wind velocity and direction at both bridge and ground level.

McRae et al (2020) gave out a method to use Weather Research and Forecasting or WRF model to generate inputs for the ENVI-met model to produce building scale canyon temperatures. A land use distribution was generated by WRF, and simulations were run out for 1 km grid and output at its grid closest to the study area in ENVI-met with lateral boundary conditions. They came up with three mitigation strategies with the increase in vegetation, rooftop albedo or architectural shade elements.

Pei et al (2021) studied the effect of quantitative evaluation of the effects of heat island on a high-rise building energy performance using the micro- climatic simulation tool ENVI-met and building energy simulation tool COMFIE. They proposed a method to generate hourly 'site-specific climate data' to avoid long micro-climate simulation time. Results showed the yearly average urban heat island effect intensity at the height of 3 m to be 0.45 ^{o}C and decreased with the increasing height.

Balany et al (2020) presented a review on Green Infrastructure (GI) research for urban heat island mitigation to provide human thermal comfort. They also reviewed that the ENVI-met software is one of the modelling tools considered reliable for the simulation and research was conducted on a limited spatial scale focusing mainly on mitigation strategies.

Sharma and Kaur (2019) studied about the possible factors responsible for UHI effects in Hyderabad city with an empirical support to this effect. He developed an original conceptual framework for the mapping of the formation of urban heat island. That is by analysing the UHI factors of the selected case study area like the requirement of meteorological data and second using the satellite image to be generating NDVI map for the city to get the land surface temperature map.

Rehan (2014) aimed to determine the UHI mitigation strategies and their effectiveness in the temperature reduction of urban cities at urban design level. They achieved the goal through exploring the cool city by theoretical, analytical and practical viewpoints. They analysed the concept of coolest city in the world Stuttgart, Germany by practical approach.

Mohan et al (2009) took the field campaign to understand the intensity and dynamics of heat-island phenomenon in Delhi. Surface meteorological observations were performed using multi-site ground based mini weather stations and meteorological towers. Urban heat island effects were found to be most dominant in areas of dance built up infrastructure and intense human activity. High magnitude of UHI observed during day hours in summer is expected to increase cooling energy requirements in tropical cities such as Delhi and further strengthen the UHI leading to vicious cycle problem.

CHAPTER 3

METHODOLOGY

The first step is to start with the selection of a site area. In this case, site area is inside the college campus itself. The process requires data for which site visit is necessary to know about the type of material by which building has been constructed, the type of vegetation it has been covered in and around. The area that has been selected consists of building, vegetation and roadways. The length and width of the selected area is approx. 300 m and 120 m respectively, having an area of 36000 sq. m. Out of this, the build of area is approximately 6840 sq. m which is 19% of the total area, Vegetation comprises of 21000 sq. m of area which is 58.34% of the total area and lastly, the pavement and roadways comprises of 8160 sq. km of total area covering 22.66% of the area.

To validate the effect of green spaces in reduction of temperature, here we have taken two scenarios. One, the base case scenario having physical properties as the real environment and second, the green case scenario in which the vegetation is increased in the selected study area by means of green roofs and more roadside cover. After the addition of green spaces, the built-up area is 9%, vegetative cover is 71.34% and the roadside pavement comprises of 17.66 %.

After this, the real metrological data like atmospheric temperature, relative humidity, wind speed and wind directions are taken for an entire year and simulation is done for the hottest day of the hottest month. For this purpose, a micro-climate simulation software is used known as Envi-met.

3.1 ENVI-MET

The ENVI-met is an urban micro-climatic software that simulates three-dimensional non-hydrostatic modelling of building-air-vegetation interactions, especially but not exclusively inside an urban environment. It is a model- based software that works on the fundamental laws of fluid dynamics and thermodynamics, including simulation of several phenomena such as heat and steam exchange at soil level and between walls, heat flux around and between buildings, thermo-hygrometric exchange in vegetation, turbulence, bioclimatology, fluid dynamics of small particles and polluting agents.

The software takes into consideration various calculating models:

- The shortwave and longwave radiation fluxes, reflection and re-radiation within the building systems and vegetation.
- Evapotranspiration and sensible heat flux from the vegetation into the atmosphere with plant physical parameters taken into consideration for simulation.
- In the grid parameters, the surface and wall temperature interactions.
- Water- and heat-exchange into the soil system.
- Calculation of various bio metrological parameters like Mean Radiant Temperature (MRT) or Franger's Predicted Mean Vote (PMV) values.
- Dispersion of inert gases and particles coming from various pollutant sources including sedimentation of particles on leaves of the vegetation, surfaces of the building and on pavements.

This software considers the interplay roles between buildings, vegetation and various surface coverings, all affecting the atmospheric conditions of the modelled area. The ENVI-met software consists of five model groups:

- The atmospheric model helps in calculation of the air movement, three-dimensional turbulence, temperature, relative humidity and considers the obstacles such as buildings and vegetation where shading is also considered.

- The surface model helps in the calculation of the emitted long wave, and the reflected short-wave radiation from the different surfaces, considering the incident long and shortwave radiation. It considers the albedo property of the building material, the shading of the structure in function of the solar path and calculates the water vapor evaporation from the vegetation and the transpiration from the soil all together is considered to show the air flow-modifying effect of the vegetation and the transpiration from the soil.

The vegetation model helps in the calculation of the foliage temperature and the energy balance of the leaves considering the physiological and metrological parameters. The

- vegetation is characterised mainly by two parameters, the normalised leaf area density (LAD) and the normalised root area density (RAD). The evaporation rate and the turbulence calculation are based on the airflow fields around the vegetation's physical properties such as the shape, density and height. The evaporation rate on the surface of the leaves which is regulated by the stomata is mainly affected by the heat exchange between the leaf and its surrounding environment. The absorption characteristics of the foliage of trees are calculated in function of the sun path and the projected shade.

- The soil model helps in the calculation of the thermos and hydrodynamic processes that takes place in the soil. This model considers the combination of the natural and artificial surfaces of the urban area that has been taken into consideration and it can also calculate heat exchanges between a water body and its environment.

- The bio-metrological model which helps in the calculation of the PMV index from the metrological data and anthropogenic data. It mainly states about the human comfort at an average human height.

The following flow chart shows the methodology of assessing the effectiveness of UGI in the study area.

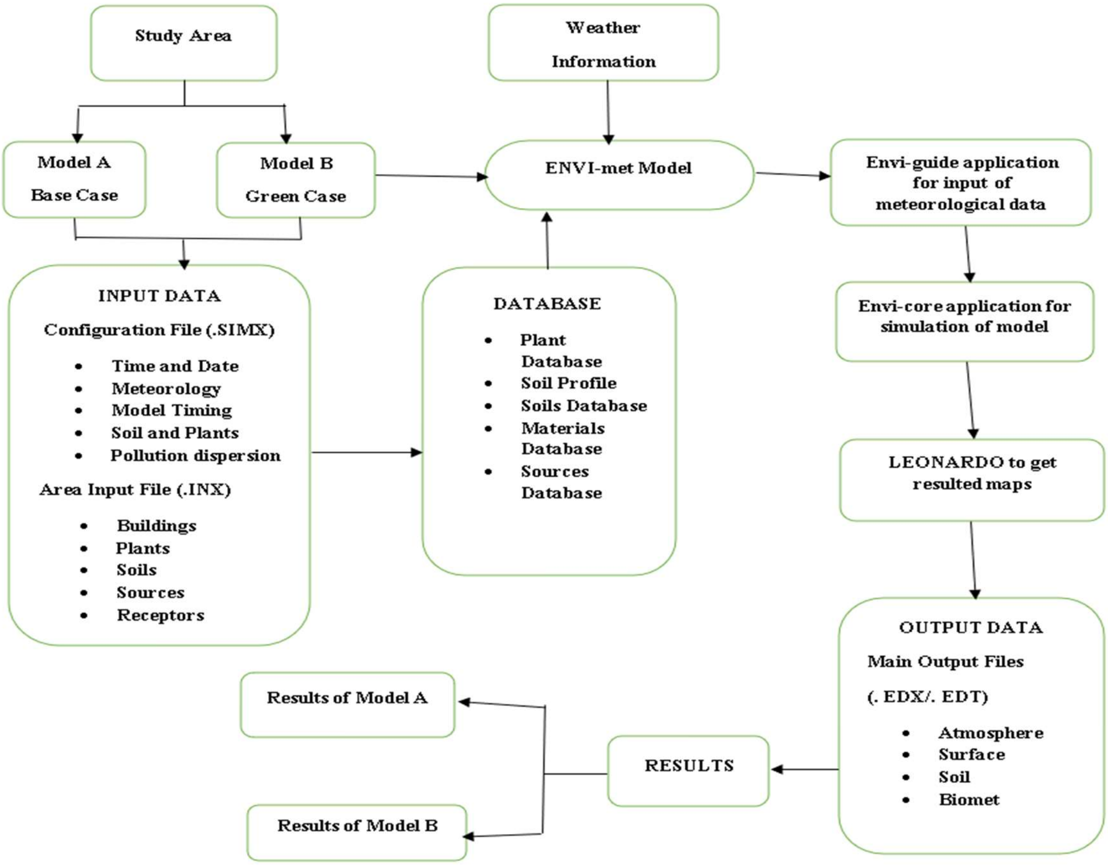


Figure 3.1.1: Methodology flow-chart

3.2 STUDY AREA

The study area for this study has been taken as the Civil Engineering Department of Delhi Technological University situated in the north-west of Delhi in Rohini area. This sub-city has a The University is spread across 164 acres of land with lush vegetation and the building structure constructed with the concept of ‘green architecture’. The college area is surrounded by mass population on each side and with very few farmlands nearby. The nearby area has a very high population density with no proper road facilities in front of the college. The roads in front of the college are a single carriageway with 2-lane and 2-way road which results in heavy congestion of the heavy vehicles during peak hours. Due to this reason, the vehicles stand for more period as expected and the pollution coming out from them has also an effect on the anthropogenic heat flux. Addition to this, large number of vehicles also enter the premises which comprises of mainly 2-wheelers such as motorcycles, scooters, etc., and 4-wheelers such as cars, heavy trucks, etc. The anthropogenic heat flux is a major factor for the heat generation within the campus. As observed, the heating, ventilation and the air conditioning (HVAC) system of the nearby households are very poor and does not meet as per the requirements of the comfort of occupants and a process. The vegetation of the nearby area is also in poor condition as the number of trees are less as compared to the number of households. Population of the area is around one million and covers an area of 3015 hectares. The image below shows the study area circled in blue, which is in Delhi Technological University, boundary marked in yellow colour.

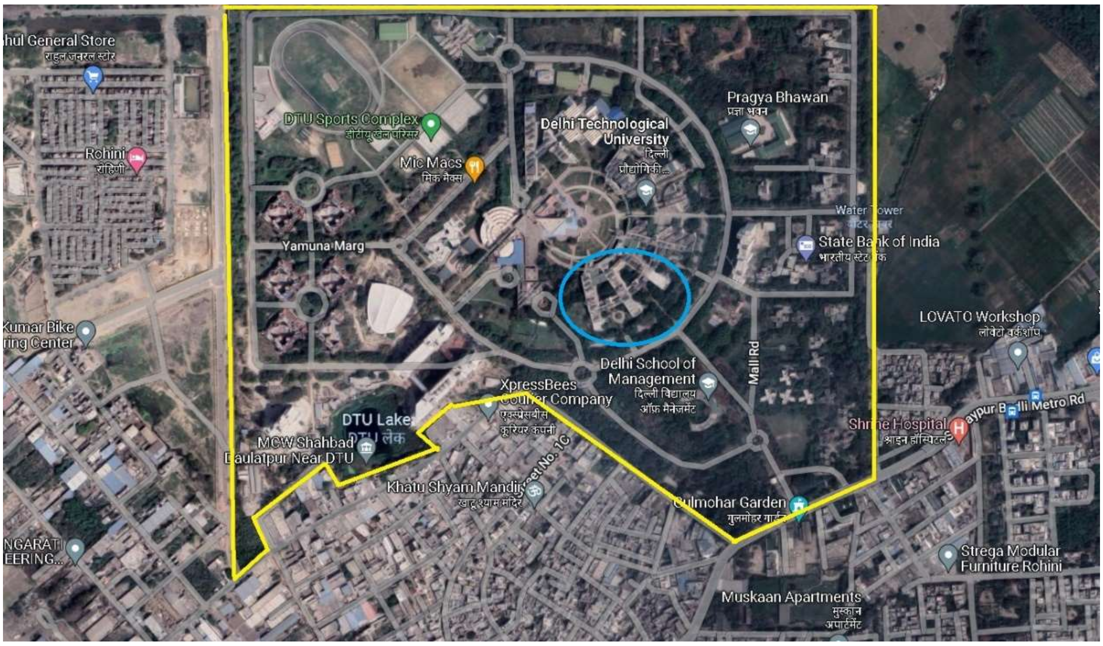


Figure 3.2.1: Satellite image of Delhi Technological University (Source: Google Maps)

The selected building is situated very near to the main gate of the campus. The building is G+3 storey high and is in a shape of ‘**E**’ which accounts for a good condition of ventilation. It is covered with various species of trees and plants all around.

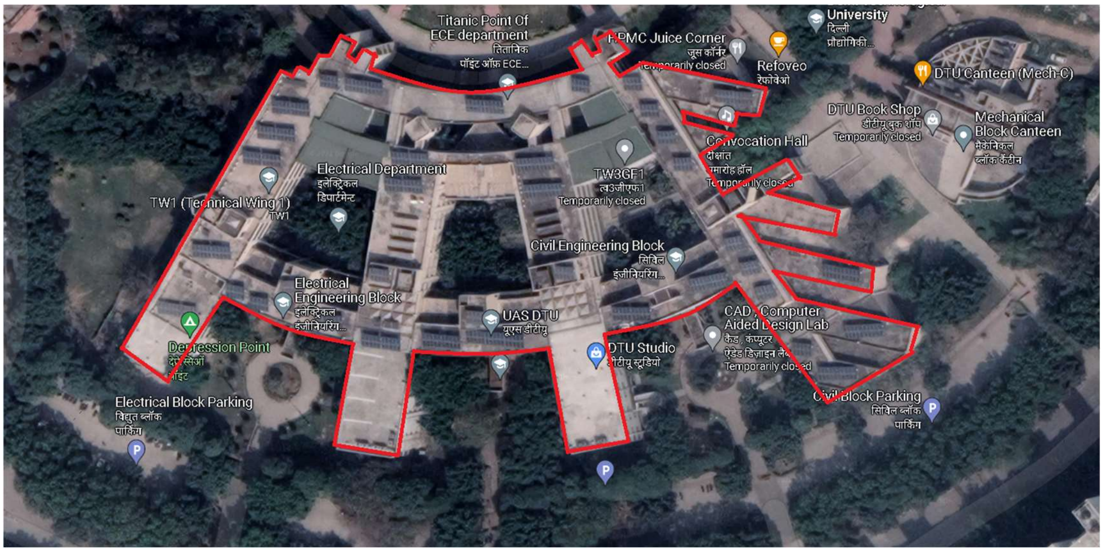


Figure 3.2.2: Satellite image showing the study area in zoom (Source: Google Maps)

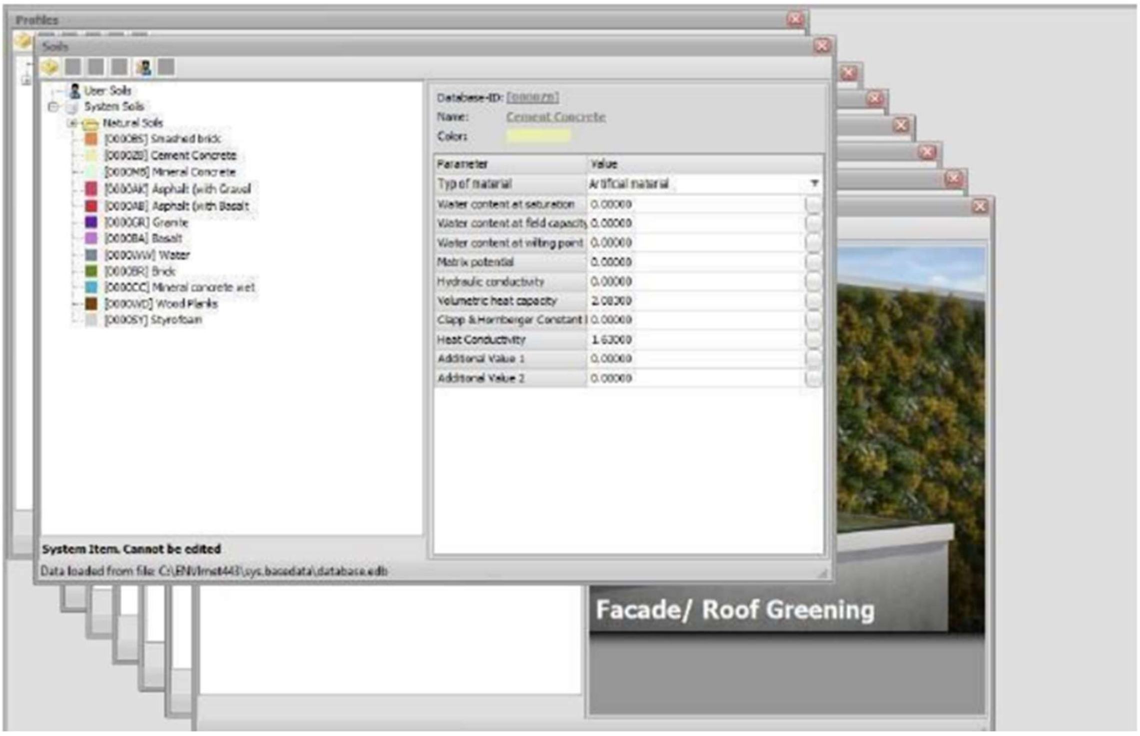
3.3 STUDY METHOD

Two scenarios have been taken here, one the current case scenario where the simulation is done with real case and the other being the green case scenario where the greenery is increased nearby the building. The building material is also enhanced with some physical properties to increase the cooling effect. After that the simulation is done and the results are being compared from both the cases to analyse the results in terms of Predicted Mean Vote (PMV) index, anthropogenic heat, graphs of atmospheric temperature, relative humidity and wind direction.

All the simulation is done for 24-hours data and the results are analysed for various parameters at a specific hour time of 5 am. This time is said to be the buffer time as the modelling area starts to heat at this time as it is sunrise time.

3.4 MODELING

The modelling starts with the Database Manager where addition of all the physical properties of building materials, vegetation, soils and pollution sources is done. It is one of the most critical features since they provide an identifier for the occupied voxels. Each material has a variety of characteristics that affects its behaviour, such as an albedo value or a leaf area distribution (LAD) value for trees.



- User Soils
- System Soils
  - Natural Soils
    - [0000BS] Smashed brick
    - [0000ZB] Cement Concrete
    - [0000MB] Mineral Concrete
    - [0000AK] Asphalt (with Gravel
    - [0000AB] Asphalt (with Basalt
    - [0000GR] Granite
    - [0000BA] Basalt
    - [0000WW] Water
    - [0000BR] Brick
    - [0000CC] Mineral concrete wet
    - [0000WD] Wood Planks
    - [0000SY] Styrofoam

Database-ID: [0000ZB]
Name: Cement Concrete
Color:

Parameter	Value
Typ of material	Artifical material
Water content at saturation	0.00000
Water content at field capacity	0.00000
Water content at wilting point	0.00000
Matrix potential	0.00000
Hydraulic conductivity	0.00000
Volumetric heat capacity	2.08000
Clapp & Hornberger Constant	0.00000
Heat Conductivity	1.63000
Additonal Value 1	0.00000
Additonal Value 2	0.00000

System Item. Cannot be edited
Data loaded from file: C:\ENVImet448\sys.basedata\database.edb

Figure 3.4.1: ENVI-met databases, icon display soil 6-digid code spaces

The model area consists of walls of various types that could be wall of the building itself or single walls used for partition or shading. Firstly, given are the materials chosen for the modelling of the building along with their physical properties.

Table 3.4.1: Properties of building materials

Properties	Cement Plaster	Polystyrene Insulation	Concrete Mix
Colour	Dark grey	Light grey	Black
Thickness (m)	0.02	0.01	0.15
Absorption (frac)	0.5	0.5	0.5
Transmission (frac)	0	0	0
Reflection (frac)	0.5	0.5	0.5
Emissivity (frac)	0.9000	0.9000	0.9
Specific Heat (J/Kg*K)	850	1500	850
Thermal Conductivity (W/m*K)	0.71	0.07	1.6
Density (Kg/m^3)	1500	400	2220

Properties of Walls and Single Walls:

Table 3.4.2: Properties of walls

Properties	Single Walls
Name	Masonry
Material	B2 (Brick-wall)
Aerodynamic Roughness Length (m)	0.02
Thickness	0.5

Properties of Wall/ Roof construction:

Table 3.4.3: Properties of roofs

Properties	Heavy concrete wall
Possible usage	Wall or roof
Roughness length (m)	0.02
Can be greened	True
Thickness of layers	

The physical properties of soil profile and the pavement of the modelled area are also studied. It is because the property of soil gives information about its infiltration and will ensure the cooling of the nearby area and the albedo value of the roads and pavements will ensure the reflection of the solar radiation. More the albedo value of the pavement material, more it will absorb the sunlight, hence warming up the nearby surrounding.

Properties of soil profiles:

i. Natural surfaces

Table 3.4.4: Properties of Soil

Properties	Loamy soil
Colour	Brown
Roughness length (m)	0.015
Albedo	0
Emissivity	0.98
Surface is irrigated	True
Water mixing co-efficient	0.001
Water turbidity/extinction	2.1

ii. Roads and Pavements

Table 3.4.5: Properties of roads

Properties	Asphaltic road	Concrete Pavement
Code	0100AR	0100CP
Colour	Black	Grey
Roughness length (m)	0.01	0.01
Albedo	0.2	0.5
Emissivity	0.9	0.9
Surface is irrigated	False	False
Water mixing co-efficient	0.001	0.001
Water turbidity/extinction	2.1	2.1

Properties of Soil/Ground materials:

Table 3.4.6: Properties of Soil

Properties	Concrete Pavement	Asphaltic road with gravel
Colour	Grey	Black
Type of material	Artificial	Artificial
Water content at saturation	0	0
W.C. at field capacity	0	0
W.C. at wilting point	0	0
Matrix potential	0	0
Hydraulic conductivity	0	0
Volumetric heat capacity	2.083	2.214
Clapp & Hemberger constant	0	0
Heat capacity	1.63	1.16

The type of vegetation present nearby the modelled area ensures the extent of cooling effect of the surrounding. In the Base Case, the vegetation has been as it is present in the real time while in the Green Case scenario, more greenery has been added in the form of green roofs and increasing the number of trees near the pavements.

Properties of simple plants:

i. Façade greening plants

Table 3.4.7: Properties of simple plants

Properties	Ivy	Fern	Funkia
Colour	Light green	Light green	Light green
CO_2 fixation type	C3	C3	C3
Leaf type	Deciduous	Deciduous	Deciduous
Albedo	0.2	0.2	0.2
Transmittance	0.3	0.3	0.3
Plant height (m)	0.25	0.5	0.4
Root zone depth (m)	0.5	0.5	0.5

ii. Grasses and Hedges

Table 3.4.8: Properties of grass and hedges

Properties	Grass	Hedge
Height	25 cm	2 m

In the database manager, the data for the pollution sources is also required. The roadway near the modelled area is a sub-urban type which operates on the speed of not more than 30 kmph.

Properties of pollution sources:

Table 3.4.9: Properties of pollution source

Property	Test Lane
Default height (m)	0.15
Source geometry	Line
Type of street segment	Sub-urban road
DTV (Veh/24h)	1500
No. of lanes	3

Properties for Albero:

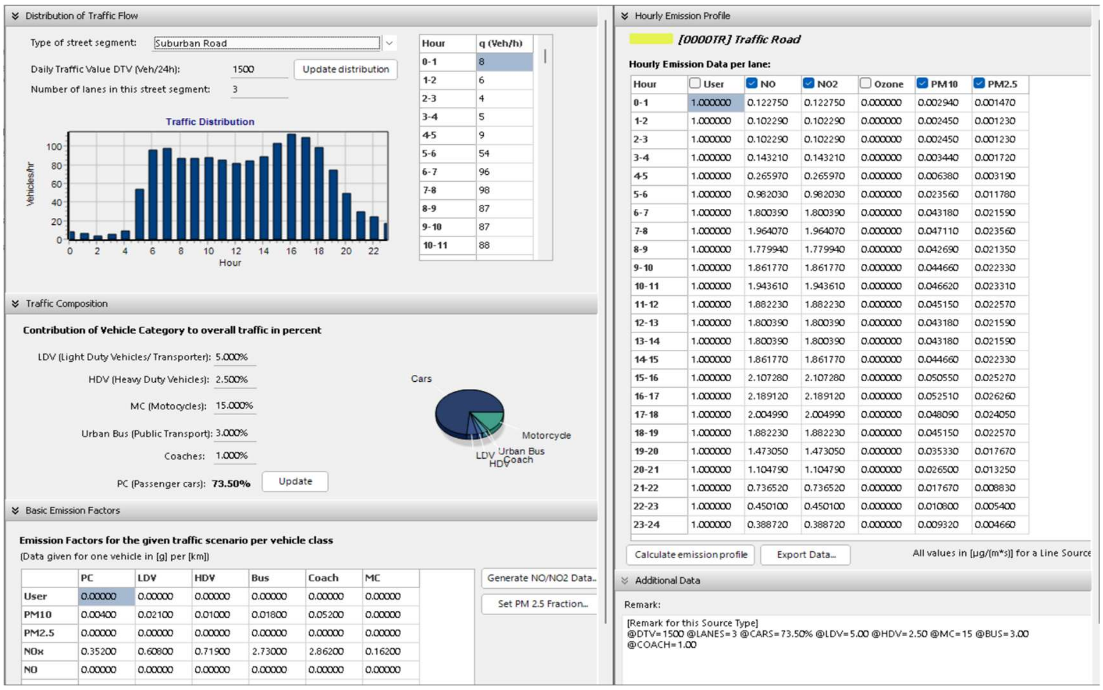
These are the species of trees that has been selected according to their suitability with the environment. Their physical properties have also been considered like if they are evergreen or provides maximum shading, etc.

Table 3.4.10: Properties of Albero

Latin Name	Height, Width	Albedo	Type	Use
Robinia pseudoacacia	4,5	0.50	E	S
Citrus Aurantium	4,3	0.40	E	AP
Acacia	2,3	0.60	D	AP
Albizia Julibrissin	12,11	0.60	D	AP
Acer Negundo	11,9	0.50	D	S
Ligustrum	5,5	0.40	D	W
Sophora Japonica	10,15	0.60	D	S/AP
Sophora Japonica	15,23	0.60	D	S/AP
Sophora Japonica	5,9	0.60	D	S/AP
Azadirachta Indica	15,20	0.7	E/D	AP

D= Deciduous, E= Evergreen, S= Shadow, AP= Air Pollution

The sources extension in Database Manager gives information about the vehicles and pollution caused by them. Figure below shows the distribution of traffic flow in the area. The Daily Traffic Value DTV (Veh/24h) has been taken as 1500. According to this number, the system has distributed the traffic flow on hour basis.



Type of street segment: Suburban Road

Daily Traffic Value DTV (Veh/24h): 1500

Number of lanes in this street segment: 3

Hour	q (Veh/h)
0-1	8
1-2	6
2-3	4
3-4	5
4-5	9
5-6	54
6-7	96
7-8	98
8-9	87
9-10	87
10-11	88

Contribution of Vehicle Category to overall traffic in percent

LDV (Light Duty Vehicles/ Transporter): 5.000%

HDV (Heavy Duty Vehicles): 2.500%

MC (Motocycles): 15.000%

Urban Bus (Public Transport): 3.000%

Coaches: 1.000%

PC (Passenger cars): **73.50%**

Emission Factors for the given traffic scenario per vehicle class

(Data given for one vehicle in [g] per [km])

	PC	LDV	HDV	Bus	Coach	MC
User	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PM10	0.00400	0.02100	0.01000	0.01800	0.05200	0.00000
PM2.5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
NOx	0.35200	0.60800	0.71900	2.73000	2.86200	0.16200
NO	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

[0000TR] Traffic Road

Hourly Emission Data per lane:

Hour	☐ User	☑ NO	☑ NO2	☐ Ozone	☑ PM10	☑ PM2.5
0-1	1.000000	0.122750	0.122750	0.000000	0.002940	0.001470
1-2	1.000000	0.102290	0.102290	0.000000	0.002450	0.001230
2-3	1.000000	0.102290	0.102290	0.000000	0.002450	0.001230
3-4	1.000000	0.143210	0.143210	0.000000	0.003440	0.001720
4-5	1.000000	0.265970	0.265970	0.000000	0.006380	0.003190
5-6	1.000000	0.982030	0.982030	0.000000	0.023560	0.011780
6-7	1.000000	1.800390	1.800390	0.000000	0.043180	0.021590
7-8	1.000000	1.964070	1.964070	0.000000	0.047110	0.023560
8-9	1.000000	1.779940	1.779940	0.000000	0.042690	0.021350
9-10	1.000000	1.861770	1.861770	0.000000	0.044660	0.022330
10-11	1.000000	1.943610	1.943610	0.000000	0.046620	0.023310
11-12	1.000000	1.882230	1.882230	0.000000	0.045150	0.022570
12-13	1.000000	1.800390	1.800390	0.000000	0.043180	0.021590
13-14	1.000000	1.800390	1.800390	0.000000	0.043180	0.021590
14-15	1.000000	1.861770	1.861770	0.000000	0.044660	0.022330
15-16	1.000000	2.107280	2.107280	0.000000	0.050550	0.025270
16-17	1.000000	2.189120	2.189120	0.000000	0.052510	0.026260
17-18	1.000000	2.004990	2.004990	0.000000	0.048090	0.024050
18-19	1.000000	1.882230	1.882230	0.000000	0.045150	0.022570
19-20	1.000000	1.473050	1.473050	0.000000	0.035330	0.017670
20-21	1.000000	1.104790	1.104790	0.000000	0.026500	0.013250
21-22	1.000000	0.736520	0.736520	0.000000	0.017670	0.008830
22-23	1.000000	0.450100	0.450100	0.000000	0.010800	0.005400
23-24	1.000000	0.388720	0.388720	0.000000	0.009320	0.004660

All values in [µg/(m*s)] for a Line Source

Remark:

[Remark for this Source Type]
@DTV=1500 @LANES=3 @CARS=73.50% @LDV=5.00 @HDV=2.50 @MC=15 @BUS=3.00
@COACH=1.00

Figure 3.4.2: Setting of pollution sources

In the traffic composition, vehicle has been segregated based on their operation such as Light Duty Vehicle, Heavy Duty Vehicle, Motorcycles, etc.

In the next step, hourly emission data per hour by the vehicles has been generated. The main constituents are the oxides of nitrogen and particulate matters.

In the next step, the model location and geometries are assigned so that the modelling can be done in 2D mode and later can be converted into 2.5D to analyse the structure and 3D mode for detailed designing.

Model Location:

Table 3.4.11: Model location

Location	Delhi Technological University
Longitude	77^0 7’ 6”
Latitude	28^0 44’ 58”
Indian Standard Time	+5.30 hrs
Reference longitude	75^0

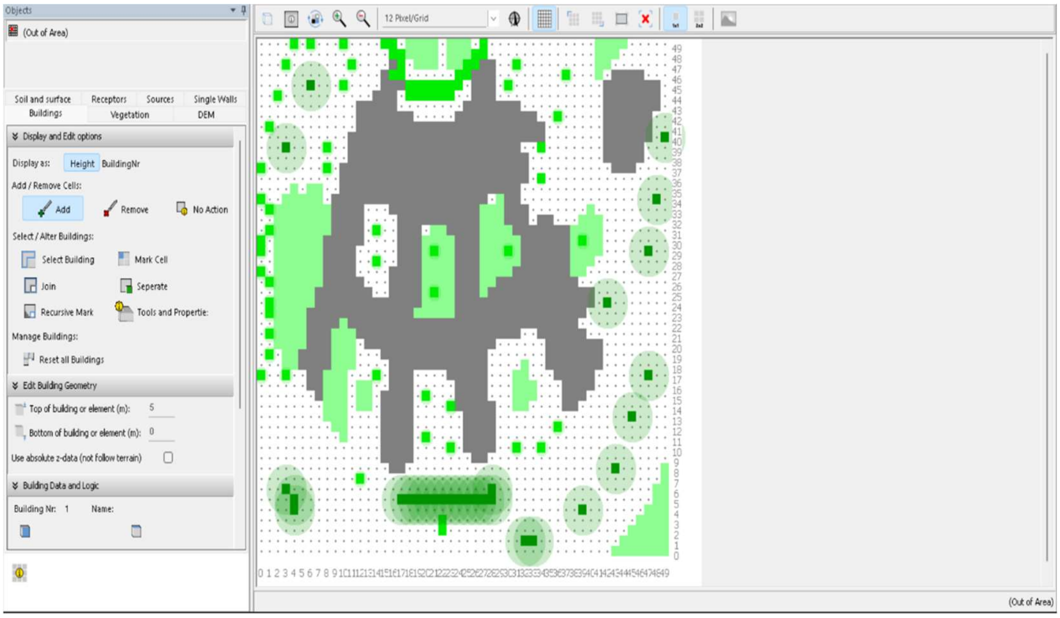
Model Geometry:

Table 3.4.12: Parameters for model geometry

Simulation Model Size (m)	100 x 100 x 80
Model Area (Number of Grids) xyz-Grids	50 x 50 x 40
Size of grid cell (m) dx, dy, dz	2 x 2 x 2
Nesting grids	6
Method of vertical grid generation	Equidistant

The modelling is done in SPACES tab in 2D mode and can also be converted into 2.5D mode.

First designing is done for the current case scenario with the properties and vegetation density as the real physical conditions.



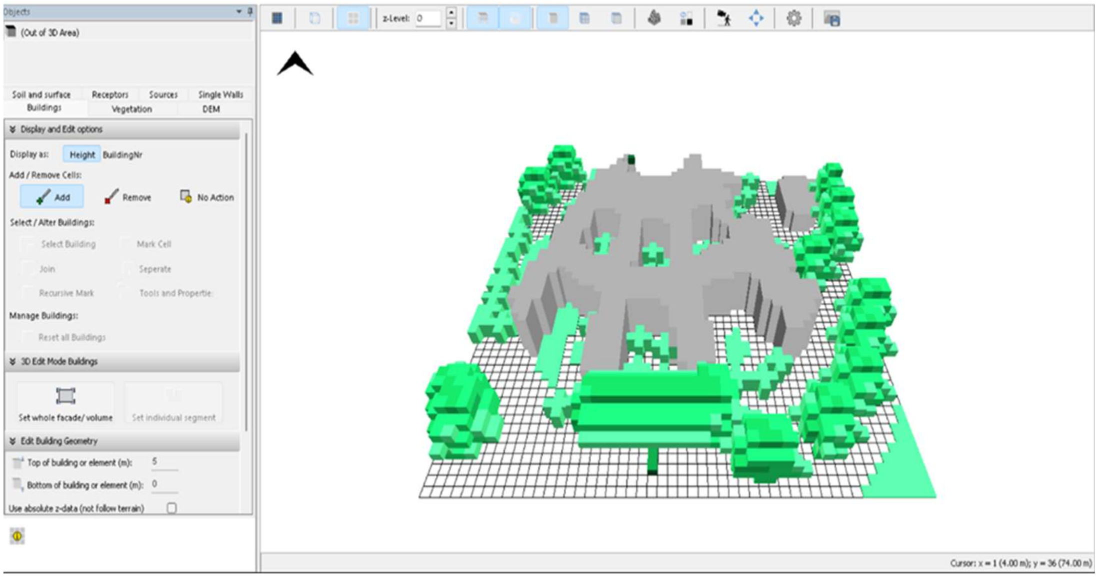
Top of building or element (m): 5

Bottom of building or element (m): 0

Use absolute z-data (not follow terrain) ☐

Building Nr: 1 Name:

Figure 3.4.3: SPACE Interface for Site Modelling



z-Level: 0

Top of building or element (m): 5

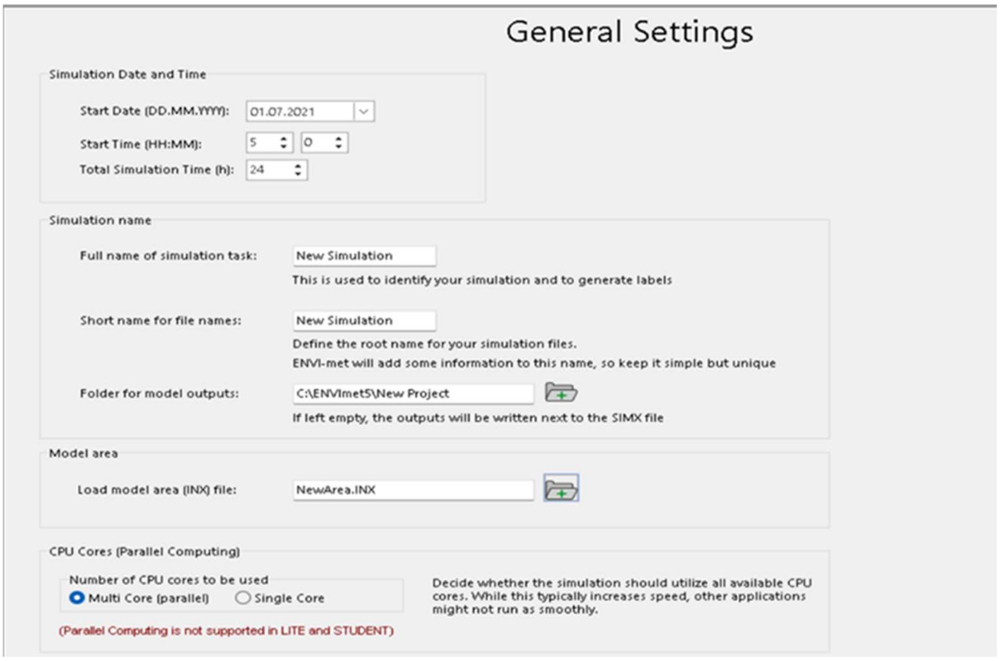
Bottom of building or element (m): 0

Use absolute z-data (not follow terrain) ☐

Cursor: x = 1 (4.00 m); y = 36 (74.00 m)

Figure 3.4.4: 3D view of the site model on SPACE Interface

The model area gets saved into the workspace with .INX extension. For this project, various parameters of metrological data have been collected for each hour for the year 2021. From the data collected, it is observed that the hottest month has been July. The simulation is done for the hottest day of July which comes out to be first day of the month. The metrological data is simulated for each hour of the same day. Here, Simple Forcing has been used as it allows the user to build a graph of hourly temperatures and relative humidity values to be added to the simulation file.



General Settings

Simulation Date and Time

Start Date (DD.MM.YYYY): 01.07.2021

Start Time (HH:MM): 5 : 0

Total Simulation Time (h): 24

Simulation name

Full name of simulation task: New Simulation

This is used to identify your simulation and to generate labels

Short name for file names: New Simulation

Define the root name for your simulation files.
ENVI-met will add some information to this name, so keep it simple but unique

Folder for model outputs: C:\ENVImet5\New Project

If left empty, the outputs will be written next to the SIMX file

Model area

Load model area (INX) file: NewArea.INX

CPU Cores (Parallel Computing)

Number of CPU cores to be used

● Multi Core (parallel) ○ Single Core

(Parallel Computing is not supported in LITE and STUDENT)

Decide whether the simulation should utilize all available CPU cores. While this typically increases speed, other applications might not run as smoothly.

Figure 3.4.5: Selection of basic parameters in ENVI-met

The meteorological data collected for 1st July 2021 is shown in the table below:

Table 3.4.13: Meteorological Parameters

Time	Air Temp. (°C)	Relative Humidity (%)	Wind Speed(m/s)	Wind Direction (radian)
00:00:00	34.72	42.16	1.1	193.38
01:00:00	34.83	42.37	0.88	202.98
02:00:00	34.87	41.96	0.59	187.64
03:00:00	34.54	42.98	0.58	179.82
04:00:00	34.26	44.59	0.4	181.17
05:00:00	33.7	47.08	0.38	152.15
06:00:00	34.21	47.12	0.33	196.24
07:00:00	35.86	43.3	0.7	215.02
08:00:00	37.32	40.1	0.94	246.4
09:00:00	39.4	36.86	0.79	168.66
10:00:00	40.49	35.1	0.62	198.46
11:00:00	41.53	33.08	0.51	241.73
12:00:00	43.06	30.18	0.77	170.35
13:00:00	43.66	28.1	0.92	93.19
14:00:00	44.28	26.67	0.65	80.57
15:00:00	44.77	25.19	0.4	156.09
16:00:00	43.86	24.87	0.53	218.42
17:00:00	40.95	29.18	0.36	279.17
18:00:00	39.04	32.59	0.58	288.17
19:00:00	36.52	38.27	1.24	192.45
20:00:00	34.91	43.36	1.17	177.1
21:00:00	34.59	45.4	1.04	157.29
22:00:00	35.2	50.4	1.4	34.4
23:00:00	35.21	53.48	1.15	48.12

🟨 Maximum Value 🟦 Minimum Value

Air temperature variation for the date 1st July 2021 is shown in the graph below:

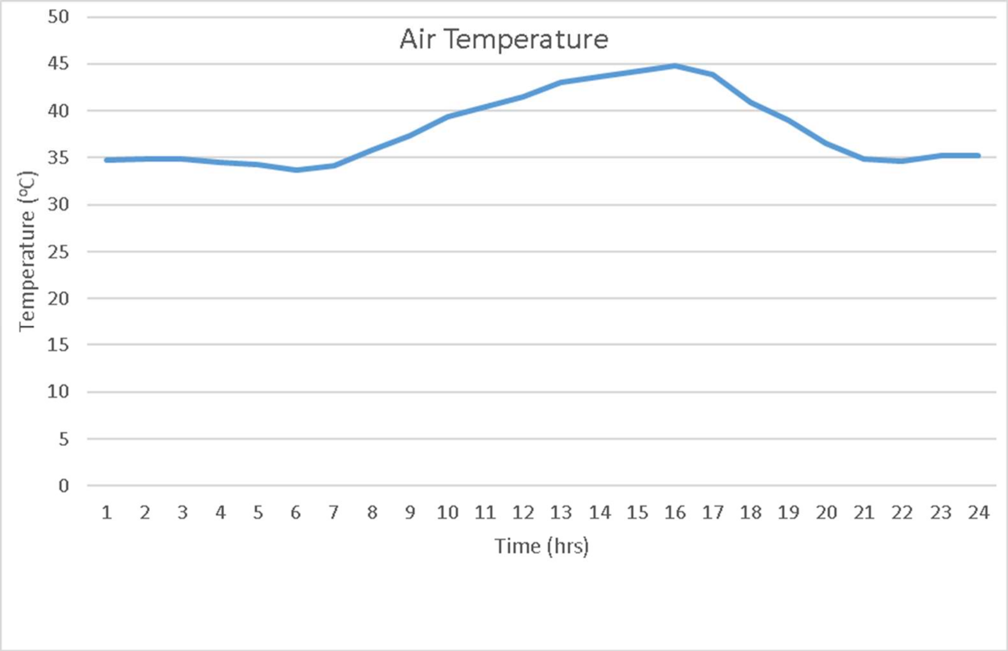


Figure 3.4.6: Hourly Variation of air temperature for 1st July 2021

Relative humidity variation is also shown for the same day in the graph below:

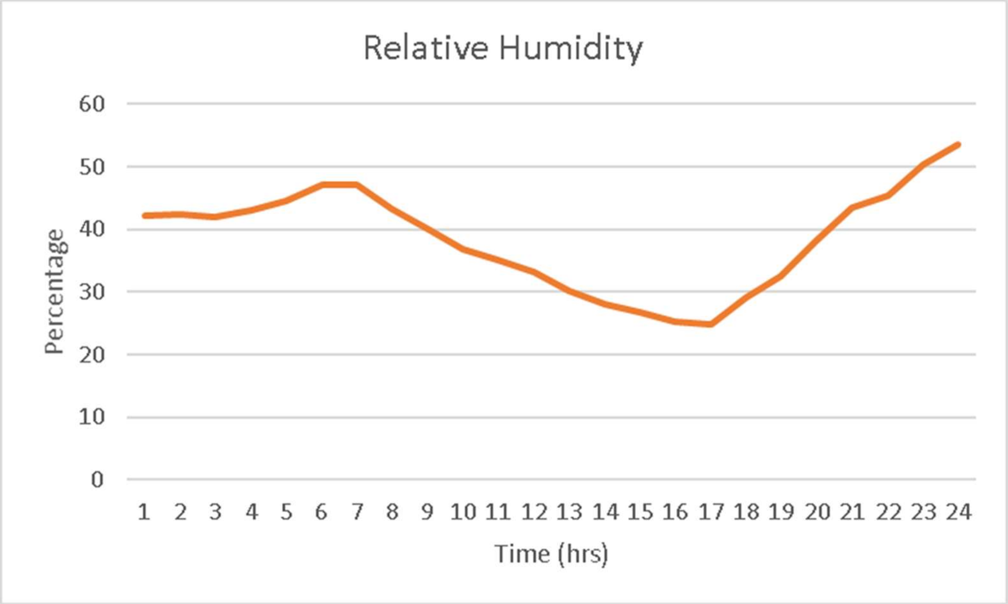
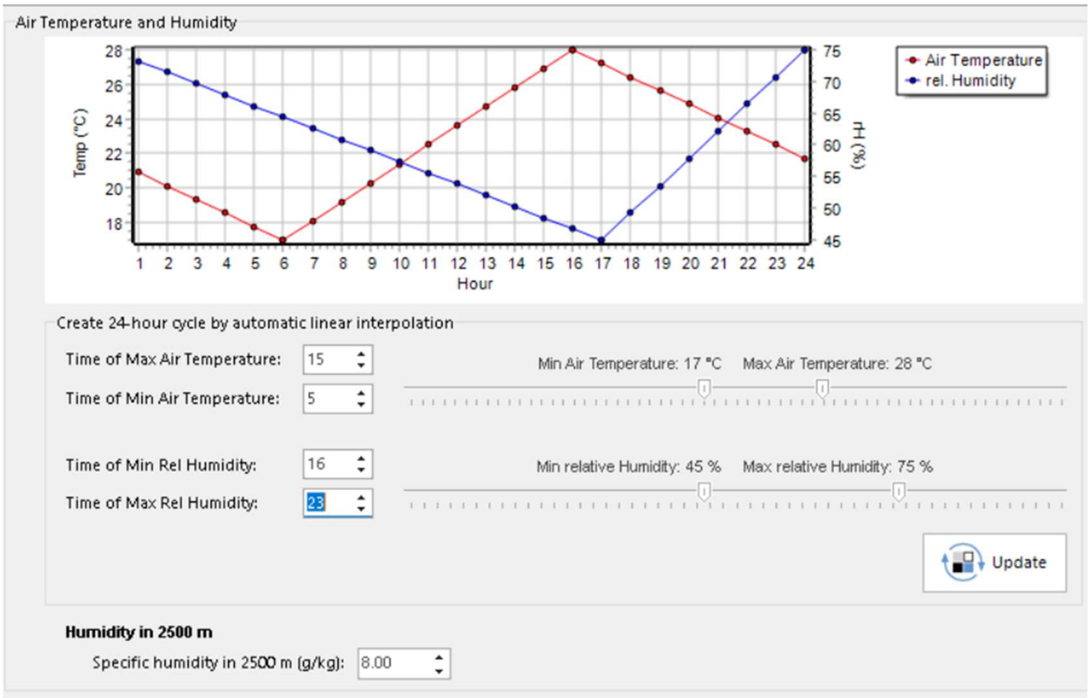


Figure 3.4.7: Hourly Variation of relative humidity for 1st July 2021

From the graph. we can infer that temperature and relative humidity are inversely proportional i.e., when the temperature is increasing, the relative humidity is decreasing comparatively and vice-versa.

The data for air temperature and relative humidity is fed in the system for the simulation purpose and a file with format .SIMX gets saved to the workspace to get read further in the simulation.



Create 24-hour cycle by automatic linear interpolation

Time of Max Air Temperature: 15

Time of Min Air Temperature: 5

Min Air Temperature: 17 °C Max Air Temperature: 28 °C

Time of Min Rel Humidity: 16

Time of Max Rel Humidity: 23

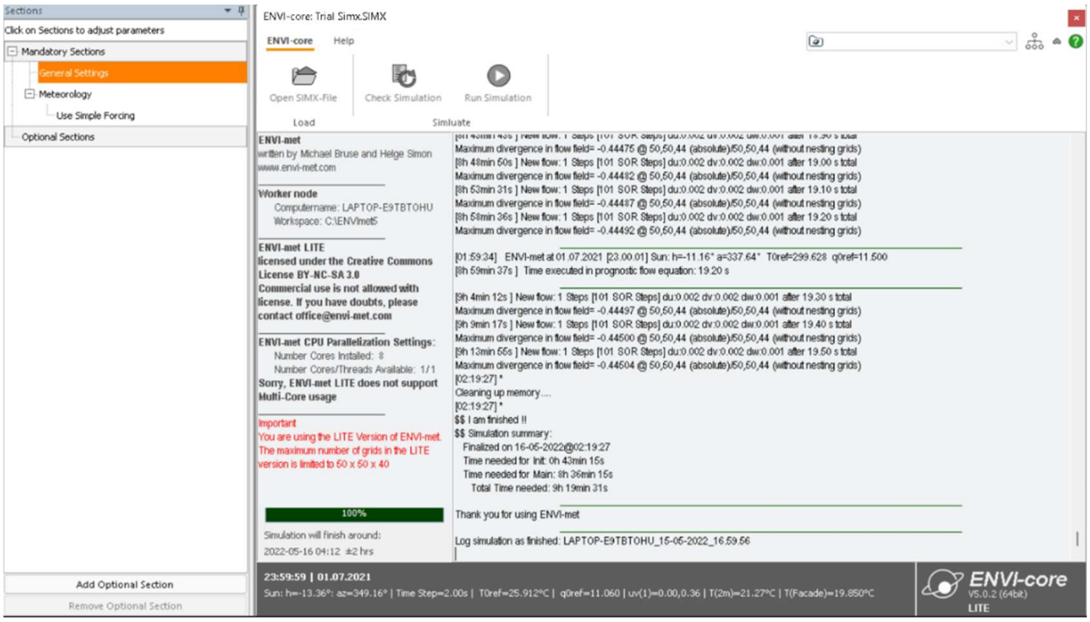
Min relative Humidity: 45 % Max relative Humidity: 75 %

Humidity in 2500 m

Specific humidity in 2500 m (g/kg): 8.00

Figure 3.4.8: Simple forcing graph of weather parameters in ENVI-Met

The simulation lasts for 15±2 hrs to give out the results which can be further analysed. Below is the figure of the configuration file written for the simulation.



```
ENVI-met
written by Michael Bruse and Helge Simon
www.envi-met.com

Worker node
    Computername: LAPTOP-E9TBTOHU
    Workspace: C:\ENVImet5

ENVI-met LITE
licensed under the Creative Commons
License BY-NC-SA 3.0
Commercial use is not allowed with
license. If you have doubts, please
contact office@envi-met.com

ENVI-met CPU Parallelization Settings:
    Number Cores Installed: 8
    Number Cores/Threads Available: 1/1
Sorry, ENVI-met LITE does not support
Multi-Core usage

Important
You are using the LITE Version of ENVI-met.
The maximum number of grids in the LITE
version is limited to 50 x 50 x 40

Simulation will finish around:
2022-05-16 04:12  ±2 hrs
```

```
Maximum divergence in flow field= -0.44475 @ 50,50,44 (absolute)/50,50,44 (without nesting grids)
[8h 48min 50s ] New flow: 1 Steps [101 SOR Steps] du:0.002 dv:0.002 dw:0.001 after 19.00 s total
Maximum divergence in flow field= -0.44482 @ 50,50,44 (absolute)/50,50,44 (without nesting grids)
[8h 53min 31s ] New flow: 1 Steps [101 SOR Steps] du:0.002 dv:0.002 dw:0.001 after 19.10 s total
Maximum divergence in flow field= -0.44487 @ 50,50,44 (absolute)/50,50,44 (without nesting grids)
[8h 58min 36s ] New flow: 1 Steps [101 SOR Steps] du:0.002 dv:0.002 dw:0.001 after 19.20 s total
Maximum divergence in flow field= -0.44492 @ 50,50,44 (absolute)/50,50,44 (without nesting grids)

[01:59:34]   ENVI-met at 01.07.2021 [23.00.01] Sun: h=-11.16° a=337.64°  T0ref=299.628  q0ref=11.500
[8h 59min 37s ]  Time executed in prognostic flow equation: 19.20 s

[9h 4min 12s ] New flow: 1 Steps [101 SOR Steps] du:0.002 dv:0.002 dw:0.001 after 19.30 s total
Maximum divergence in flow field= -0.44497 @ 50,50,44 (absolute)/50,50,44 (without nesting grids)
[9h 9min 17s ] New flow: 1 Steps [101 SOR Steps] du:0.002 dv:0.002 dw:0.001 after 19.40 s total
Maximum divergence in flow field= -0.44500 @ 50,50,44 (absolute)/50,50,44 (without nesting grids)
[9h 13min 55s ] New flow: 1 Steps [101 SOR Steps] du:0.002 dv:0.002 dw:0.001 after 19.50 s total
Maximum divergence in flow field= -0.44504 @ 50,50,44 (absolute)/50,50,44 (without nesting grids)
[02:19:27] *
Cleaning up memory....
[02:19:27] *
$$ I am finished !!
$$ Simulation summary:
  Finalized on 16-05-2022@02:19:27
  Time needed for Init: 0h 43min 15s
  Time needed for Main: 8h 36min 15s
    Total Time needed: 9h 19min 31s

Thank you for using ENVI-met

Log simulation as finished: LAPTOP-E9TBTOHU_15-05-2022_16.59.56
```

```
23:59:59 | 01.07.2021
Sun: h=-13.36°: az=349.16° | Time Step=2.00s |  T0ref=25.912°C |  q0ref=11.060 | uv(1)=0.00,0.36 | T(2m)=21.27°C | T(Facade)=19.850°C
```

Figure 3.4.9: Simulation completion on ENVI-core Interface

The topography, structures, trees, and surface materials are all represented in layers in modelling. This software after simulation provides a large volume of hourly data that is stored in various directories of the workspace. There are two types of generated outputs in general. To begin, there are two sets of XML-encoded metadata and binary (EDX, EDT) and ASCII-formatted files.

The contents of the directories are summarized in the following list:

- Buildings,
- Pollutants,
- Atmosphere,
- Radiation,
- Inflow,
- Vegetation,
- Soil,
- Solar Access,
- Surface,
- Receptors,
- Soil,
- Solar Access,
- Surface,
- Vegetation

The Leonardo software, which comes with ENVI-met, will visualize outputs in both 2D and 3D views.

The second case is the green case in which greenery is increased comparatively, such as by means of green roofs are implemented. Greenery is increased with other means also like the pavement area is covered with more vegetation.

The 2D model for Green Case Scenario is shown:

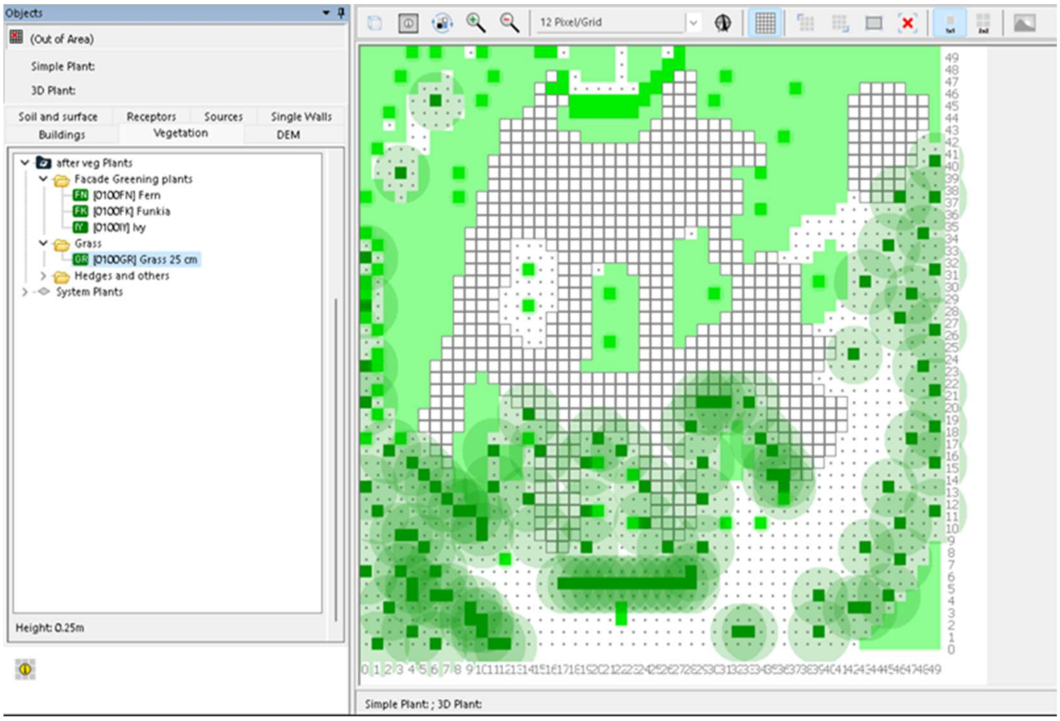
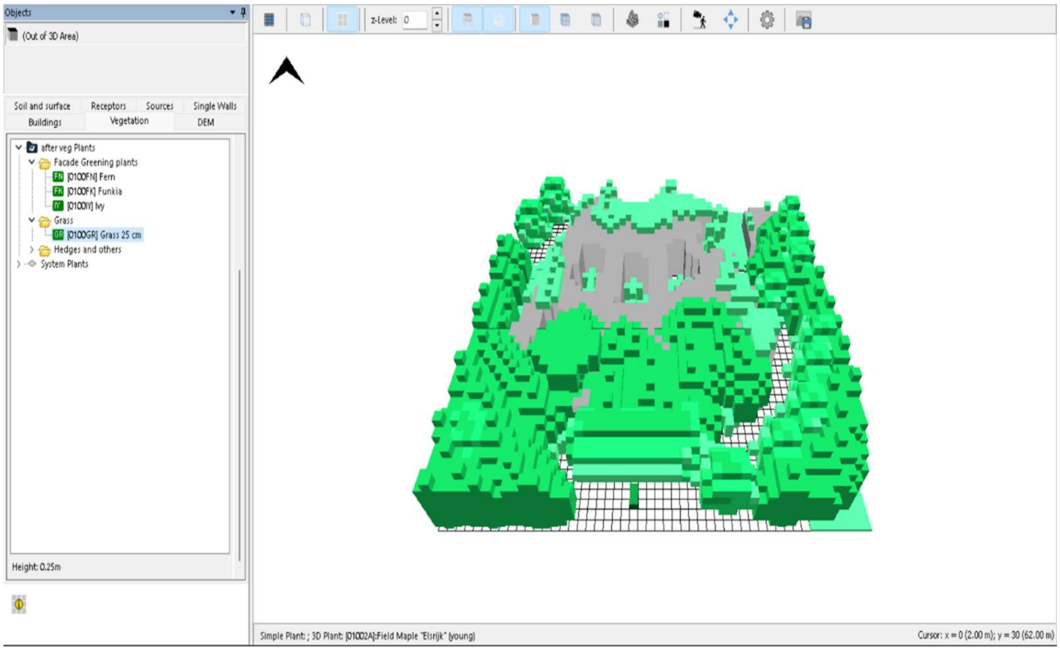


Figure 3.4.10: Site model area for Green Case

The 3D view of the model is shown below:



z-Level: 0

Height: 0.25m

Simple Plant: ; 3D Plant: [01002A]:Field Maple "Elsrijk" (young)

Cursor: x = 0 (2.00 m); y = 30 (62.00 m)

Figure 3.4.11: 3D model of site area for Green Case Scenario

The metrological data is taken same as the previous one case and then the simulation is done and after that the results will be compared.

CHAPTER 4

RESULTS AND DISCUSSION

The file formats that get saved in workspace after simulation is analysed in LEONARDO.

The results are analysed from midnight to every 6 hours to see the variations in Potential Air Temperature at a height of 1.4 meters which is an average human height and will depict about thermal heat comfortability. The results are first being analysed for the base case scenario first.

Given below are the figures of the Potential Air Temperature of the modelled area for base case scenario:

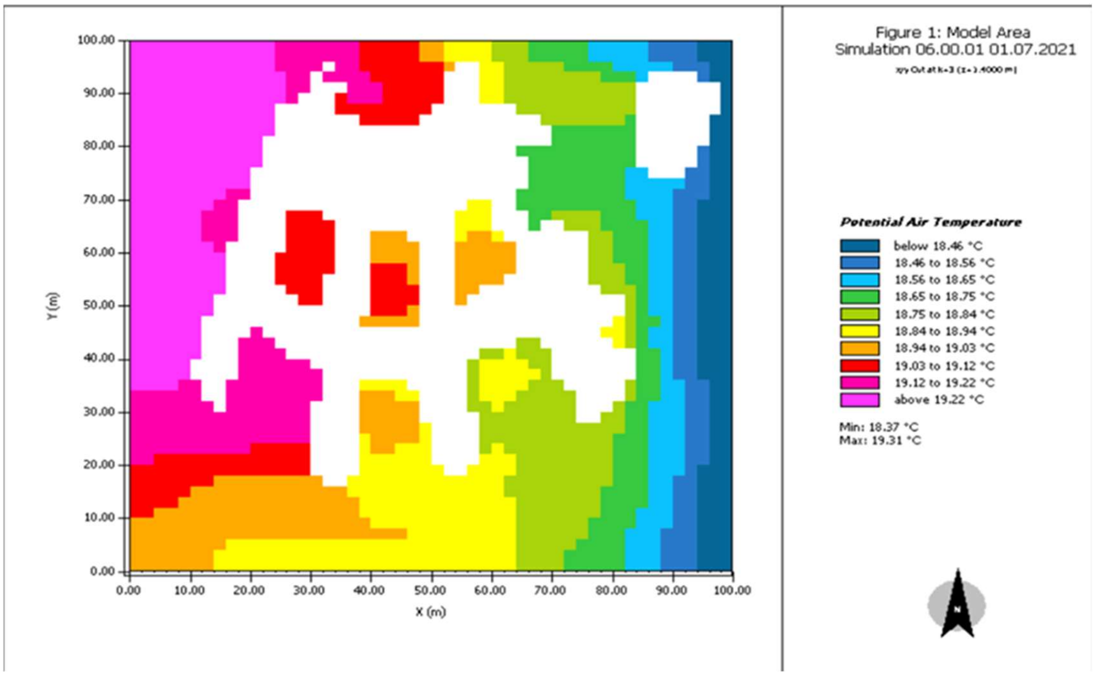


Figure 4.1: Visualization of PAT data of modelled area at 6 am

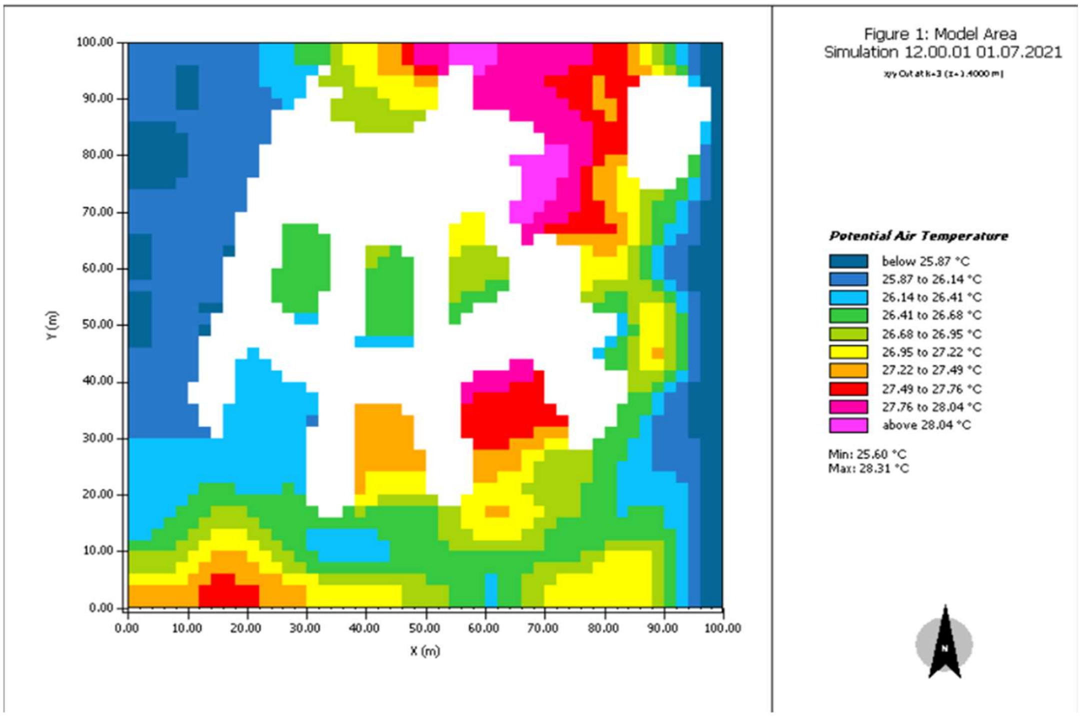


Figure 4.2: Visualization of PAT data of modelled area at 12 noon

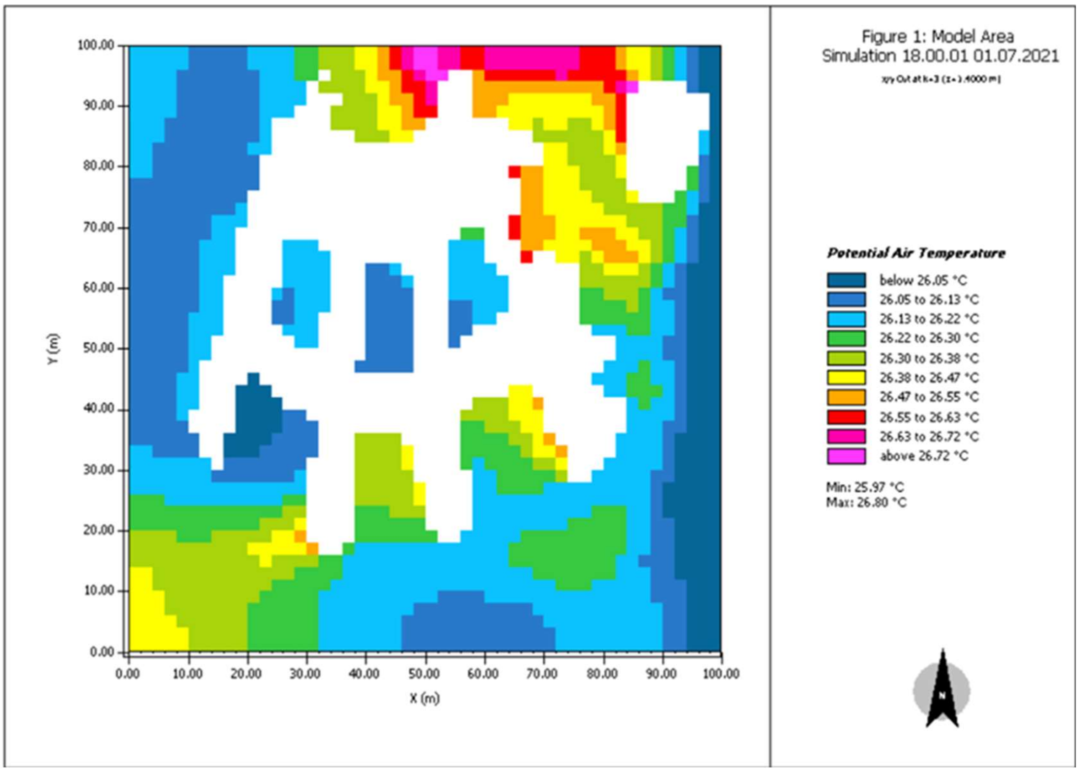


Figure 4.3: Visualization of PAT data of modelled area at 6pm

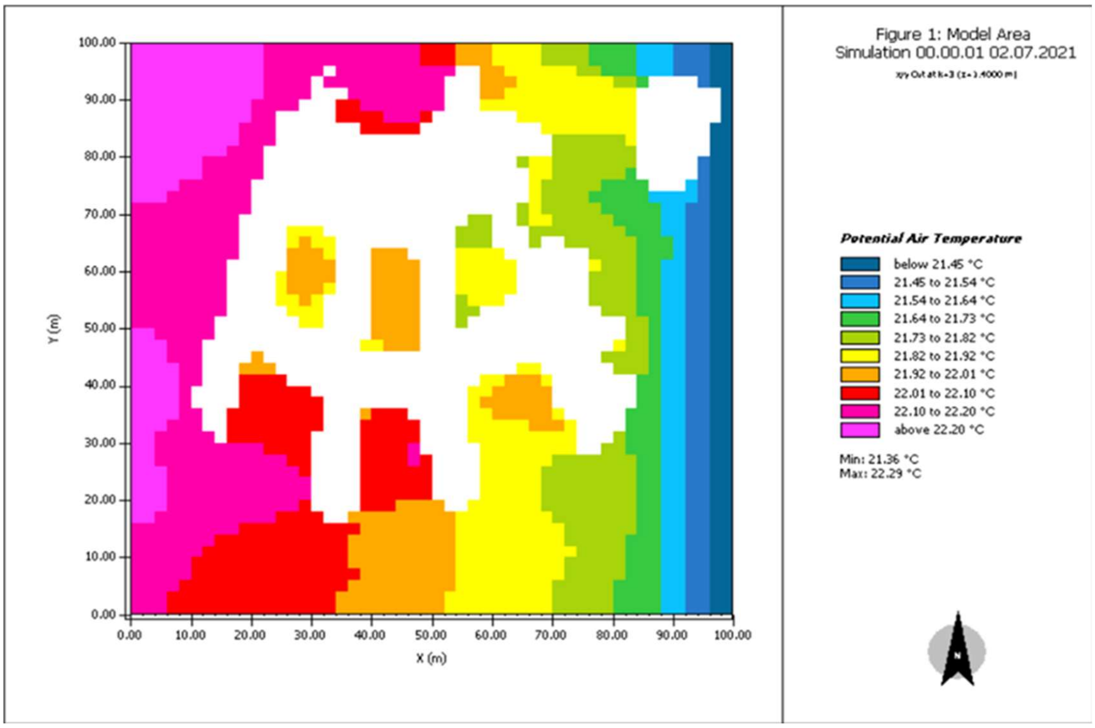


Figure 4.4: Visualization of PAT data of modelled area at mid-night

Next, we will analyse the PAT data for the green case scenario:

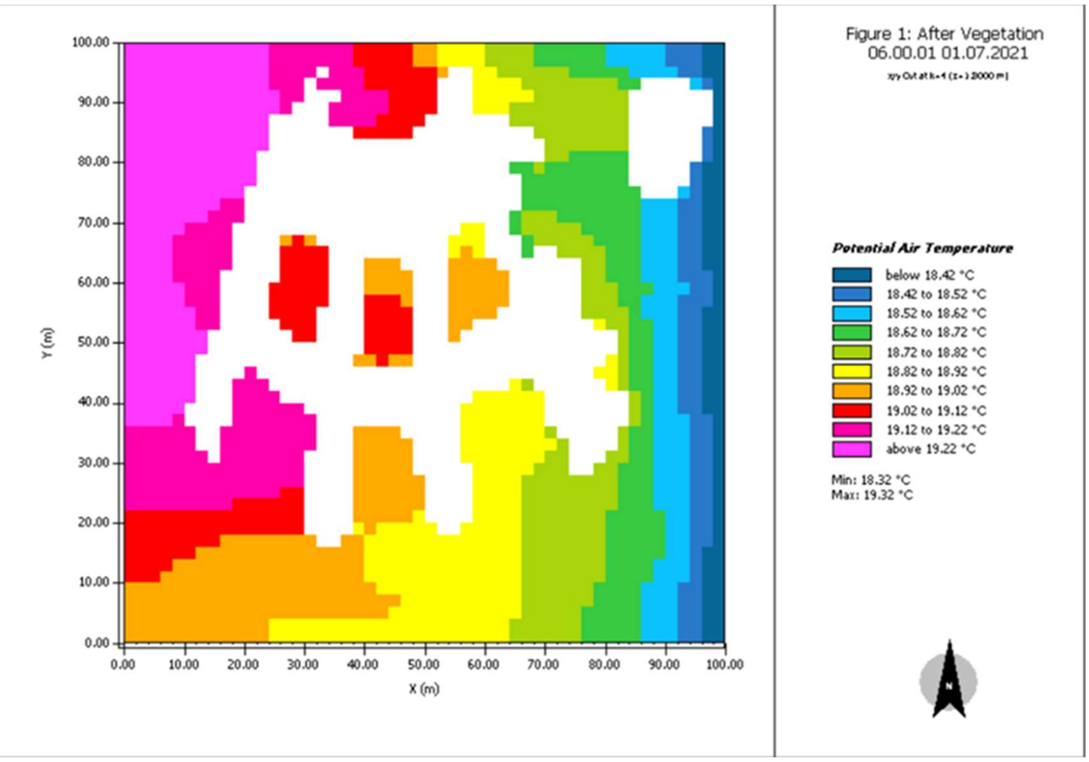


Figure 4.5: Visualization of PAT data of modelled area at 6 am

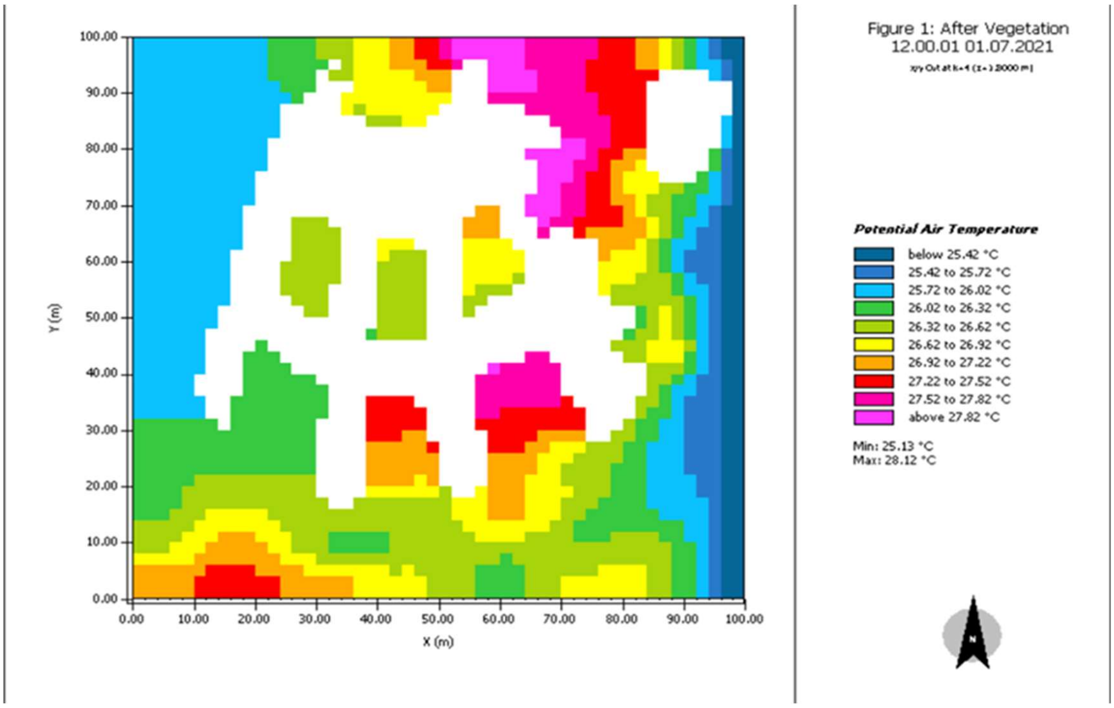


Figure 4.6: Visualization of PAT data of modelled area at noon

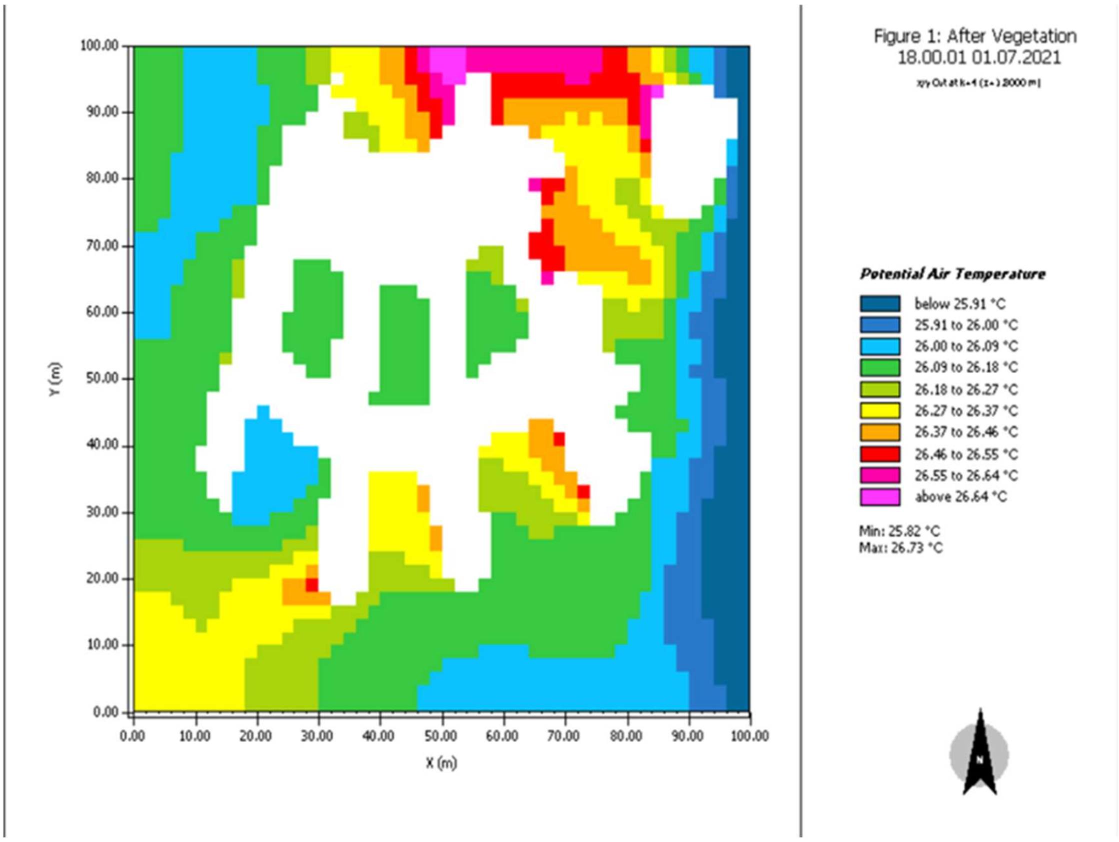


Figure 4.7: Visualization of PAT data of modelled area at 6 pm

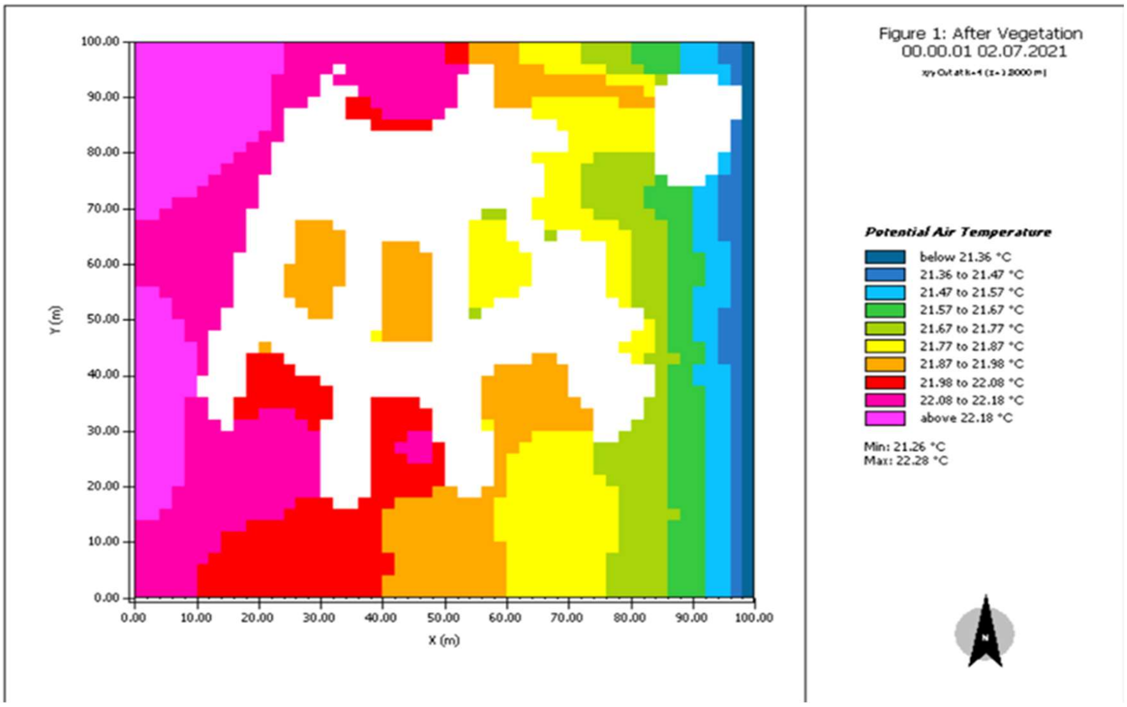


Figure 4.8: Visualization of PAT data of modelled area at mid-night

Now, we will compare the PAT values for Base Case Scenario and Green Case Scenario.

Table 4.1: Maximum and minimum PAT values for both scenarios

Time	Base Case		Green Case	
	Max Temp(°C)	Min Temp(°C)	Max Temp(°C)	Min Temp(°C)
6 am	19.31	18.37	19.32	18.32
12 pm	28.31	25.60	28.12	25.13
6 pm	26.80	25.97	26.73	25.82
12 am	22.29	21.36	22.28	21.26

From the table, we can infer that due to the increase in vegetation near and on the building, there has been a slight reduction in the Potential Air Temperature. The maximum reduction in temperature for the maximum temperature value for the entire day is 0.19 °C which is during the noon time. And the maximum temperature reduction for the minimum temperature value for the entire day is 0.47 ºC which is also during the noon time. So, the maximum temperature reduction is by half a degree Celsius which can provide thermal comfort to some extent and can also save building energy by making it more efficient.

Now, we will analyse the PAT data for the Base Case scenario at 5 am in the morning at the height of 1.4 m above the ground. This time has been taken as the starting time, which is during the sunrise, so that the model can warm up fast. It is also known as the buffer for the model to stabilise

.

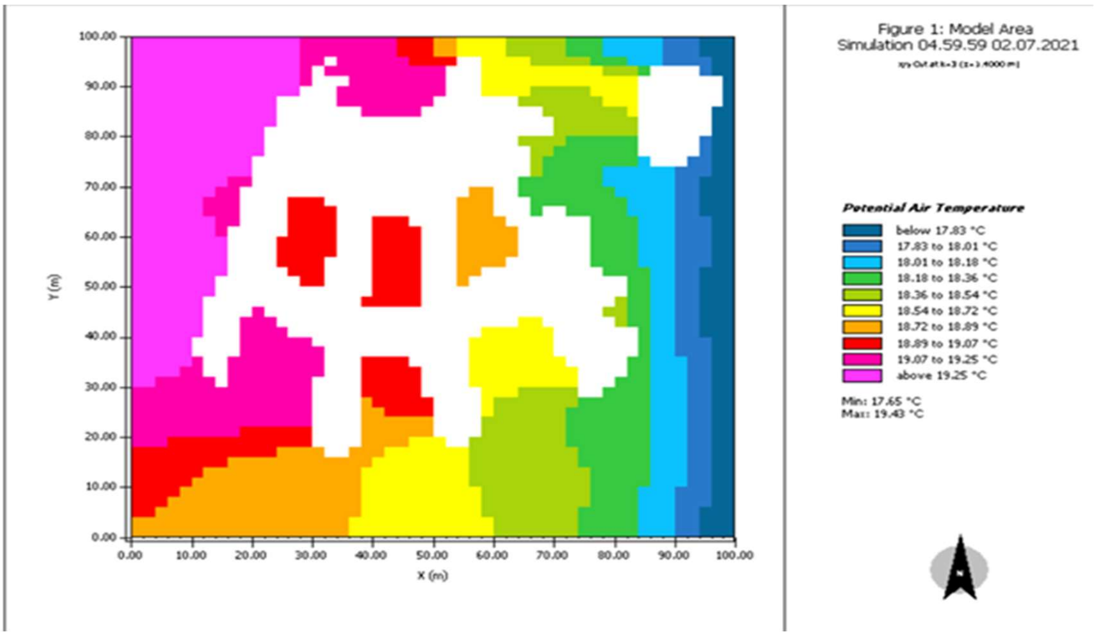


Figure 4.9: Visualization of PAT data of base case at 5 am

Figure for PAT data for Green Case Scenario:

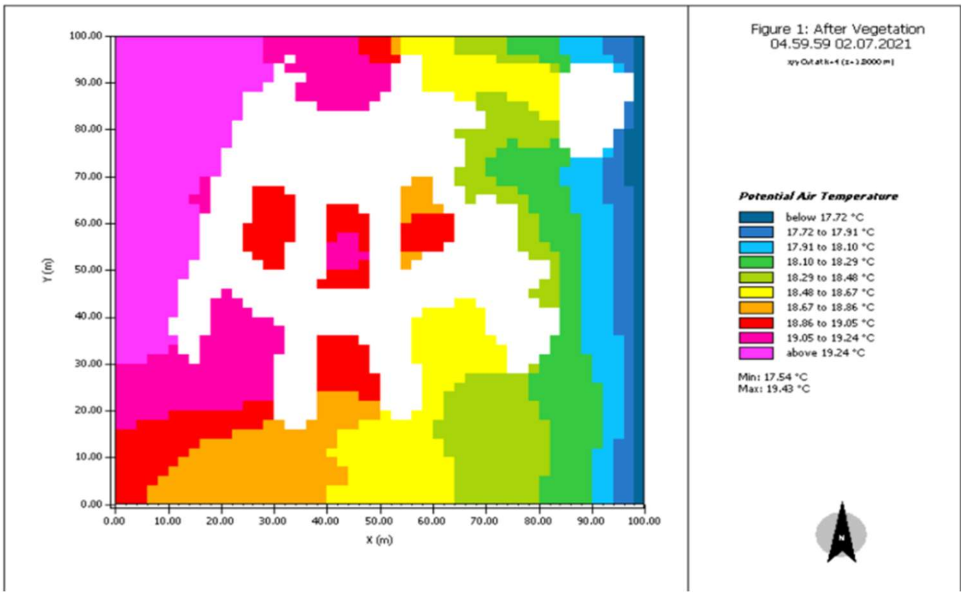
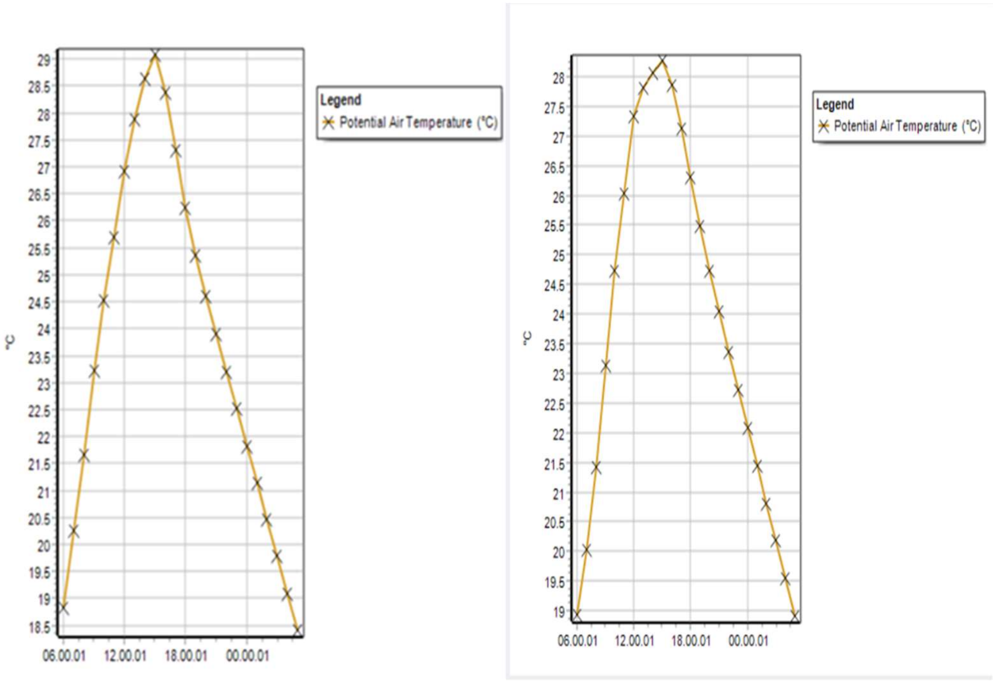


Figure 4.10: Visualization of PAT data of green case at 5 am

Table 4.2: Maximum and minimum PAT values for both scenarios

Time	Base Case		Green Case	
	Max Temp(°C)	Min Temp(°C)	Max Temp(°C)	Min Temp(°C)
5 am	19.43	17.65	19.43	17.54

From the data, we can observe that there is no change in the value of the maximum temperature but a slight decrement in the value of minimum temperature by 0.11 °C. Now, we will compare the different metrological parameters for both the case scenarios.

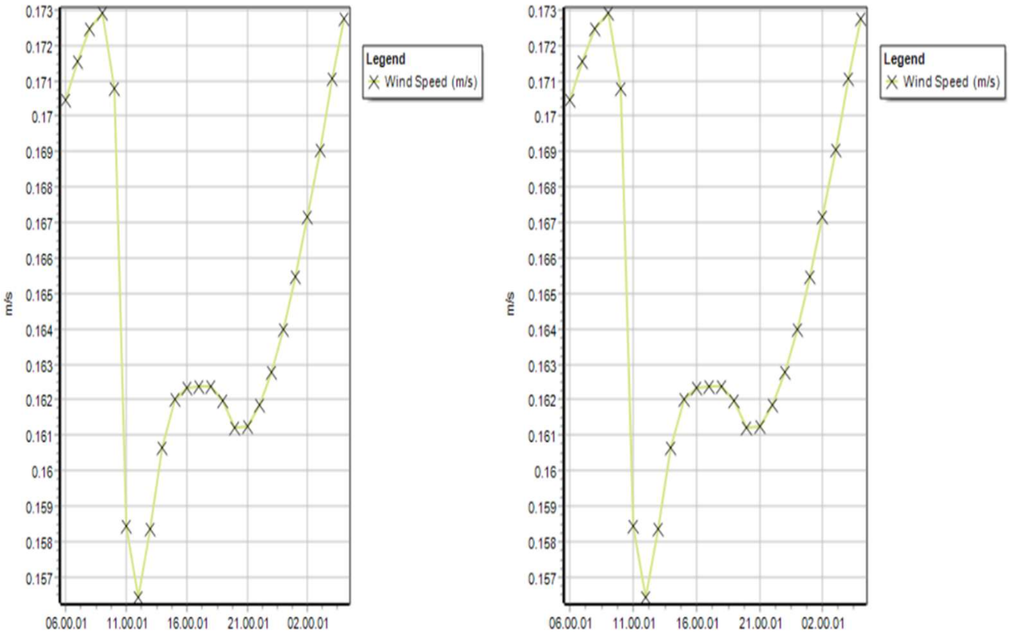


PAT graph for Base Case

PAT graph for Green Case

Figure 4.11: Hourly PAT graph for both scenarios

From the graph, we can observe that there has been the peak temperature declination between 12 to 2 pm in the afternoon by around 1° C which is said to be the peak hour for heat.

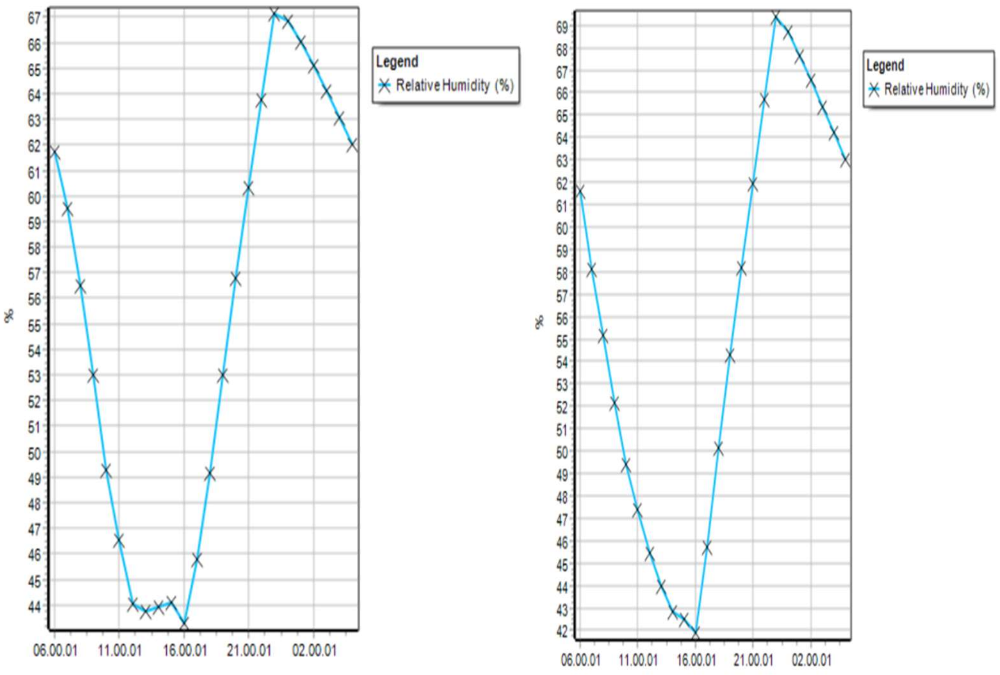


Wind Speed graph for Base Case

Wind Speed graph for Green Case

Figure 4.12: Hourly Wind Speed graph for both scenarios

There has been slight improvement in the wind speed also. The maximum wind speed for the base case is not even close to the minimum wind speed of the green case scenario which in turn can cool the atmosphere and is also comfortable for the human.



Relative Humidity for Base Case

Relative Humidity for Green Case

Figure 4.13: Hourly Relative Humidity graph for both scenarios

There has been a slight improvement in the relative humidity values during the peak hours. As we know, the temperature is maximum around 12pm to3 pm during the day, so the decrement in this value will be for relief.

Now, we will also compare the CO_2 values for both the scenarios.

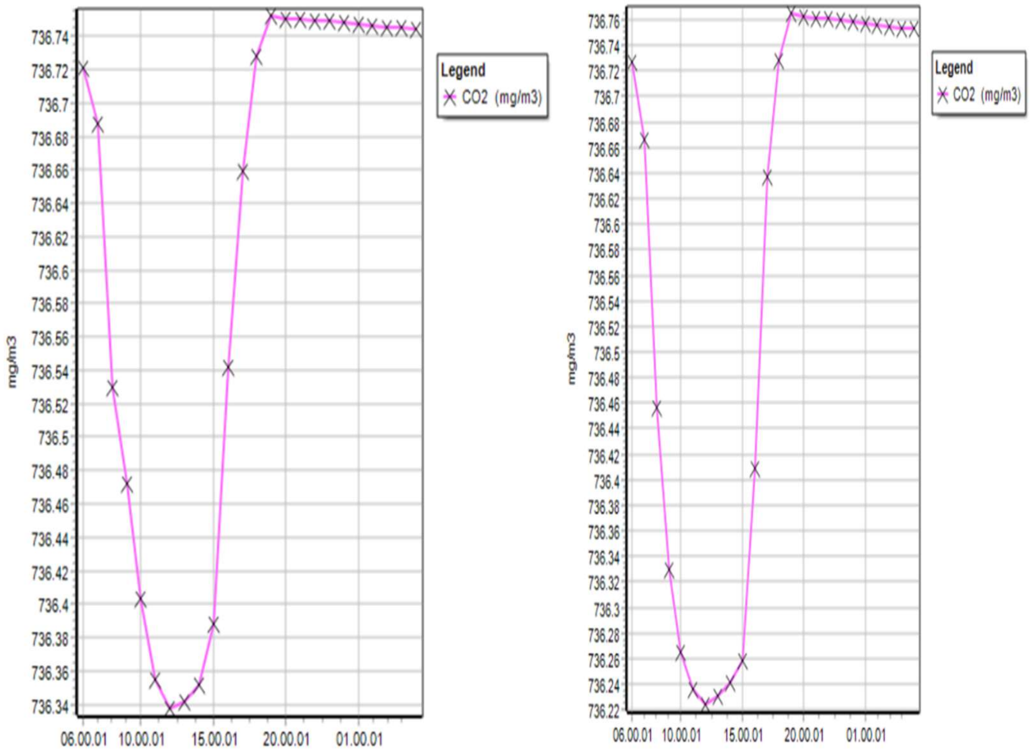


Figure 4.14: Hourly CO_2 graph for both scenarios

As it can be seen from the graph that there has been a slight decrease in the value of carbon-di-oxide during daytime. The CO_2 value started increasing after 12 noon but when comparing, we can see that the value is still low for the Green Case scenario for each passing hour as compared to the Base Case scenario. Also, the value of the CO_2 started increasing after 7 pm in the evening but during this time the value is more in the Green Case scenario due to the increase in the vegetation percentage by area.

By analysing all the parameters, wit can be said that even the vegetation has been increased with small percentage, it can improve the quality of the air nearby and can also decrease the potential air temperature by some range which in turn can give relief to some extent from heat.

Now, the comparison of Predicted Mean Vote for both the scenarios i.e., the Base Case and the Green Case. The results are analysed from midnight to every 6 hours to see the variations in Predicted Mean Vote at a height of 1.4 meters which is an average human height and will depict about thermal heat comfortability. The results are first being analysed for the base case scenario first.

Given below are the figures of the Predicted Mean Vote of the modelled area for base case scenario:

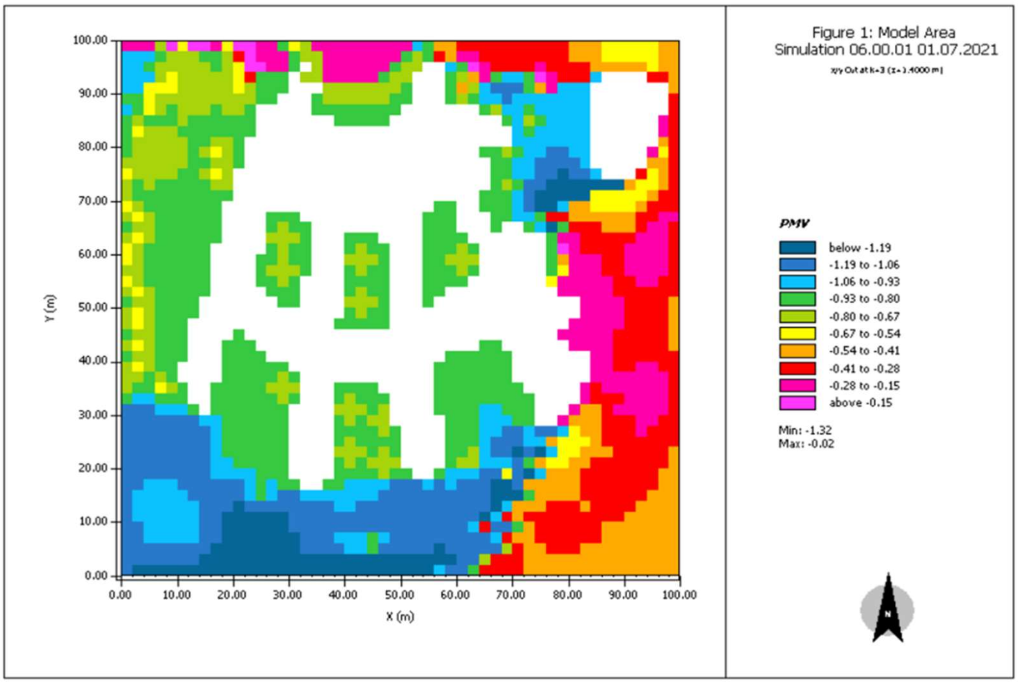


Figure 4.15: Visualization of PMV data for base case at 6 am

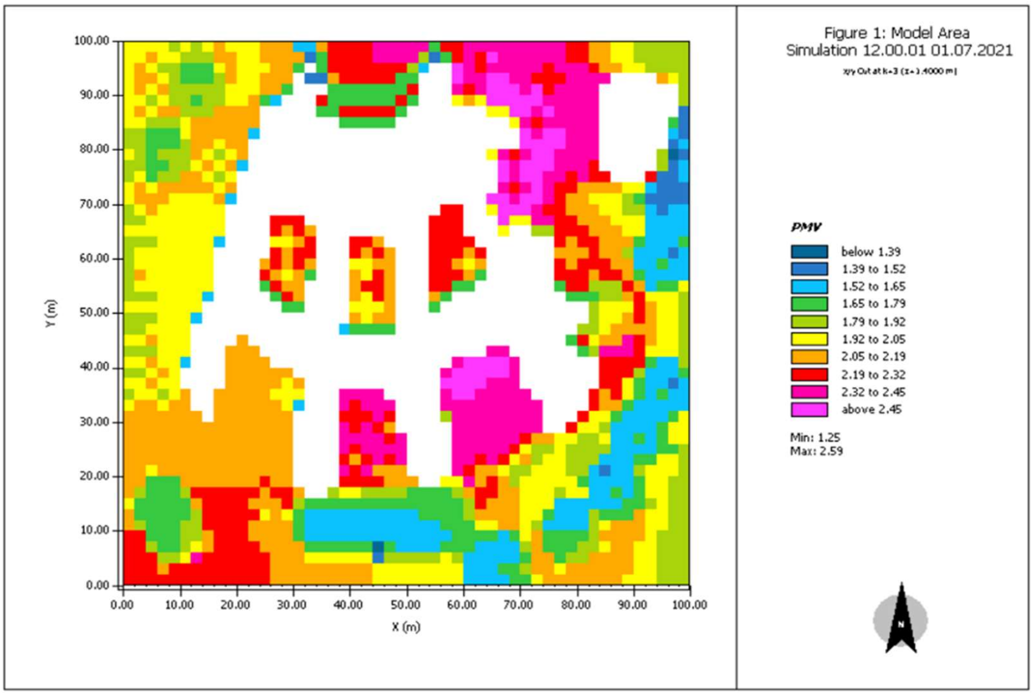


Figure 4.16: Visualization of PMV data for base case at noon

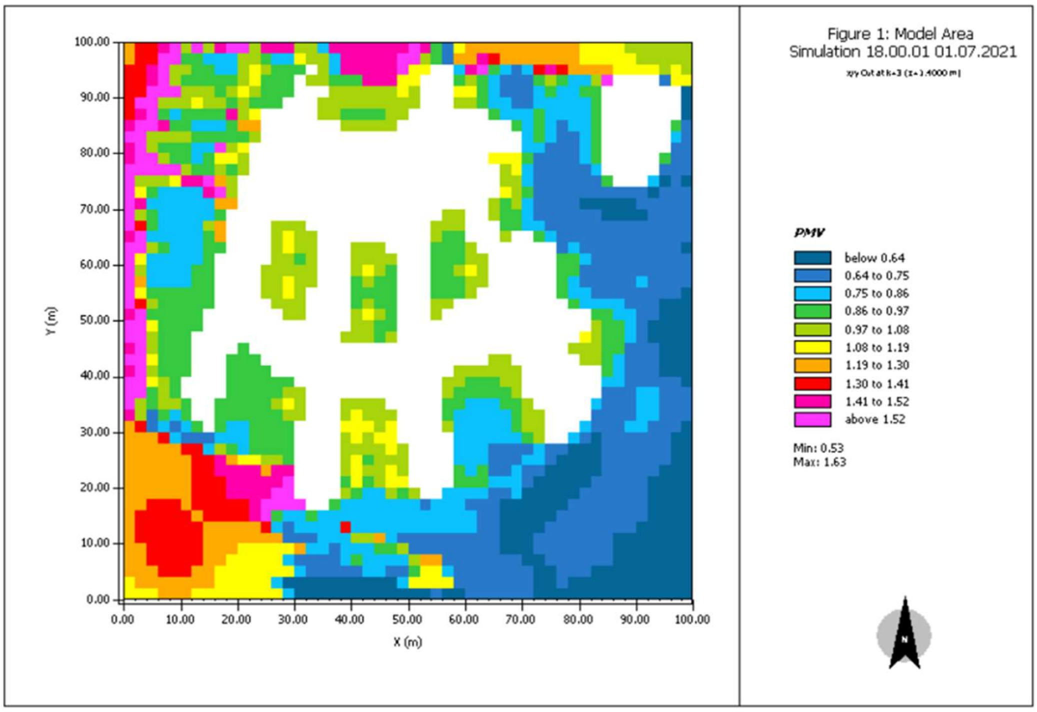


Figure 4.17: Visualization of PMV data for base case at 6 pm

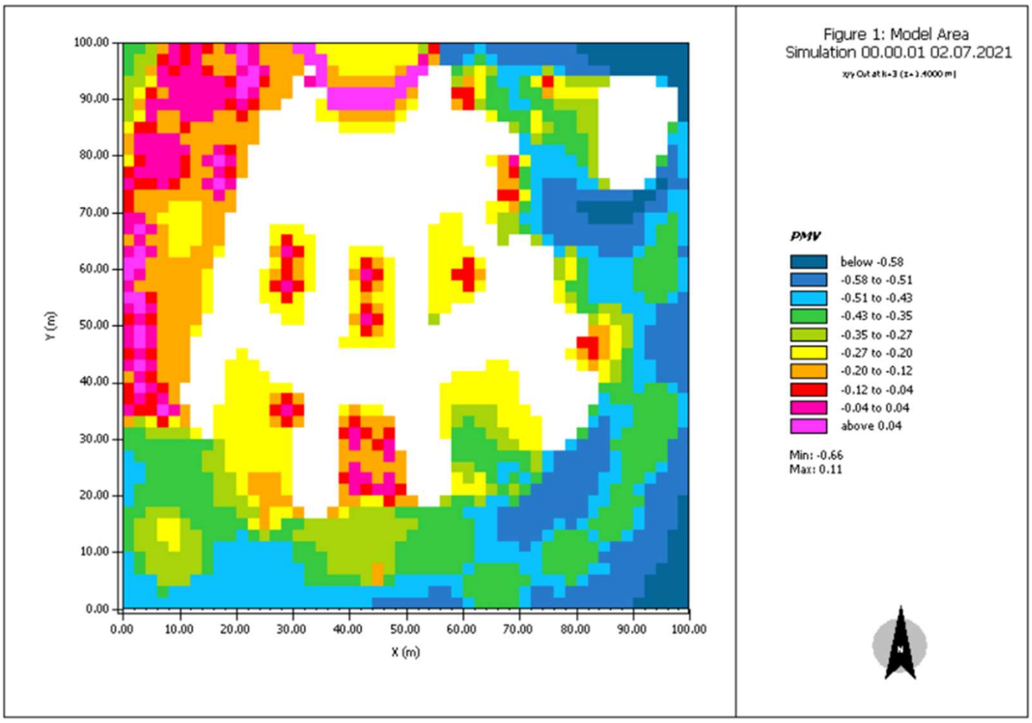


Figure 4.18: Visualization of PMV data for base case at mid-night

Now, the PMV map for the green case scenario is also analysed from mid-night to every 6 hours for the day.

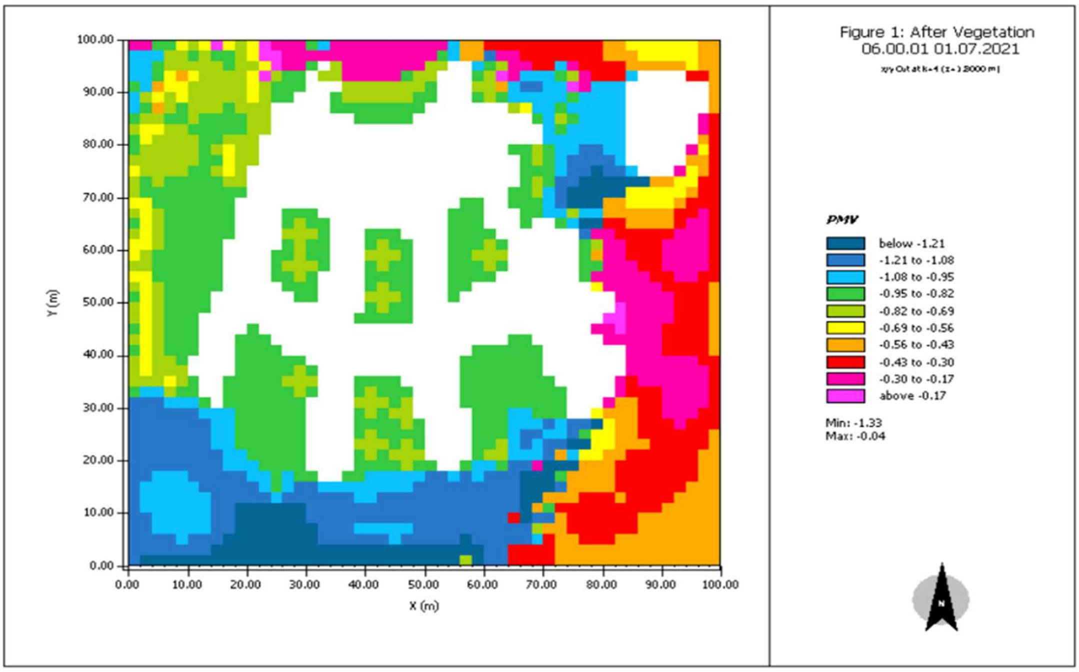


Figure 4.19: Visualization of PMV data for green case at 6 am

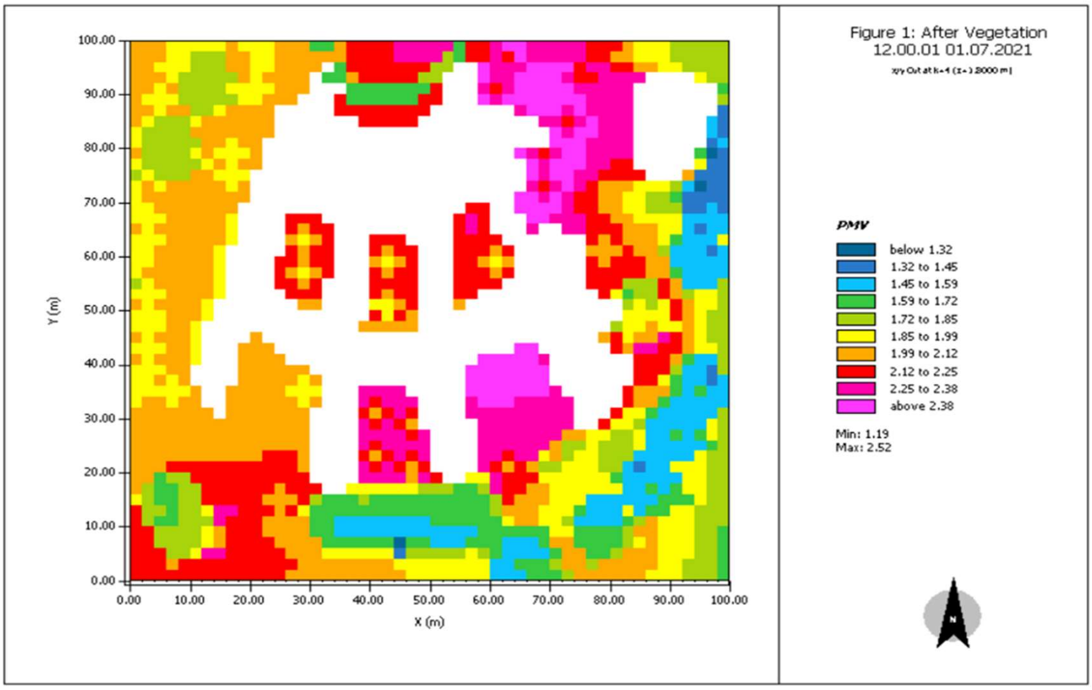


Figure 4.20: Visualization of PMV data for green case at noon

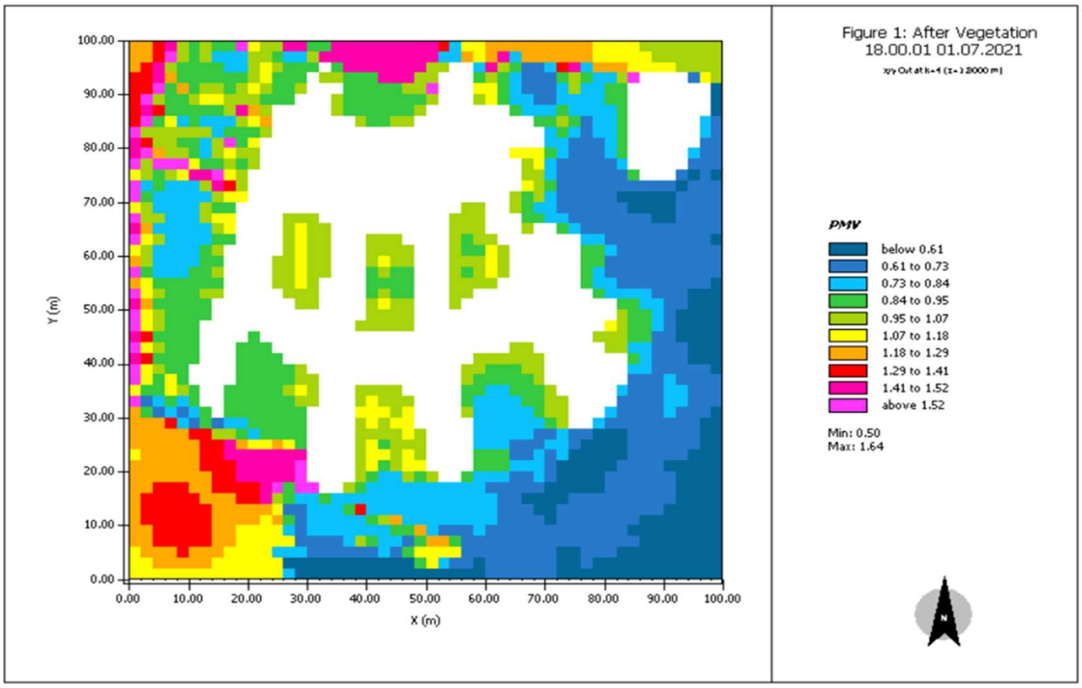


Figure 4.21: Visualization of PMV data for green case at 6 pm

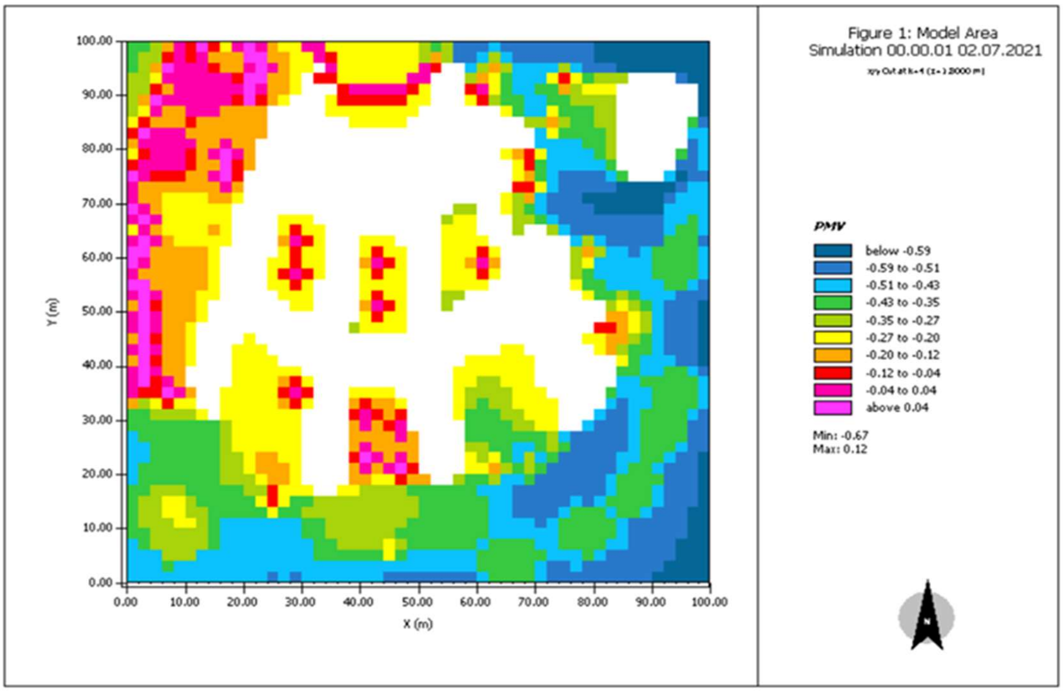


Figure 4.22: Visualization of PMV data for green case at mid-night

The comparison between the PMV values for Base Case and Green Case scenario is given in the table below. The PMV index value varies between -3 to +3 which describes feeling cold to hot.

Table 4.3: Maximum and minimum values of PMV for both scenarios

Time	Base Case		Green Case	
	Max Value	Min Value	Max Value	Min Value
6 am	-0.02	-1.32	-0.04	-1.33
12 pm	2.59	1.25	2.52	1.19
6 pm	1.63	0.53	1.64	0.50
12 am	0.11	-0.66	0.12	-0.67

From the table above we can conclude that PMV index has decreased all through the day except for the maximum values for 6 pm and the mid-night. But the difference is negligible. The maximum value of PMV index has decreased is by the range of 0.07 and the minimum value that has decreased is by the range of 0.06. Both of these values have decreased during the noon, hence giving thermal comfort to human.

Now, the PMV index value for the Base Case scenario and Green Case at 5 am in the morning at the height of 1.4 m above the ground are analysed.

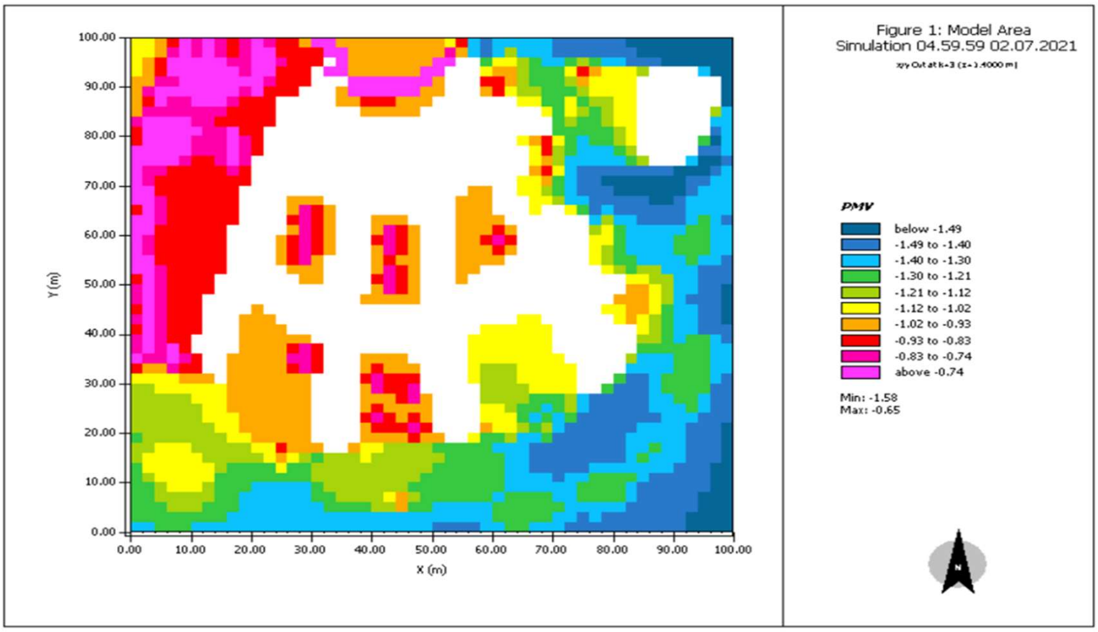


Figure 4.23: Visualization of PMV data for base case at 5 am

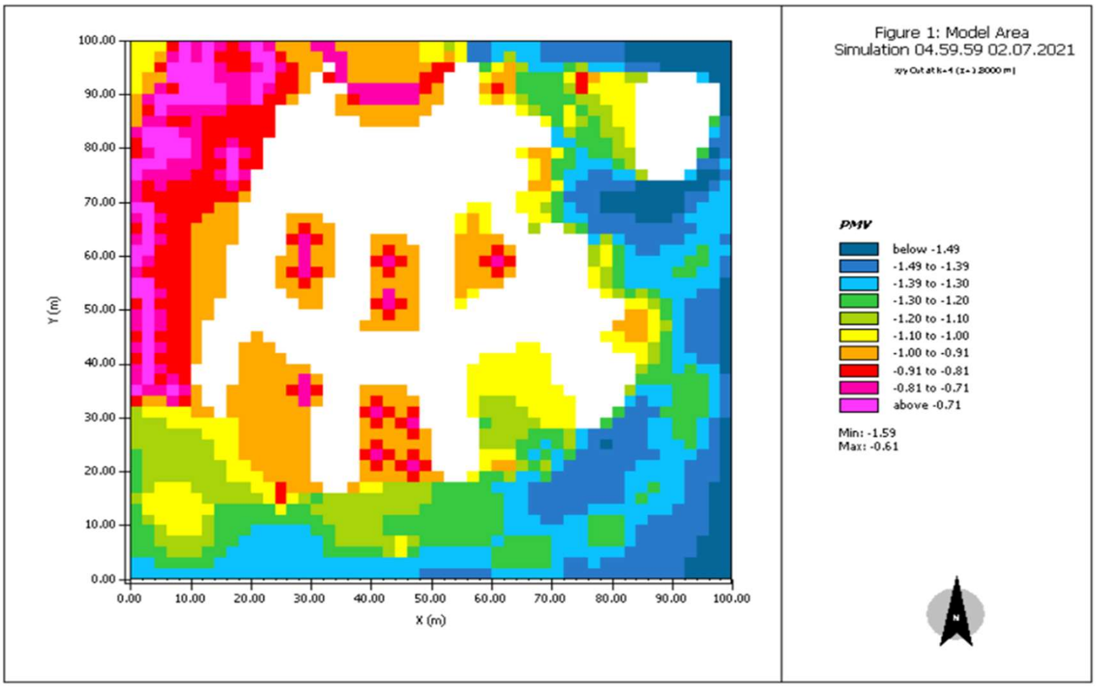


Figure 4.24: Visualization of PMV data for green case at5 am

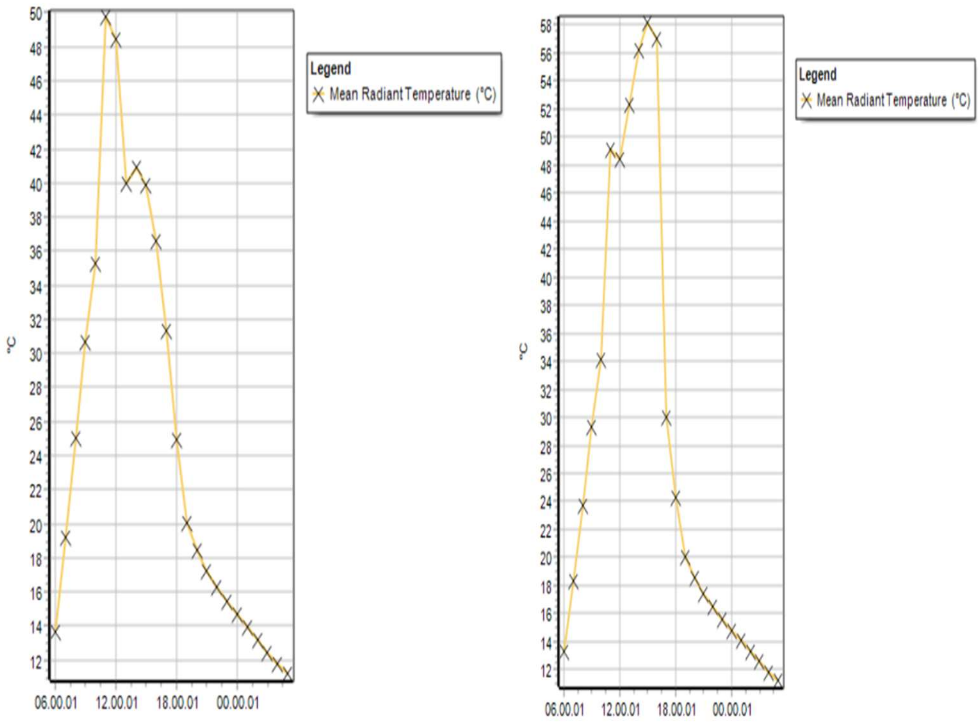
Table 4.4: Maximum and minimum values for PMV for both scenarios at 5am

Time	Base Case		Green Case	
	Max Value	Min Value	Max Value	Min Value
5 am	-0.65	-1.58	-0.61	-1.59

From the table it can be concluded that the maximum value has been increased by -0.04 while the minimum value decreased by 0.01. The PMV index is almost the same before and after increasing the greenery.

This is due to the reason that this is the time for sunrise and the area starts to get warm up but there is no such difference in the human thermal comfort level.

Comparing the graphs of Mean Radiant Temperature fore both the scenarios.



Base case Green Case

Figure 4.25: Hourly MRT for both the scenarios

The value Mean Radiant Temperature for the Green Case Scenario has decreased by 2 ºC giving human thermal comfort. The value is increased after the peak in MRT value between 1-3 pm in the base case. While in the green case scenario, the MRT value is decreasing after it attains its peak at 3 pm. As it is related to thermal comfort in the building so it can be inferred that the increase in greenery can provide relief during peak maximum temperature hours of the day.

CHAPTER 5
CONCLUSION

The goal of this thesis was to perform microclimatic simulations using ENVI-met software using two case scenarios. One having the physical properties and the other with the enhancement in the properties like Albedo of the material, Albero around the structure, etc. Analysing the two cases, it can be concluded that by the increase of vegetation, the air temperature of the surrounding area can be reduced. It also provides relief at human thermal comfort level by decreasing the value of PMV index.

This study also gives the information that by the increment of the vegetation, it makes the building energy efficient. As the human thermal comfort level will increase, the use of cooling effect in the building will decrease making it energy efficient.

Addition of greenery to the building makes it more sustainable and resilient and hence various techniques can be adopted to make building energy efficient. Some of them can be:

- Green roofs/ Cool roofs
- White roofs
- Vertical Gardens
- Permeable pavements

Earth’s surface continues to significantly rise in temperature because of global warming. The temperature has increased by 0.18 degrees Celsius per every decade since 1981. It was recorded that 2020 was the second warmest year on record. This extra heat is bringing about a lot of climatic changes, melting the glaciers, changing the habitat for plants and animals, etc. The scale with which the concern for global climate change is increasing, it is high time that major cities of the world should start adopting sustainable ways for urban infrastructure and become resilient. The study shows that by adopting such sustainable techniques, the temperature can be considerably reduced.

LITERATURE GAP

While going through various papers, I have concluded to the following points which needs special attention to carry-out the research further.

- Research can be done using this software to find out the energy efficiency of the building.
- Research can be done in selecting the suitable type of species for the given environment to make building more resilient.
- Research can be done in planning a sustainable city by designing buildings with such orientation and structure so that it provides more thermal comfort level.

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