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Original Article

Impact of Vegetation and Building Height on Urban Ambient Temperature in Hot and Dry Climate

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The effect of urbanization is directly observed on the physical environment within and surrounding areas of cities. The size and spatial structure of the city affect the amount of solar heat gain by buildings and ground. The phenomenon of gradual rise in ambient air temperatures in cities is well established, and known as the Urban heat island (UHI). To mitigate unwanted impact of UHI effect various approaches are carried forward, out of which act to increase vegetation cover is considered to be one of the important measures, it is well researched area along with its practicality in implementation. An urban canyon of Central Business District (CBD) area is configured according to the rules of ground coverage, Floor space index (FSI) and site setback. To understand microclimatic conditions generated by buildings, a three dimensional numerical computer model, which analyzes micro scale thermal interaction with urban environment, is used for this study. Parametric variations are made to get prediction with reference to surface temperature and ambient temperature. The results show that, trees are very important to control ambient air temperature and achieve nearly comfortable site's microclimate. Vegetation is seen more effective during harsh afternoon hours, due to shading and evapo-transpiration and their effects are also seen in the surrounding areas.

Keywords: *Urban heat island, Sky view factor (SVF), Urban canyons, Simulations, Leaf area index (LAI)*

1. Introduction

The changes and developments in the built environment invariably affect the microclimate, which in turn affects human health and increase consumption of energy in buildings. The increase in urbanization is loading urban areas with complex networks of built environments and human activity. Hence, it is important to incorporate the climate issues in urban planning and design. Among the urban design elements, urban density is an important factor that reflects the changes in the sites microclimate. Higher urban density means larger ratio of the height of the buildings to the distances between them (H/W) and less view of the sky. During daytime hours the effect of the width of streets on temperature is quite different than at night. In fact, higher urban density reduces the amount of sun reaching the street and thus it can effectively lower the urban daytime maximum temperature. (Kakaon Anisha, 2009). In the densely developed areas, the neighborhood structures reflect the radiation and do not allow the heat to dissipate creating warmer air temperature, results in increasing the evening time temperatures. Johansson analyzed that deep street canyon had considerably lower air temperature than a shallow street canyon during daytime.

Urban geometry has a significant impact on the radiation and convection heat exchange in urban canopy layer (UCL), and thus impact the UCL microclimate and UHI.(Yang et al.,2010). The air temperature inside the site depends on the shading intensity; partial shaded area, the thermal properties of the soil, and the air temperature of its immediate surroundings. (Shashua-bar et al., 2000).

Planting of vegetation is one of the main strategies to mitigate the Urban Heat Island (UHI) effect. Previous studies indicate that the cooling effect of city greens are remarkable not only on vegetated areas but also on surrounding built environment. (Jusuf Steve et al., 2006). In many urban areas, the loss of vegetation is considered as an important factor contributing to the development of heat island effect. Trees help in moderating temperature

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and they can be most useful when planted in strategic locations around buildings. Simulations show that incorporating street trees in the urban canyon had a limited cooling effect on the air temperature (up to 1.1°C), but led to a significant cooling of the ground surface (up to 12°C). The most important mechanism through which trees contribute to the reduction of high urban temperatures is evapo-transpiration and shading. As per the studies done by Zhuolun Chen and others (2009), it was found that the spots under shadows were always 0.6 – 0.8°C cooler and 20% less in high temperature frequency. It is evident, therefore, that vegetation, to a large extent can improve the thermal environment. The UHI effect is a common feature found in most cities. Therefore the basic strategies applicable to all urban areas in reducing urban temperatures are shading the hard surfaces that are directly exposed to sun.

In the present study, an attempt is made to quantify such a modifying effect of built density on urban heat island of Gandhinagar CBD. For this purpose, three cases are selected with varying vegetation density. For each case different configuration has been classified and their combined effect on outdoor air temperature is analyzed. These configurations are varied in terms of their vegetation and building proportions. The study here aims to understand the effect of vegetation on reducing the sites temperature in reference to changes in building height.

2. Methodology

2.1 Site and Climate

This research is based on Gandhinagar, India, which experiences hot-dry climate. It is located at 23°13' N latitude and 72°38'E longitude. It is believed to be one of the greenest capitals of the world. Gandhinagar is a developing city, due to its proximity various new developments are focused in this area. A proposed CBD area in Gandhinagar, sector 11 is identified as an area for study. New construction byelaws are promulgated by Gandhinagar urban development authority. This incorporates the rules of floor area ratio(FAR), ground coverage and site setbacks. According to these rules, the height of buildings will be determined by the FAR in respect to plot sizes and land uses. Hence, there is need to evaluate the effects of these rules on the thermal climate of the city. As per the byelaws, in Sector 11, it is permissible to achieve height of the building till 7floors with the ground coverage of 30%. As per the plantation byelaws of Gandhinagar, it is mandatory to plant 1 tree per every 100m^2 at every individual plot. In this study the whole sector is simulated and a typical urban module is identified as an area for discussion.

As shown in the plan, Fig.1, existing built-up is only 6% of the total site area. Rest other plots are marked for the future development of the commercial areas. The central open plaza is allocated for pedestrian activities. In this study a group of plots is considered as a part of this study on the basis of which further development can be worked out. The study is trying to understand the effects due to the geometric effects. Hence on the basis of the observations, further changes in the new development can be introduced.

Other parametric variations are done with changing aspect ratio, implementing vegetation and changing density of vegetation.

2.2 Techniques and Tools Used

The analysis is done using simulation model ENVI-met. ENVI-met is a three-dimensional computer model which uses the calculation of both fluid dynamics, such as air flow and turbulence, as well as the thermodynamic processes taking place at the ground surface, at walls, at roofs and at vegetation. ENVI-met works in two basic steps. First is editing input file, this takes the information of building, soil and vegetation in both X and Y direction. The resolution of the cells ranges from 0.5 m to 10 m. The lower the cell size, the higher the resolution. The model has working area up to 250x250m.

The second step is generating the configuration file, where the information about the site's geographical location, temperature, wind movement, humidity, and other required output parameters are entered. The software takes the input for the day of simulation and adjusts solar position accordingly. The simulation is processed using both the input and configuration files. Each output file has layers of information which can be visualized using LEONARDO 3.0.

This study seeks to understand the effect of vegetation on the outdoor microclimate in the central business district area. Sector 11 is planned with grid-ion pattern road network and rectangular plots having roads on side of plots. This area is also allocated for other

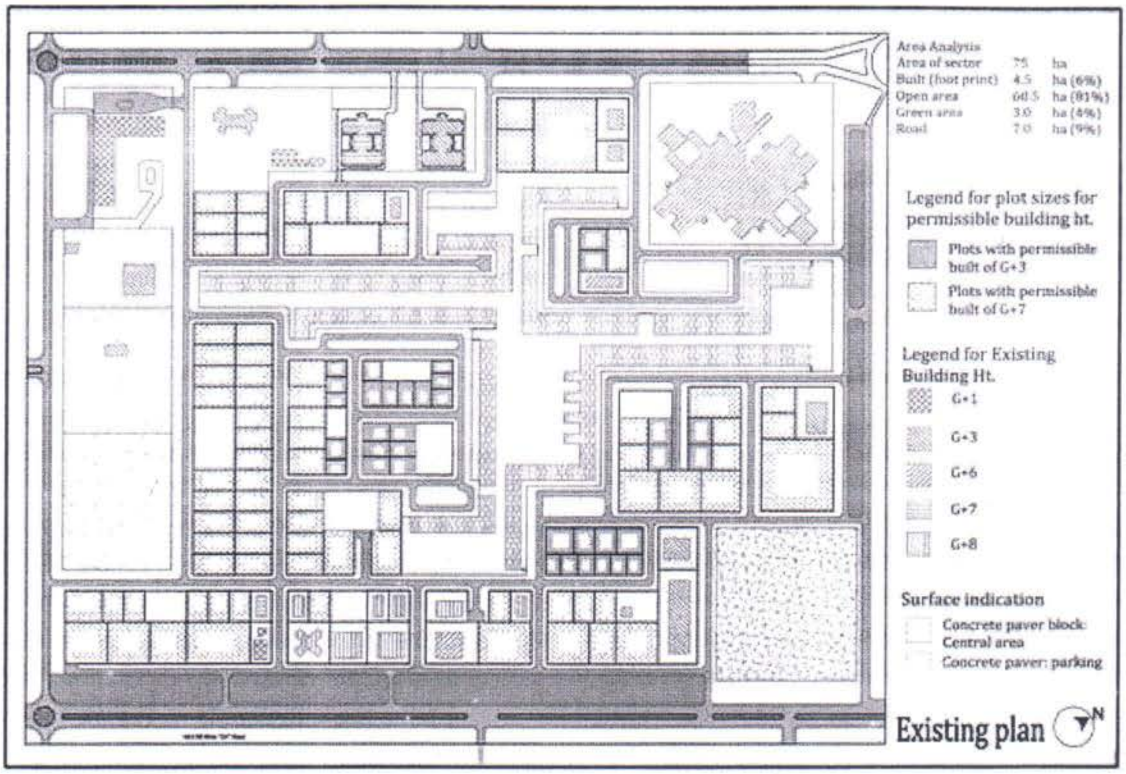


Fig. 1 Proposed Development Plan of Sector 11, Gandhinagar

government and private offices. Three model canyons were configured with their varying building heights. These canyons are assumed to be the future planning of that area. The orientation, width of road, surface cover and vegetation density is kept same for all the cases.

A group of four plots are selected, and in each, ground cover is configured as per site byelaws. In each case, building height and vegetation are considered as variables. Totally, three cases are modeled. They are for low-rise, medium- rise and high-rise and their impact on outdoor climate is analyzed.

1. Case A: 20m x 20m x 9m (Low rise)
2. Case B: 20m x 20m x 15m (Medium rise)
3. Case C: 20m x 20m x 21m (High rise)

Each of these cases is further modeled with the addition of vegetation as per regulation of a 1tree/100m^2 Light foliage tree which attenuates 30% direct shortwave solar radiation is selected for typical simulation run. Peak summer day is selected as a basis for study. Simulation is processed for 24 hours. Basic settings employed in this simulation are Table1.

The input parameters for the simulation run are applied for the model initialization. The major advantage of ENVI-met is that it seeks to reproduce the major processes in the atmosphere including the simulation of wind flow, turbulence, radiation fluxes, temperature and humidity on a well-founded physical basis. ENVI-met simulates the microclimatic dynamics within a daily cycle (48 hrs.) in complex urban structures, buildings with various shapes and heights and with different ground surfaces.

In the hot-dry climate, it is important to understand the role of trees in lowering the air temperature. Microclimate is governed by many parameters like temperature, evapo-transpiration, wind movement etc. Evapo-transpiration is the most important mechanism through which trees contribute to the reduction of high urban temperatures and it is the sum of evaporation and plant transpiration that can be observed through humidity trends. In this case, for the analysis, ambient air temperature is considered as important parameter and hence focus is kept on the calculation of the same. Here in the visualization below ambient air temperature range is expressed in terms of Pot. Temperature (potential temperature).

Table 1 Input Parameters for the Simulation Run

Input Parameters	
Simulation day	15 May 2010
Simulation time and hours	6:00 a.m., 24 hours.
Wind speed and wind direction	3.61m/s, 243.50°
Ambient temperature	303.15K
Humidity	85%
Indoor building temperature	297.15K
Heat transmission wall and roof	1.94 W/m^2K, 6 W/m^2K
Reflectivity wall and roof	0.2, 0.3
Gandhinagar Location data	
Latitude and Longitude	23.13° N, 72.38° E
Soil, Road, site paving	Loamy, Asphalt, Concrete paving

3. Results and Discussion

3.1 Without Vegetation

In all the three cases, the diurnal temperature variation is discussed and the temperature variations at 6:00a.m., 12:00p.m., 6:00p.m. and 12:00 a.m. are noted. During the afternoon office period, the peak hours starts from 12:00 p.m., when the sun is overhead and the contrast in temperature during evening hours is seen at 6:00p.m., which are the basis for the selection of this temperature range. At 6:00a.m., the sun is at the azimuth of 66.5° whereas at 6p.m., the sun is at the azimuth of 264.4°. The observations are taken at 1.6m height above ground level considering shading under tree. The 1.6m height under tree is used to represent a pedestrian comfort point of view.

In the above mentioned cases at 12p.m., when sun is at an azimuth of 159.5°, it is noted that in all the cases the blocks have started to experience rise in temperatures at the central area. This is due to the geometric effects; urban canyons provide multiple surfaces for the reflection and absorption of heat. The buildings absorb some portion of radiation and other gets reflected back. The neighborhood structures, re-radiate this radiation, and do not allow the heat to dissipate. Due to this, the heat gets trapped in the centre on the urban canyon creating a hotter air-mass. Urban canyons block wind, and create a major impact on radiation and convective heat exchanges within the air masses and built form; creating warmer air in the surrounding area. This trapped heat can compensate only during evening time creating warmer air masses surrounding the built form. There is on an average rise of 1.2°C rise in temperature in the central area compared to the outdoor air temperature.

During the evening hours at 6 p.m., as the ambient air temperature starts to reduce, the warmer air mass starts to dissipate from the centre through convection, creating a hot zone surrounding the built mass. With the decrease in the outdoor air temperature, canyon surfaces starts to release heat making the surrounding area warmer. There is on an average rise of 0.5 to 0.8°C in air temperature at the central area compared to the surrounding.

At 12a.m., hot air pockets are observed surrounding the built form, creating warmer areas in the vicinity. Due to convection, the leeward area also remains warmer. This is because the heat which is trapped through the surface materials during day-time is released during night time creating hotter zones around the built masses. This formation of hot contours depends on the amount of surfaces available for absorption of heat during daytime.

At 6 a.m., the outside air becomes cooler, but still the temperature surrounding the building is quite warmer. There is on an average rise in 0.5°C temperature near the built surfaces compared to the open area as seen in Fig.1.

The amount of heat that is trapped within the blocks is different for all the cases. This is due to the variation in the sky view factor values. Sky view factor defines the amount of sky that can be viewed between the buildings, which is generally less in urban built form. This indicates that lot of heat is trapped by the buildings during daytime which get released during night. The amount of solar radiation received by the built forms also depends on the height of the building and width between them. During daytime the buildings cast shadow on each other, preventing the surfaces from getting warmer. With the increase in the height of urban canyon, larger portion of the area remains shaded. But this also indicated the availability of larger mass for the absorption of solar radiation. As it is clearly seen from the temperature graphs, in case A, as the height of the buildings are low, central area gets heated up highly during the day compared to Case C. Whereas during evening hours, heat starts to get dissipated faster in Case A compared to Case C. The higher temperatures are best developed over city centers at night under stable conditions and the situation is often referred to as the 'urban heat island'.

This can be understood better in temperature amplitude graph as shown below.

The graphs at different location and different time period indicating temperature differences are discussed below. As shown in Fig.3, Graph1, the temperature at central area remains higher compared to the surrounding area, but still its effects are seen in the leeward direction as well as between the canyons. At 12p.m. and 6p.m., the temperature at central area is higher compare to other two, as the heat is trapped within this area, blocked by the other urban structures and is not allowed to dissipate. Whereas during the early morning hours the temperature between two canyons is much higher compared to other areas as shown in Graph3. This is because the wind is directed from west side, so due to convection, the central area starts to dissipate heat, but its effects are prominent in the surrounding area. Comparing all the cases, caseA (Low rise) receives more solar radiation during day time hours compared to Case C (High rise) making the outdoor condition worst. But the condition is reversed during early morning hours.

Although deeper and narrower urban canyons tend

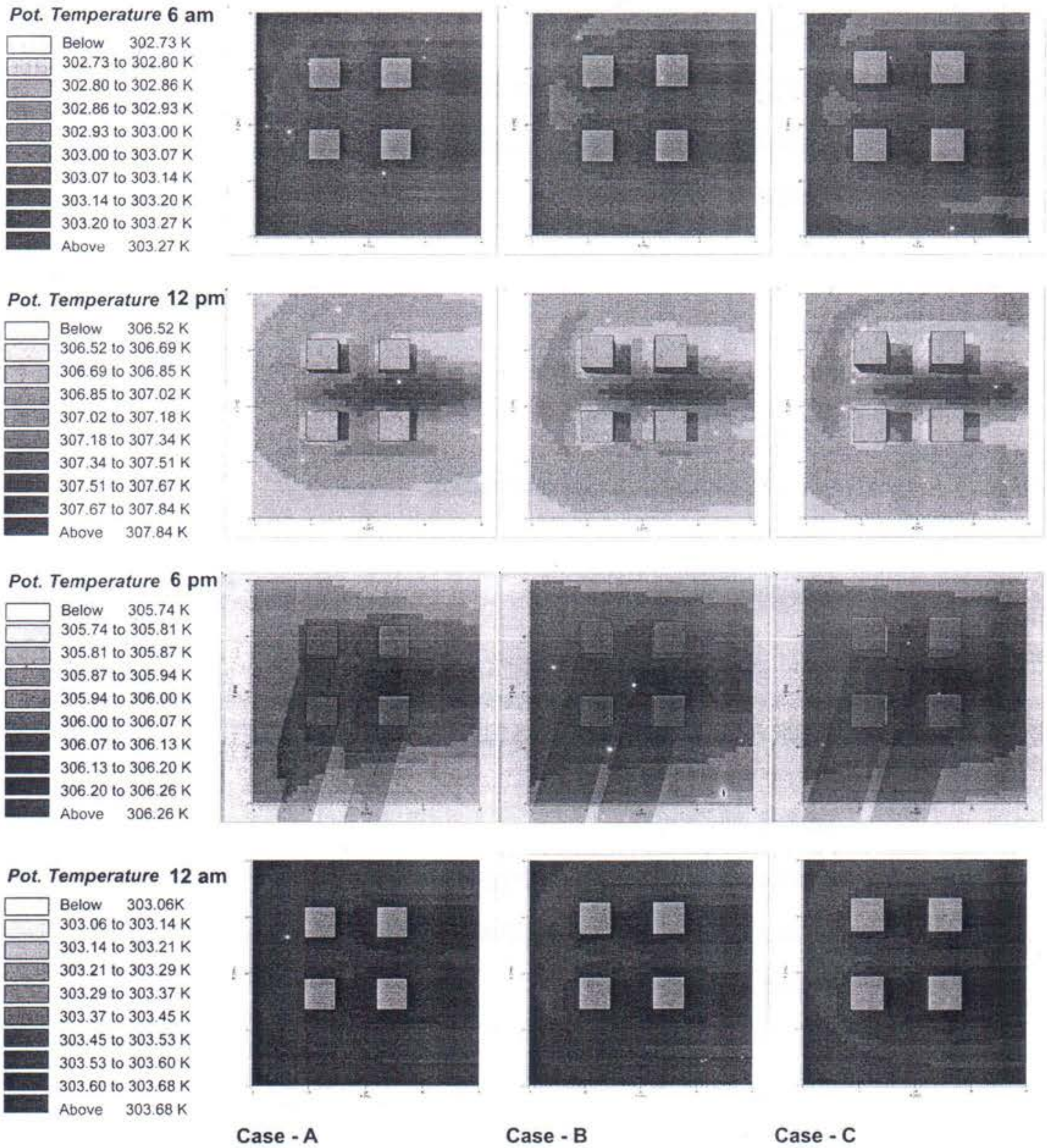


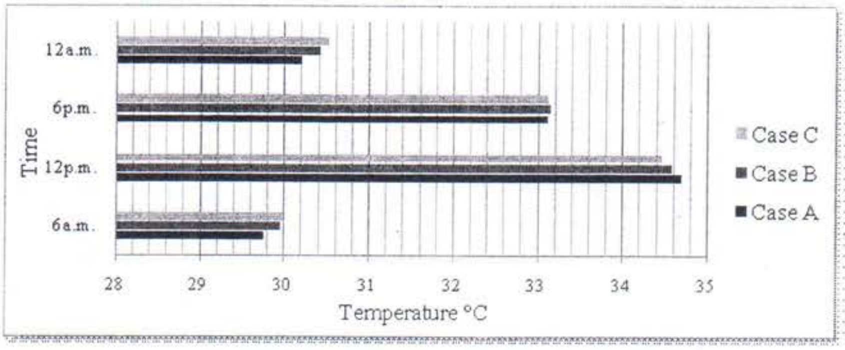
Fig. 2 Temperature Profile for All Different Conditions without Vegetation

to elevate night-time temperatures because of the "heat trapping" effect, the daytime thermal conditions in hot days can be much improved compared to more open areas, mainly due to the building shading effect. This is supported by both field measurement and numerical modeling by Yang et al. (2010).

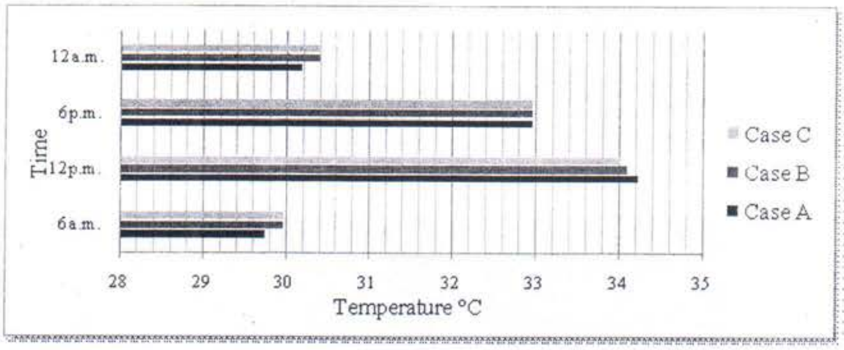
3.2 With Vegetation

In all the above mentioned cases, there is an addition of urban trees, as per the site byelaw. Vegetation reduces temperature with respect to its shading and evapo-transpiration properties. During the harsh afternoon hours, shade of the trees reduces short wave radiation and block long wave radiation coming off from various surfaces. Evapo-transpiration cools the air by using heat from the air to evaporate water converting sensible heat into Latent heat flux (Georgi J., 2010). Selection of trees depends on its thermal performance of its shape which depends on the size of its foliage and its maturity.

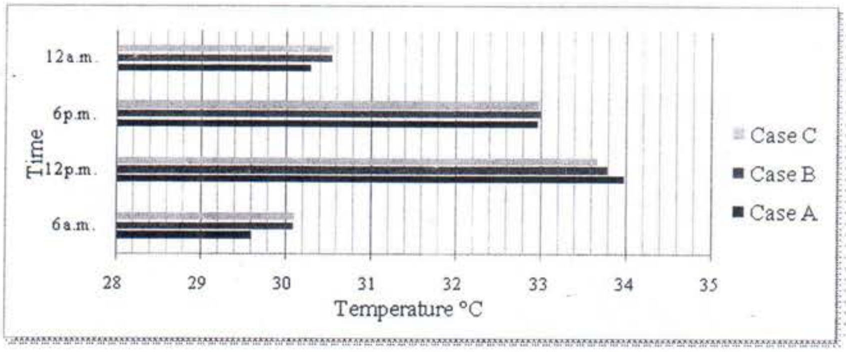
As seen above, in all the three cases, Case A experiences hotter surrounding areas due to reduced sky view factor. This heat can be minimized by addition of trees around the urban form to shade them which can



Graph 1 Temperature Amplitude of All Three Cases at Central Area without Vegetation



Graph 2 Temperature Amplitude of All Cases without Vegetation at Leeward Direction



Graph 3 Temperature Amplitude of All Three Cases without Vegetation between Canyon

Fig. 3 Temperature(°C) and Time Graph for All the Three Cases without Vegetation at Various Locations

be understood through the discussions on the following graphs.

It is observed that the effect of vegetation is more in the morning as compared to the afternoon period. The reduction in temperature with the addition of vegetation is more in the central area as seen in Graph4. During the night and early morning hours, the temperature range is constant. The average temperature difference of 0.5°C is achieved with the alteration of condition. For an outdoor setting, the globe temperature plays important role. Globe temperature is a clear indicator of outdoor environment, whereas in this study only air temperature is tested. Therefore in air temperature scale a drop of 0.5 °C can be considered as a achieved difference with the introduction of vegetation. From Graph4, Graph5 and Graph6, the effect of trees on the urban blocks is seen.

The heat contours that were developed initially with the cases without vegetation still persist but reduction in temperature is observed. The heat contours that were formed around the buildings during night were neutralized by the addition of trees near the buildings (as seen in Fig.1 and Fig.2). The comparison also shows

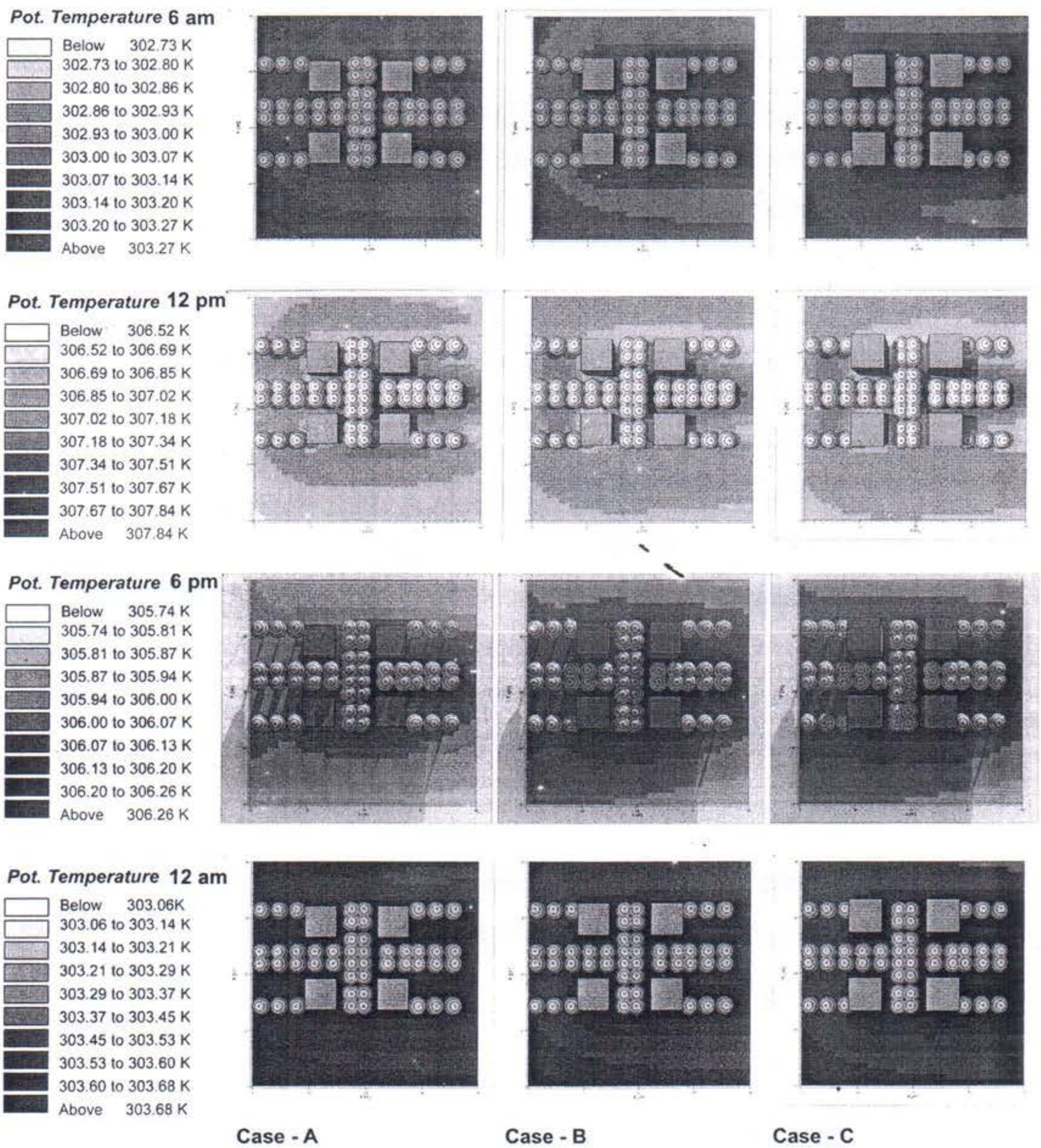


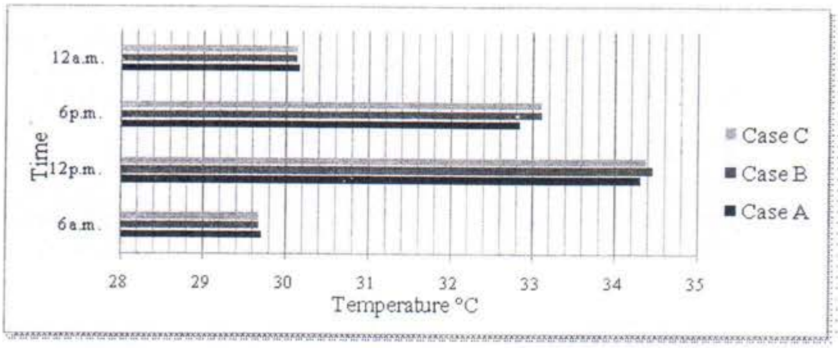
Fig. 4 Temperature Profile for All Different Conditions with Vegetation

that the cooling effects due to green area on the outdoor climate are affected by building density as discussed above. Due to higher built form, the cooling effect is very less. This is more clearly seen during evening hours, as the heat from the built surfaces begins to get released. It is observed that the cooling effect around the building in the leeward direction is seen but it is not so pronounced as compared to other central area due to dissipation of heat through convection.

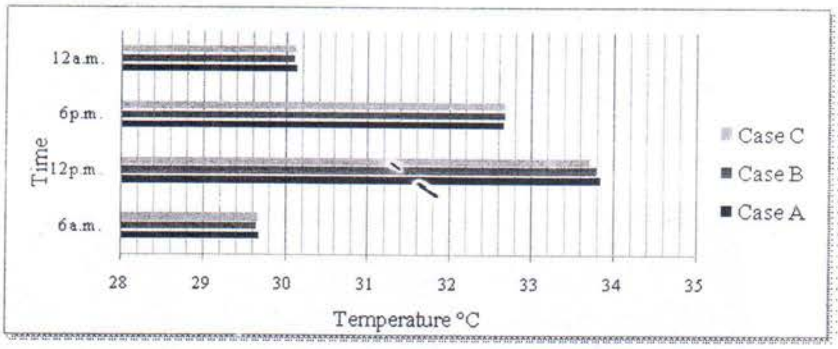
From the above results it is identified that cooling due to trees is achieved more during day time because of its shading and evapo-transpiration. The process of evapo-transpiration happens during day time, so cooling effects at night time is not seen. Hence this also results in constant temperature range of all cases during night and early morning hours.

3.3 Changing Density of Tree

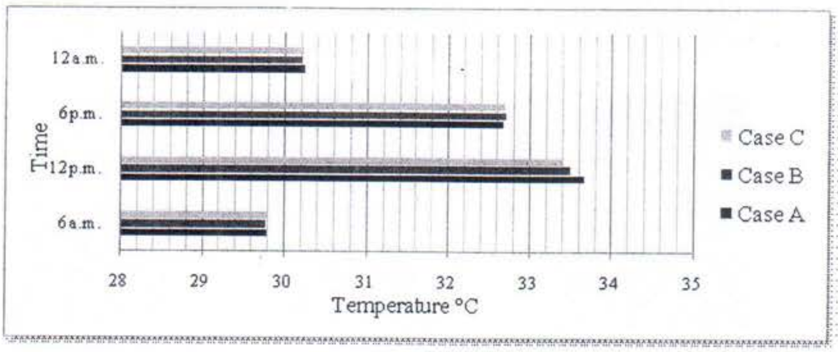
In any CBD area, the focus is to utilize maximum floor space index and therefore, it is practically not possible to build low rise buildings there. In this study, case C is considered as future growth of CBD area in Gandhinagar. Here, a dense foliage tree is analyzed and



Graph 4 Temperature Amplitude of Central Area with Trees



Graph 5 Temperature Amplitude at Leeward Direction with Trees



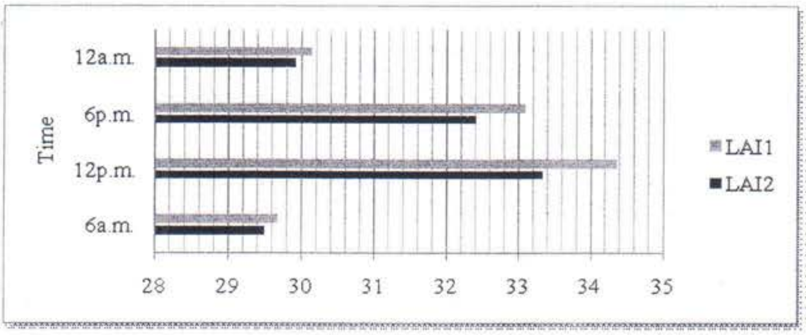
Graph 6 Temperature Amplitude between Two Canopies with Vegetation

Fig. 5 Temperature (°C) and Time Graph for All the Three Cases with Vegetation at Various Locations

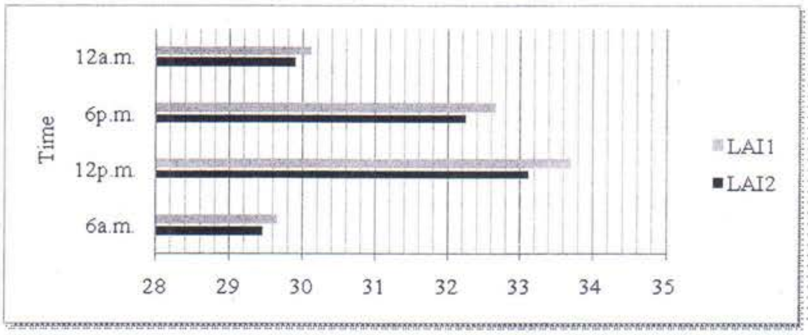
compared with the light foliage, through changing its Leaf area index (LAI). The leaf area index of a tree can vary depending on the season and its maturity.

In addition to the above situation, two different greening scenarios were simulated with reference to case C. The first is with light foliage tree (T1) and another with a dense foliage tree canopy (T2). The leaf area indices (LAI) for trees T1 and T2 were $1m^2/m^2$ and $4m^2/m^2$ respectively. Both tree types were 15m high with canopies covering the entire street. Both parametric tree models had ellipsoid leaf area distributions with maximum Leaf area Densities (LAD) located in the bottom of the crowns. The attenuation of solar radiation at midday was 28.4% for T1 and67.5 % for T2. The aim was to evaluate how the attenuation of solar radiation of the two tree canopy types influences the urban air temperature.

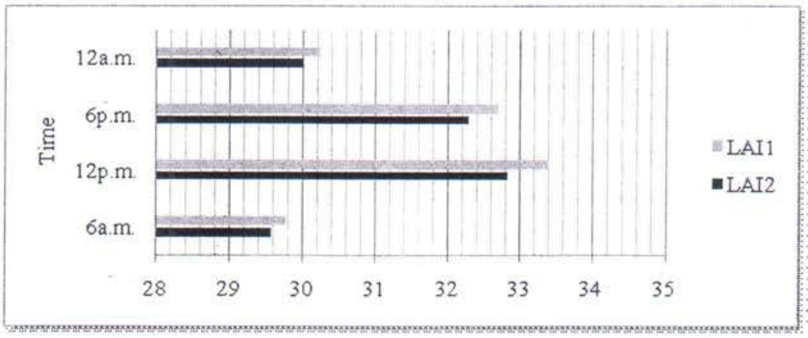
The results show that tree with the dense foliage shows an average reduction of 0.5°C than the other case. Also the variation in temperature during day time is observed more compared to evening hours.



Graph 7 Temperature Amplitude Showing the Variation between Different LAI at Central Area



Graph 8 Temperature Amplitude Showing Variation at Leeward Direction



Graph 9 Temperature Amplitude Showing Variation between Urban Canyon

Fig. 6 Temperature (°C) and Time Graph with the Variation in Tree Type

4. Conclusion

Through this study, it was observed that areas surrounding high rise buildings proved to be more comfortable during afternoon hours due to their shading.

It is clearly identified that green areas can lower the surrounding ambient temperature and helps in mitigating the urban heat island.

The leaf area index proved to be important factor in achieving reduction in temperature. However, to achieve major effects of trees on microclimate, the byelaw for 1 tree/100 m^2 needs to be re-checked, as the criteria for its foliage density and tree height is not mentioned.

Improvement in design can also be considered by adding group of trees at regular intervals rather than isolated trees.

Future urban planning should consider sky view factor and strategic tree plantation for healthy and comfortable outdoor environment.

5. Future Scope

Further study can be carried forward, by understanding the effect of urban heat island at neighborhoods level and also understanding of pedestrian thermal comfort. The understanding the cooling of native trees with respect to its form and density shall also be analyzed.

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