MINIMISING THE URBAN HEAT ISLAND EFFECT THROUGH LANDSCAPING

Naeem Irfan,
Associate Professor, Department of Architecture,
Mehran University of Engineering and Technology, Jamshoro.

Adnan Zahoor,
Divisional Forest Officer, Forest Department,
Government of Sindh.

Nadeemullah Khan,
Assistant Professor, Department of Architecture,
Mehran University of Engineering and Technology, Jamshoro

ABSTRACT

Urban areas present distinctive micro climates. In the study of causes of the special climate in cities, it is reported that "The total transformation of natural landscape into houses, streets, squares, big public buildings, sky scrappers, and industrial installations has brought about changes in climate of large cities".[1]

Temperature is one of the most important characteristics of urban areas. It is known that urban temperatures differ from those of sub-urban and rural areas. On hot summer days, one can feel the waves of blistering heat emanating from roads and dark buildings, which keep urban areas hot, even long after the sunset, where as rural areas begin to cool rapidly, depending upon topography, geological location, and anthropogenic factors. So urban areas are usually hotter than their rural surroundings. This phenomenon is described as the "Urban Heat Islands". Vegetation has a large impact on micro climate and is considered an efficient mechanism for cooling down the temperature.

The various aspects of urban heat island like causes and temperature pattern in urban heat islands, urban and rural temperatures, reasons of increase in urban temperatures and the effects of landscaping on the surrounding climate were studied. Then, to overcome their effects landscaping elements like trees and other vegetation are discussed. To know the presence and to determine the intensity of urban heat island in the cities of Pakistan, a case study of Lahore is also carried out.

This paper therefore presents the causes, magnitude and impacts of urban heat islands and suggests the beneficial effects of strategic landscaping on the climate of a particular area.

1. INTRODUCTION

The urban heat islands have major effects on energy costs and the quality of urban life.

The subsequent increased use of electricity for cooling elevates the levels of atmospheric temperature. The earth's rising temperature is one of the most debated issues in the world today. The planetry temperature has been on the rise since the industrial revolution. Today, increased energy use is one of the main contributors to rising levels of atmospheric CO_2. According to the theory of Global warming, the increased concentration of CO_2, the major "Green House Gas" is one of the main factors responsible for raising the planet's average temperature [2,3].

Vegetation has a large impact on micro climates and is considered as an efficient mechanism for cooling the communities [3,4]. Lower concentration of vegetation results in conversion of a higher portion of the net solar gains into sensible heat, thus magnifying the heat island effect.

Rural areas as compared to urban areas grow more trees/vegetation, which generate a significant cooling effect on the atmosphere by the process of evapo-transpiration. Similarly in cities, neighborhoods with more trees are cooler than those with fewer trees. Downtown areas of cities typically have the hottest temperature, as they are dominated by concrete buildings and rarely support much vegetation. An annual 4-8% total energy savings can be expected from a well-placed 25ft deciduous tree near an air conditioned home [5].

A study of plantation for energy conservation, reports that "as much as 70% - 80% of the energy conservation benefit of trees may be attributed to reduction in 'urban heat island' through the evapo-transpiration effect of trees" [6].

Therefore, vegetation is considered as one of the simplest and most effective ways to cool our communities and to save energy. It helps in protecting buildings against the scorching heat of sun in summer, and from cold winds in winter. Besides the cooling effect, vegetation also improves the urban environment by reducing noise pollution and soil-erosion.

2. REASONS OF INCREASE IN URBAN TEMPERATURE

The urbanization of natural landscape-(roads, bridges, dams, houses and high-rises) has dramatically altered the waters, soils and vegetation. In fact, the most stereotypically "urban" characteristics of cities are also those which can cause temperatures to rise. By replacing vegetation and soil with concrete and asphalt, we reduce the landscape's ability to lower daytime temperatures through evapotranspiration and lose the obvious benefits of shade. And by using dark-colored materials in the construction of roads, buildings, and other surfaces, we create cities that absorb, rather than reflect, the incoming solar radiation.

The combination of reduced "albedo" and reduced "vegetation" has resulted in the increased urban temperature. This increase in the temperature is most clear in late afternoon and early evening, when roads, side walks and walls begin to release the heat they have stored throughout the day. This increase in the temperature can be sensed more clearly while walking through the densely developed areas and thinly populated but more vegetated areas.

Although, the scientists have been aware of this phenomenon for over 100 years, but throughout the last century, increasing urbanization and industrialization have exacerbated the heat island effect.

3. CAUSES OF URBAN HEAT ISLANDS

Denuded landscapes, impermeable surfaces, massive buildings, heat generating vehicles and machines, and pollutants all help to make urban areas hotter. The replacement of vegetation or soil by concrete or asphalt reduces an urban landscape's ability to lower day time temperature through evaporation and plant transpiration. In a rural or irrigated landscape, a large amount of day time solar energy is actually spent on evaporating water, not on raising air temperatures. Trees and other vegetation perform this function through the process of "Evapotranspiration".

When a natural vegetative cover is replaced by asphalt or concrete, it loses its ability to moderate temperatures. Instead, the solar energy normally delegated to the evaporation process is left to raise the surface temperatures.

Pavements, side walks, roads and buildings, therefore, contribute to the urban heat islands in a number of ways. Since they do not have the capacity to moderate heat through evaporation, they absorb and store the day's heat and then radiate it back to the urban atmosphere at night. These buildings not only take hours to cool off every night but in addition to that, they also obstruct the natural flow of breezes, making wind speeds noticeably lower in cities.

This obstruction prevents winds from carrying heat build-up away from the city, assisting in the reduction of the heat islands.

Urban pollution also effects the heat island, depending on the time of day and season of the year. However, the severity of the heat island is determined largely by the interplay of the urban landscape and solar radiation.

Urban areas get hotter than rural settings not only because their ability to cool evaporatively is reduced, but also because they reflect less incoming solar radiation.

4. TEMPERATURE PATTERN IN A TYPICAL URBAN HEAT ISLAND

Most cities around the world today endure heat island effects. Except minor differences because of climate and geography, the overall pattern of heat islands remains the same from city to city. Temperatures are at their highest in highly built-up down town areas, and taper off towards the edge of urban areas, and deep into the countryside. While the temperature differences between urban and nearby rural areas are evident by mid day, they are at their greatest two or three hours after sunset.

The later effect occurs because asphalt and concrete structures gradually release, into the urban atmosphere, the heat they had stored during the day [7]. The solar radiation received by the surface of a building is partly absorbed and partly reflected. The radiation emitted by the sun has wave lengths of less than 3 mm. This heats the surfaces on which it falls, but as they remain much cooler than the surface of the sun, the radiation emitted by them has a much longer wave length [8,9].

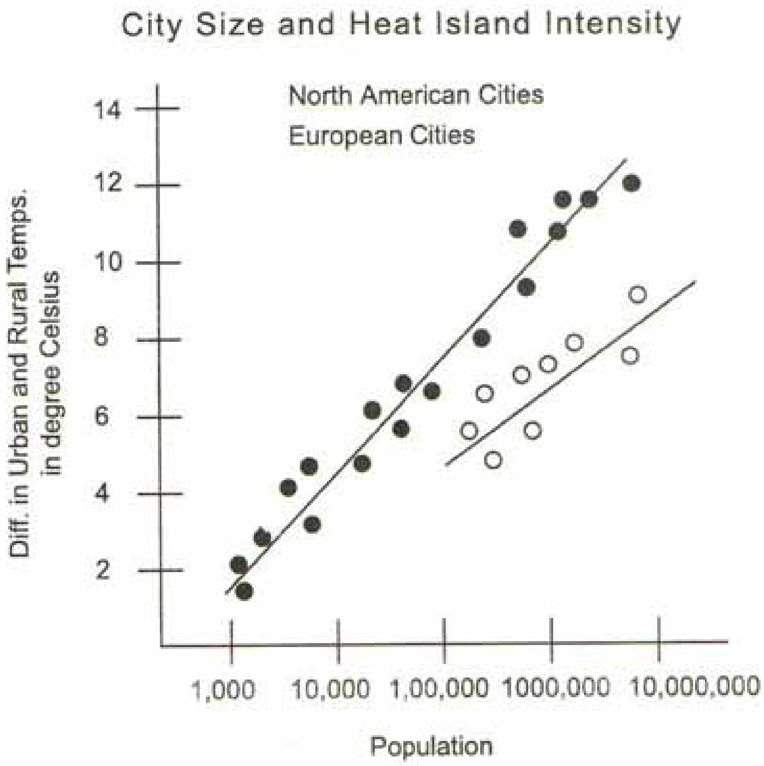

Figure # 1: Profile of a typical heat island in a hypothetical metropolitan area show temperature changes correlated to the density of development and trees [7].

Variations in the urban heat island over time are also consistent from city to city. The thermal processes causing summer heat islands occur when the sun is shining. The difference in temperatures begins to grown in mid day. The heat island, however, is most pronounced two to three hours after sunset, when paved areas and buildings slowly release their stored heat into the urban atmosphere.

The intensities of heat islands depend on a number of factors, that is, climate, topography, and physical layout of a city. Short term weather conditions also have a strong effect. Breezes in a city, for instance, prevent the formation of heat islands by mixing cooler air from surrounding areas with warmer urban air.

The increasing urbanization and industrialization have exacerbated the heat island. As cities have grown, increasing number of buildings have crowded out trees other vegetation. This loss of vegetation and its replacement by buildings or pavement causes the urban heat island to intensify. Population can also be seen as one indicator of a heat island's intensity. Studies have shown that cities with larger population tend to have more intense heat islands [7].

5. DIFFERENCES BETWEEN URBAN AND RURAL TEMPERATURES

Because of the scarcity of data directly comparing urban and rural temperatures, it is often difficult to ascertain how much of the urban warming trend resulted from changes in regional weather and how

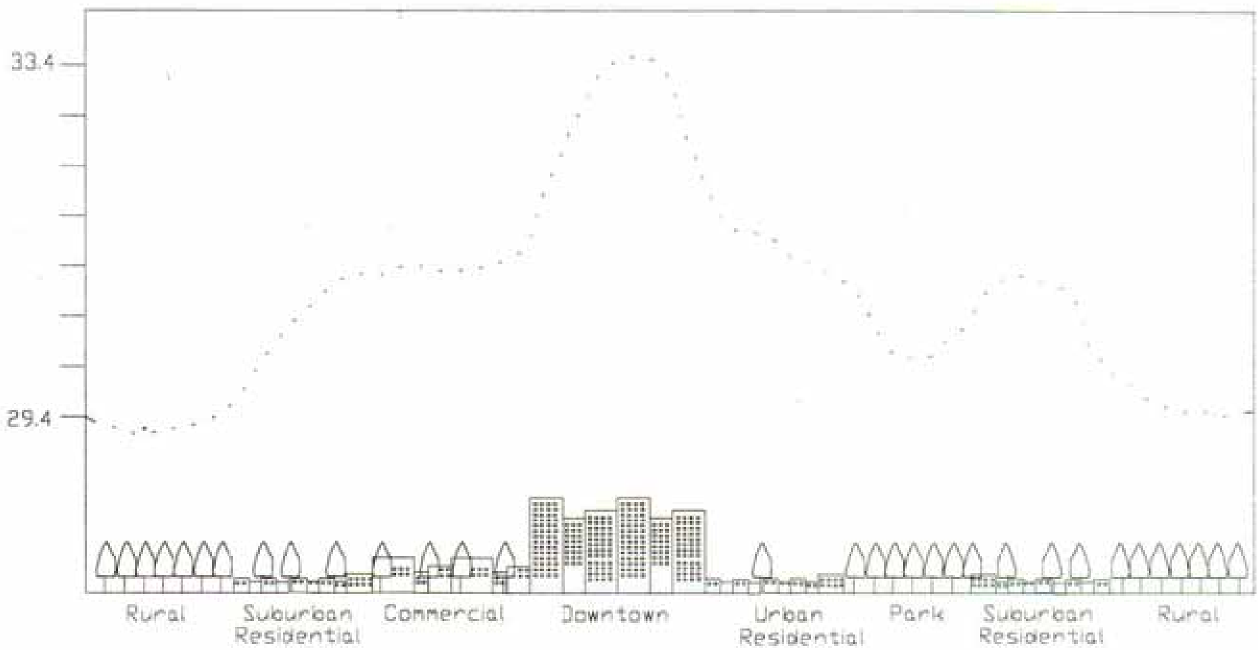

Figure #2: Maximum difference in urban and rural temperatures.

much is the result of the urban heat island effect. But the available data indicates that urban temperatures are rising faster than temperatures of surrounding rural areas. Tropical cities provide excellent examples of increasing heat island intensity. Indeed, it is nót usual for average temperatures in tropical and sub tropical cities to be as much as 5.5°C to 10°C higher than surrounding areas.

Heat islands of 8.8°C have been measured in Mexico city (Mexico) and of 6°C in Mumbai (Bombay) and Poona (India) [7]. In tropical cities heat islands have detrimental impacts on energy use, as it exacerbates cooling energy use in summer. The increasing demand for electricity will continue if our cities continue to be hot.

In addition to increasing cooling energy use, heat islands and long term urban warming affect the concentration and distribution of urban pollution, because heat accelerates the chemical reactions in the atmosphere that lead to high ozone concentrations. (Polluted days may increase by 10.8% for each 3°C increase in temperature).

6. THE EFFECT OF LANDSCAPING ON MICRO CLIMATE

Landscape in the environmental context refers to the laying out and planting of trees, shrubs, grass etc., together with the provision of related features on open spaces from smallest courtyard to large parks [10]. The effect of the sun on any area will, to a large degree, be determined by the size, nature and texture of the various surfaces on which it falls. Every type of natural ground cover - such as grass, shrubs and trees; paved surfaces: walls and roofs will have a perceptible effect on the micro climate of the area.

Natural growths tend to stabilize temperatures and minimize extremes in them. Man-made surfaces, on the other hand, tend almost without exception to exaggerate them. Generally, plant life acts as an absorbent material, blotting up heat, light and sound. Since leaves give off moisture, they actually destroy a large part of the heat which falls upon them. Thus, they re-radiate far less heat than inorganic materials.

Landscaping is therefore, recognized as an effective way and help to remain comfortable during the hot summers. Open areas can be planted with shade trees, flowering and non-flowering plants, and grass lawns. Landscaping around the buildings should be so designed to take the best advantage of prevailing winds for natural cooling in the summer. Landscaping is also used to lower air temperatures through the evaporation of water from leaves and to reduce the re-radiation from the ground and paved areas.

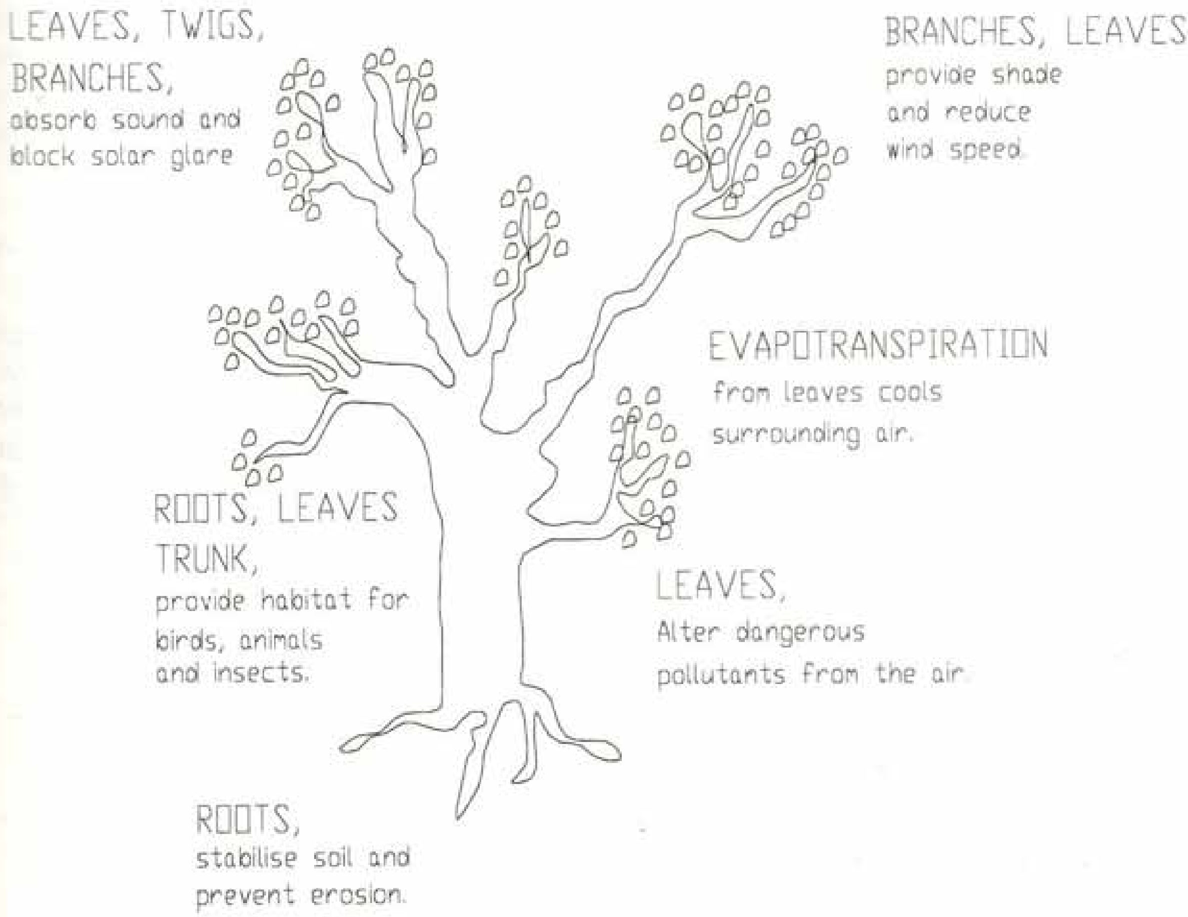

Figure # 3: The numerous ecological qualities of trees: The leaves alone can provide cooling from evapotranspiration, shelter from wind, sound absorption, and sequestering of carbon dioxide[7].

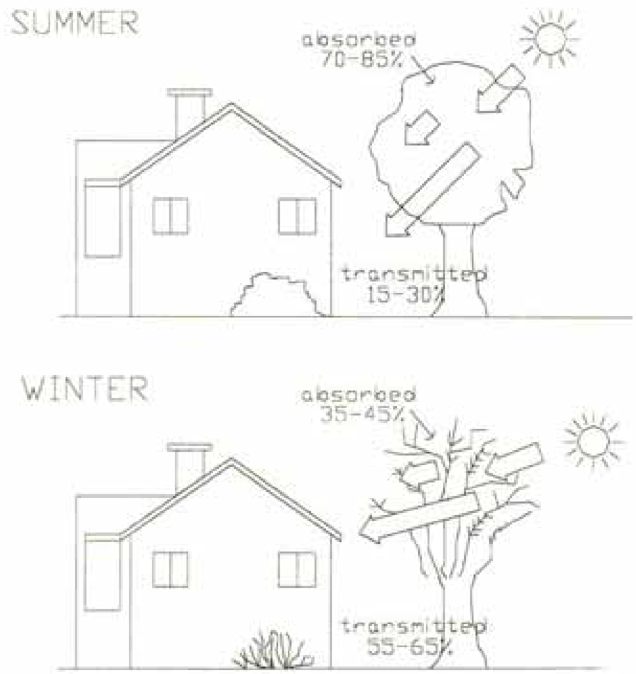

Figure # 4: Shading characteristics of deciduous trees during the summer and winter [7]

It is generally found that on sunny summer day, air temperatures at about 1'-0" above ground level are approximately 4°C and 5°C lower than those at ground level itself. Grass is also cooler than exposed soil surfaces, the difference in temperature being between 5°C and 6°C [11].

The temperature differential may be much greater between grass and paved surfaces. Further more, there is a considerable difference in temperatures between paved surfaces made of different materials. Rudolf Geiger proposed the range of temperature variations over different surfaces.

TABLE - 01
RANGE OF TEMPERATURE VARIATIONS OVER DIFFERENT SURFACES

Material	Temperature (°C)
Tar Macadam	32.6
Sand	25.9
Earth	25.0
Gravel	21.1
Grassy Ground	16.0
Clay Soil	11.2

On a bright day, concrete and similar light colored surfaces will reflect from 25 to 35 percent of the incident light, while grass surfaces, reflect only about 10-15 percent of the incident light [11].

7. SHADING WITH TREES, SHRUBS AND VINES

Plantation helps in reducing the effects of heat island in summer season, besides satisfying the instinctive need for aesthetics, leaves with viscous surfaces catch the dust and filter the air. Deciduous trees provide generous shade and that too only in the appropriate seasons so that they are quite valuable in climates where sunshine is needed in the winter and shade in the summer.

To achieve efficient shading, trees have to be placed strategically. As the sun is at low angles in the morning and late afternoon, trees should be placed facing southeast and southwest of the building. The trees will cast long shadows which can be utilized effectively on those sides which are otherwise difficult to protect from the sun's heat at this time of the day. Moreover, the type-of trees used is of great importance. They should be selected from the point of view of both their appearance and amount of shade they provide [11].

Trees are classified into three major forms. The first type of trees are those with a round shape where the spread and the height is roughly the same. The second type, are of oval shape, whose spread is nearly half the height and the foliage takes an oval shape. The third type of trees are vertical and do not spread very wide, and are known as columnar trees.

Tall, full crowned trees are best for blocking the rays of the sun when it is shinning directly over head at mid day. The oval shaped trees may be used on eastern and western exposures of the buildings to provide the maximum protection to the roof and walls from solar heat gain, while allowing the access to cool breezes. The columnar trees can be used as wind barriers and dust screens. Shrubs and other low growing foliage provide shading during the morning and late afternoon when the sun is low in the sky. They may be planted between the paved areas and the building. Vines provide a very fast growing source of shade for a building, because they require little space for growth. Thus these are most useful where space around the building is limited. Figure #5.

Ground surfaces reflect solar radiation into building and decidedly have effect on building's heat gain and loss. Light colored or concerted surfaces are good reflectors and can increases the heat gain to the building. Dark colored surfaces, such as asphalt, will absorb and store large amounts of solar radiation as heat, and re-radiate it to the building at a later time. To minimize this reflected radiation, as much ground vegetation as possible should be located around the buildings in conjunction with the trees and shrubs [12].

8. MEASURING THE INTENSITY OF HEAT ISLAND: A CASE STUDY OF LAHORE

To know the effects of landscaping on the temperature characteristics, the city of Lahore is selected as the case study. Lahore has always been known as the city of gardens before and even after the independence of Pakistan.

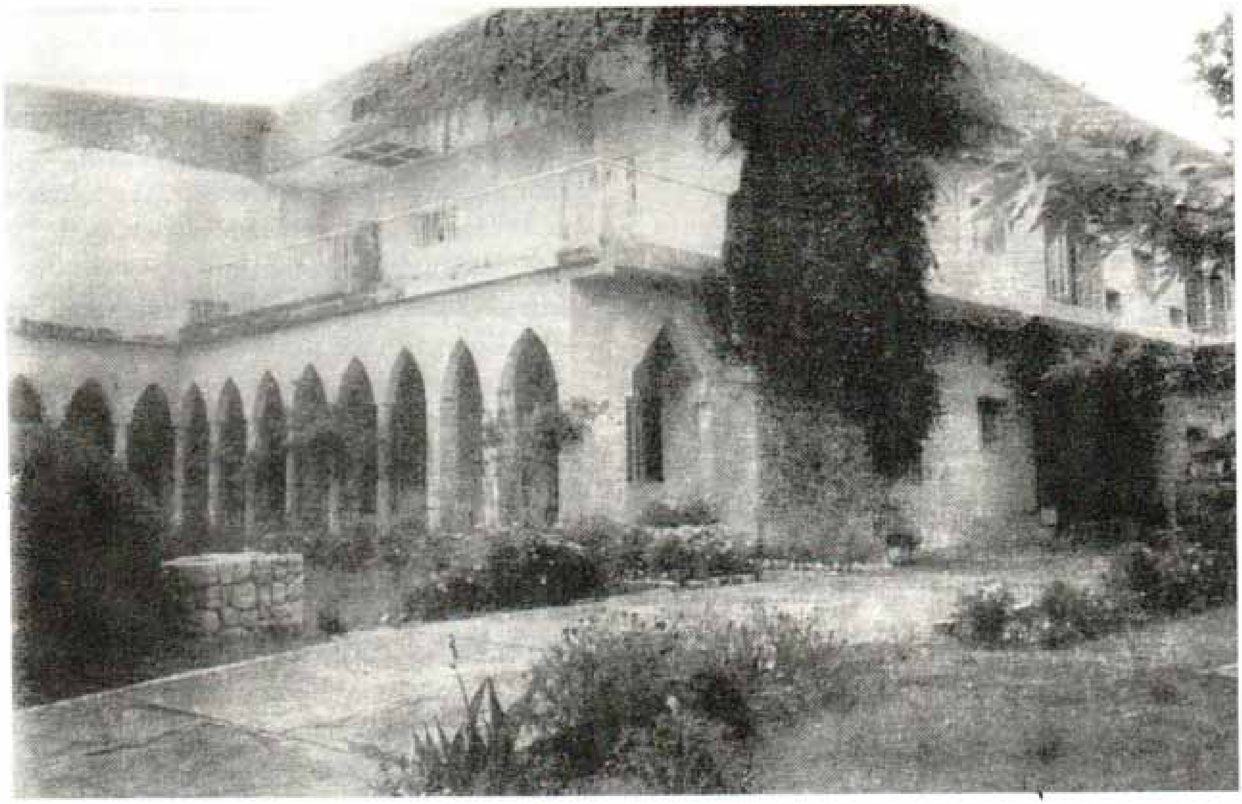

Figure # 5: Picture of Building with Vines

The selected area once had the rural surroundings and vegetation was the dominant feature. It has now turned into densely populated urban center with less tress and more roads, buildings, vehicles, etc. the weather station in the selected area is operational since 1861. This has helped in obtaining the data to be studied for the desired period of time. Climatically Lahore lies in the tropical zone with hot summers and cold winter, interspersed with monsoon rains.

There has been remarkable growth in the urbanization of Lahore since 1947. Its population rose from 0.7 million in 1947 to 5 millions in 1995. The physical area of the city has increased from 8 square miles in 1947 to 165 square miles in 1995 [13,14]. The growth of industries is also rapid. Before independence these industries were more than 1000 [14,15]. The rate of growth of Lahore in 100 years is shown in Table-2.

The increasing urbanization is also a factor for continuous replacement of the natural soil and vegetation cover of the area by artificial features like roads, buildings, etc. there is also a remarkable increase in the injection of pollutants into atmosphere.

TABLE - 02
POPULATION AND AREA GROWTH IN LAHORE FROM 1895 TO 1995 [14]

Year	Population (million)	Population Growth	Area (sq. mile)	Growth In area
1891	0.202	——	3.0	——
1947	0.760	3.76 times	8.0	2.6 times
1995	5.078	6.68 times	165.0	20.6 times

For studying the impact of urbanization on climate, the existence and intensity of the urban heat island in Lahore, data was collected in two different periods but at the same location. These periods represent the time when the area was rural in character and later the city expanded and become urban. Period-I represents rural conditions when the vegetation was the dominant land use feature while period-II represents urban conditions of a continuous built up area. The purpose of this study is the comparison of ambient air temperature "before and after" urbanization and to know the affects of landscaping on the reduction and creation of urban heat islands. Table-3,4.

Table-03, 04
PHYSICAL DEVELOPMENT IN PERIOD-I AND PERIOD-II [14,16]

Station	Landuse pattern
Period-I (1876-1895)	Rural
Period-II (1976-1995)	Urban

Periods	Year	Population (million)	Area (sq.miles)
I.	1876-1895	0.202	03
II.	1976-1995	5.078	165

The whether station chosen for this study represented similar geographical location in both periods but experienced different physical environment from 1876 to 1995. The weather station was first established in 1861 and modified in 1931, 1951, 1961, 1971 and finally in 1990 [17].

The study compares the two data sets collected at the same weather station but in different periods having a difference of 100 years. Each period consists of 20 years. The first period represents time from 1876-1895 and second period from 1976-1995. Data used in this study was the average of the month which reduces the margin of errors, if any. The months representing the monsoon season were excluded form the analysis. The months chosen for this study of annual and seasonal scales are shown in table-05.

TABLE-05
MONTHS CHOSEN FOR THE ANALYSIS

	Months
Annual	January-June and December
Winter	December-March
Summer	April-June

The effects of landscaping on temperature in Lahore was examined by comparing the temperature values of the same area with different levels of vegetation. The comparison is carried out on annual and seasonal levels and mean ambient air temperature were taken into consideration. The variations in the mean annual and mean monthly values of ambient air temperature were studied to examine seasonal variations in the urban heat island, if any. The intensity of heat island was also calculated.

It was found that mean annual temperature of the same area with lesser trees (period-II) is significantly higher than, when it was surrounded by dense vegetation (period-I) i.e. temperature in period-II is 1.1°C higher than that of period-I. At seasonal level mean monthly summer temperature is 1.9°C higher in period-II than period-I. While in winter season there is no significant difference between the temperature in both periods (Table-6).

TABLE-06
THE COMPARISON OF AIR TEMPERATURE BETWEEN PERIOD-I AND PERIOD-II AT ANNUAL AND SEASONAL LEVELS.

Periods	Mean annual temperature (°C)	Mean Seasonal Temperature (°C)	
		Winter	Summer
Period-I	21.8	15.5	30.3
Period-II	22.9	15.7	32.2

Analysis of the annual and seasonal characteristics of temperature in Lahore show than there is an increase in temperature of the city in last 120 years by 1.1°C. This rise in temperature may be because of changes in physical structure of the city and relatively fewer trees. The heat island effect of the city is clearly reflected in mean annual temperature and it displays a higher preponderance during the summer season than during the winter period.

9. DISCUSSIONS

It has been observed that heat islands have a significant impact on the temperature of the surrounding areas. The heat island are mostly formed because of the denuded landscape, impermeable and dark colored surfaces, massive buildings, heat generating vehicles and machines.

Vegetation has a large impact on the micro climate and hence plays a major part in decreasing the temperature of a particular area. The rural areas are therefore, much cooler than the adjacent urban areas. This can also be compared with neighborhoods with more trees to the neighborhoods having less trees/vegetation within the same urban area. All such spaces that are being turned into 'heat islands' need special treatment.

Since the urban heat islands are mostly created because of hard surfaces having less or no landscaping, it is important that such surfaces should be covered through a well planed and placed vegetation/landscaping.

It is, therefore, very important and necessary to study and analyses such spaces carefully and then be treated with strategic landscaping for controlling the heat island effect.

CONCLUSION

Landscaping has a definite effect on surrounding environment.

1. Landscaping is therefore considered to be the most effective way to cool our communities and to save energy.
2. It helps in protecting buildings and surroundings against the scorching heat of sun in summer, and from cold winds in winter.)
3. (Besides the cooling effect, landscaping also improves the urban environment by reducing noise pollution and controlling the dust).
4. To minimize the heat island effect through landscaping the following recommendations may be considered when trying to control the climate.

   - Deciduous trees should be used in the areas where sun's warmth is needed in winter.
   - For more cooling increase the area of lawn, number and size of trees.
   - Low shrubs to be used to make sure that the air circulation is not hindered.
   - Paving should be shaded by trees as much as possible, to prevent heat absorption.
   - Water as a landscape element can also be used very successfully to reduce the effects of heat islands.

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[1] In this process the plant draws moisture from the ground, utilizes what it needs for growth and moderating its own temperature, transpires the excess, and cools the surrounding air